Minimally invasive treatment strategies with Polymer-Infiltrated-Ceramic-Network (PICN) materials

Julie OUDKERK

Thesis submitted to obtain the degree of Doctor in Dental Sciences of the University of Liège, Belgium

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Abstract

Tooth wear (TW) is a multifactorial issue, making the understanding of its risk factors essential for effective management. Despite its importance, a comprehensive review that synthesizes findings to guide clinical decisions is lacking. Bruxism and TW may be linked to various chronic diseases, but current data are limited, highlighting the need for further research. Diagnosis and prevention of TW are crucial, but selecting appropriate restorative treatments is equally important. Currently, there is no consensus on the optimal technique or material for restoring severely worn dentition, particularly due to the lack of long-term studies.

The **One-Step No-Prep technique** is a non-invasive restorative approach for generalized TW, using Polymer-Infiltrated Ceramic Network (PICN or hybrid ceramic, Vita Enamic) CAD-CAM restorations. Introduced in 2018, the technique has shown successful preliminary results, but its long-term effectiveness needs to be validated through extensive research. PICN materials seem well-suited for this technique, but their clinical performance, especially long-term, is not well-studied, particularly regarding wear resistance—an important factor for bruxism patients.

The primary aim of this thesis was to contribute to the assessment of the One-Step No-Prep technique. Additionally, this study sought to advance TW diagnosis and to investigate the intraoral wear of PICN materials.

The first work package (WP) introduced the **ToWeR checklist**, a tool to enhance the understanding of TW risk factors in clinical practice. The second WP explored the association between bruxism, TW, and MSDs, emphasizing the need for a holistic approach. The third part of this work presents a critical review of the **evolution of indirect composites** to better understand their properties and the contributions of new materials to improved treatment strategies. Subsequent WPs focused on evaluating the One-Step No-Prep technique in a prospective clinical context. The fourth WP investigated the clinical performance of PICN restorations and their impact on patients' oral health-related quality of life over a two-year period in seven patients.

The fifth WP evaluated the **intraoral wear of PICN** CAD-CAM composite restorations over five years using *ex vivo* 3D profilometry analyses. The sixth WP reported up to nine years of follow-up in 24 patients and assessed the influence of restoration thickness on fracture rates.

PICN was confirmed as well-suited to the One-Step No-Prep protocol due to its thin milling capability, adaptability during in-mouth adjustments, and ease of repair, especially in bruxers. The material's polymer component aids in occlusal stress absorption. At nine years, the survival rate was 98.4%, with a success rate of 79.7%, rising to 86.7% when

excluding minor chipping. The thesis demonstrated that maintaining a restoration thickness of 0.56 mm could reduce minor chipping. After five years, PICN restorations exhibited wear values slightly lower than natural enamel, without significant abrasive effects, maintaining occlusal stability. PICN offers a balanced option between the excessive abrasiveness of glass-ceramics and the high wear of direct composites. The esthetic properties of PICN, particularly with Vita Enamic multiColor blocks, were rated as excellent or good over time, outperforming direct composites in resistance to staining and discoloration.

The One-Step No-Prep protocol was shown to combine the benefits of direct techniques-minimally invasive, easy repair—with those of indirect techniques, such as access to superior materials and efficient restoration anatomy creation. This work highlights the successful longterm outcomes of the One-Step No-Prep technique and exhibits the clinical performance of PICN material, an appropriate material for this non-invasive treatment of TW.

Keyword:

Tooth wear, Risk factors, Bruxism, Musculoskeletal disorders, CAD-CAM composite, PICN, Minimally-invasive treatment, Fixed prosthodontics, Clinical study, Dental materials, Material wear, Profilometry

Glossary

This glossary presents the different scientific expressions used throughout the manuscript and their abbreviations. Scientific expressions could change from one chapter to another due to journals' requirements: however, they carry the same meaning.

PICN: Polymer-Infiltrated Ceramic Network
CAD-CAM: Computer-Aided Design - Computer-Aided Manufacturing
TW: Tooth Wear
ETW: Erosive Tooth Wear
BR: Bruxism
MSD: Musculoskeletal Disorder
ICs: Indirect Composites
DF: Dispersed fillers
VDO: Vertical Dimension of Occlusion
FDI: Fédération Dentaire Internationale
TMD: Temporomandibular Disorders
TMJ: Temporomandibular Joint
OHIP-49: Oral-Health-Impact-Profile-49
OHRQoL: Oral-Health-Related Quality of Life
AFR: Annual Failure Rate
UDMA: Urethane Dimethacrylate
HT: High Temperature
HP: High Pressure
Bis-GMA: Bisphenol A-Glycidyl Methacrylate
TEGDMA: Triethylene Glycol Dimethacrylate
BPO: Benzoyl Peroxide
DMA: Dimethacrylates
HEMA: Hydroxyethyl Methacrylate
PMMA: Polymethyl Methacrylate
BMI: Body Mass Index
GERD: Gastroesophageal Reflux Disease

GORD: Gastro-Oesophageal Reflux Disease
BEWE: Basic Erosive Wear Examination
PVS: Polyvinyl Siloxane
HF: Hydrofluoric Acid
MO: Monoblock
MC: MultiColor
RMS: Root-mean-squared
OCA: Occlusal Contact Area
FOA: Full Occlusal Area

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1

Introduction

1. What is tooth wear ?

Tooth wear (TW) is defined as the loss of tooth hard tissue from the surface of the tooth by means other than caries, trauma or developmental disorders. Recent years have seen a significant increase in the prevalence of TW, particularly in young patients [1, 2]. A previous study reported that TW affects 68.8% of the population aged 16-97 in the United States, with 9.6% having extreme TW [3]. In the Netherlands, moderate and severe TW affected 86% of the adult population [2]. It is possible to differentiate between various categories of TW: attrition (wear process by direct tooth-to-tooth contact), erosion (dissolution of dental hard tissues by non-bacteriogenic acids), abrasion (caused by sliding or rubbing of abrasive external objects against tooth surfaces) and abfraction (caused by tensile stress generated by non-axial cyclic occlusal forces) (Figure 1.1) [4]. Tooth wear can be generalized, affecting all the teeth, or localized, being restricted to a few anterior and/or posterior teeth.

Fig. 1.1 Illustration of different types of tooth wear. Note that tooth wear is a multifactorial phenomenon, and different types of tooth wear are often present in the same mouth
a) Erosion is visible on the buccal surfaces of upper incisors. It is characterized by a shiny and a slight rounded feature of enamel (Photo courtesy of Prof. A. Mainjot)
b) Abfraction is characterized by microfractures in the enamel and dentin that form an axe-shaped lesion (wedge) with distinct internal and external angles
c) Attrition identified as flat, shiny lesions with variable margins, and wear is also visible in the opposing tooth
d) Abrasion caused by repeated excessive rubbing of the teeth with a toothbrush. The lesion has an indeterminate contour with a hard, polished surface, accompanied by gingival recession (Photo courtesy of Prof. A. Mainjot).

TW is an age-related phenomenon and the difference between physiological and pathological TW is important [5]. Physiological wear is a normal, gradual phenomenon associated with age and typical oral activities, while pathological wear is abnormal and often due to behaviors or conditions that accelerate TW (Figure 1.2). For example, occlusal surface wear of permanent teeth is considered physiological when tissue loss is approximately 15 µm per year for premolars and 29 µm per year for molars [6]. On the contrary, pathologic TW is atypical for the patient's age and may cause pain, discomfort, functional problems, or deterioration of esthetic appearance, which, as it progresses, may lead to unwanted complications of increasing complexity [7].

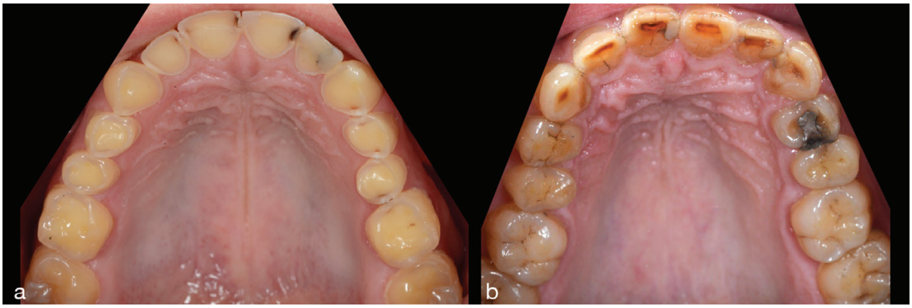


Fig. 1.2 a) Pathologic tooth wear (32-year-old patient with dental pain and difficulty chewing) b) Physiologic tooth wear (72-year-old patient and absence of symptoms).

The etiology of TW is complex and multifaceted. A comprehensive understanding of the risk factors associated with TW is essential to facilitate early diagnosis, implement effective prevention strategies, and provide prompt intervention when indicated. A substantial corpus of literature has been devoted to the investigation of risk factors associated with TW. Two distinct categories of risk factors can be identified: chemical and mechanical. Reported chemical factors include drinking consumption, such as soft drinks and dietary habits, medical history (reflux (GORD), eating disorders) or behavioral factors. Drinking habits such as soft drinks, fruitjuices, energy drinks and especially alcoholic drinks seem to affect TW in many studies. This could be explained by the low pH of these drinks. For example, citrus fruit consumption has been shown to be a risk factor due to its acidity (pH 0-2) [8]. Mechanical factors include bruxism, oral hygiene habits, or lifestyle factors (nail-biting).

In terms of oral hygiene, it was demonstrated that the presence of TW has been shown to be associated with the use of a hard fiber toothbrush or a horizontal brushing technique [8, 9]. The term «bruxism» is defined by the international consensus as «a repetitive muscular activity of the masticatory system, characterized by clenching or grinding of the teeth and/or grinding or pressing of the mandible» [10]. It is notable that TW may serve as

an indicator of sleep and awake bruxism. Conversely, a number of factors and pathologies, including obstructive sleep apnea, gastroesophageal reflux, headaches, and temporomandibular disorders (TMD), have been documented to be linked with bruxism [11-13].
In severe cases of TW, patients may suffer from dental pain (due to exposure of dentin tubules) [14], impaired esthetics, masticatory dysfunction, temporomandibular joint disorders, masticatory muscles, and orofacial pain [7, 11], with a significant impact on oral health-related quality of life [15]. In addition, severe TW results in an unsightly appearance for most patients, who report a real psycho-social handicap [7, 16]. In generalized TW, restoring functional occlusal relationships and esthetics requires full-mouth rehabilitation with an increase in the vertical dimension of occlusion (VDO), which is a complex treatment (Figure 1.3)[16][17][18].

Fig. 1.3 Case of severe tooth wear with erosion and attrition, requiring complex rehabilitation with an increase in VDO a) Frontal view, b) Smile photograph, c) and d) Occlusal views, and f) Lateral views.

2. Tooth wear management

Current guidelines advice that restorative treatment of worn dentition is indicated according to the severity of TW and when the patient has some pain, esthetic or functional

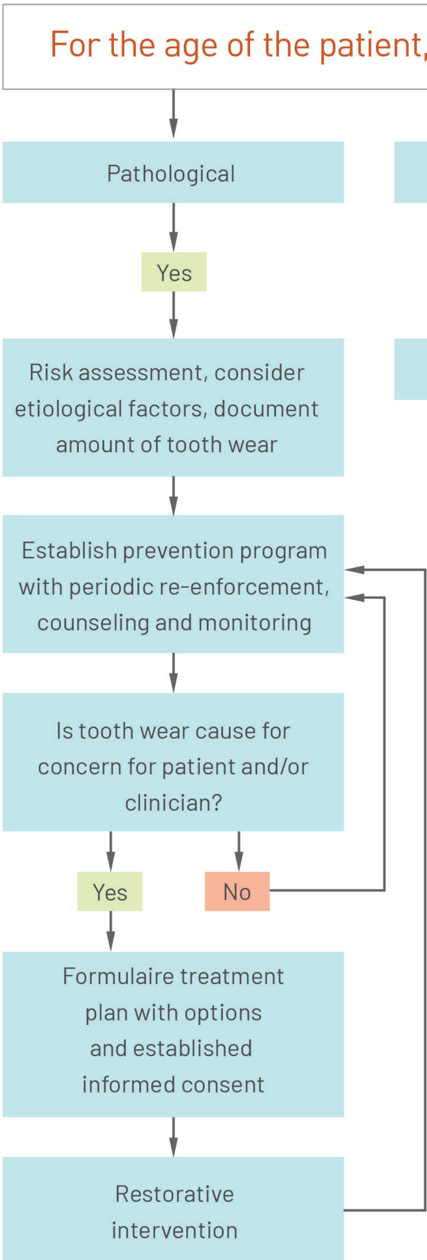
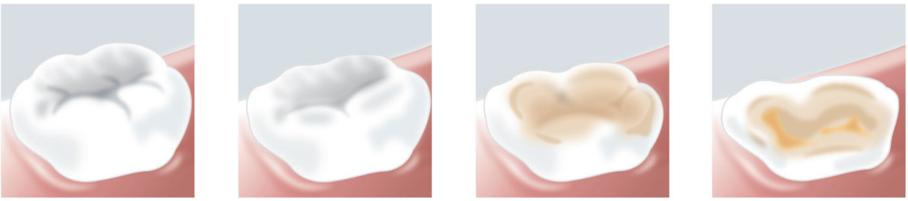


Fig. 1.4 A flowchart to help clinicians make appropriate decisions and give treatment advice, from counselling and monitoring to restorative treatment. Adapted from: "Severe Tooth Wear: European Consensus Statement on Management Guidelines" Loomans, B et al., J Adhes Dent, 2017.

complaints [7]. It is also necessary to distinguish between physiological and pathological wear before starting a treatment (Figure 1.4). In other cases, TW needs to be monitored and controlled, and proper diagnosis and management of TW risk factors is essential to prevent further progression of the process. In addition, correct diagnosis of TW risk factors will help diagnose important comorbidities, and dentists are the first line of defense in detecting sleep apnea and gastroesophageal reflux, for example.
Several types of indexes have been developed to classify and assess the severity of TW in prevalence and incidence studies and can be used by dentists to monitor the progression of TW. These indexes may vary according to the type of scale used to score wear progress, the choice of teeth used as reference, leading to non-comparability and a lack of standardization [19]. Among these indexes, the most commonly used are the Basic Erosive Wear Examination (BEWE) index (Figure 1.5) [19], the Tooth Wear Index (TWI) [20] and a modified version of the TWI [21]. Some of these indexes can be used as a treatment decision tool, such as the BEWE index.

BEWE score definition



0 No erosion

1 Initial loss of surface texture

2* Distinct defect, hard tissue loss less than 50% of the surface area

3* Hard tissue loss more than 50% of the surface area

Fig. 1.5 The Basic Erosive Wear Examination (BEWE) index has therefore been developed to provide a simple scoring system. *in scores 2 and 3 dentine often is involved. Adapted from: "Basic Erosive Wear Examination (BEWE): a new scoring system for scientific and clinical needs" Bartlett D. et al., Clin Oral Invest, 2008.

To monitor TW and check the effectiveness of risk factor management, such as lifestyle changes, dentists can also take regular photographs, full-arch impressions or intraoral scans for comparison (Figure 1.6) [22, 23]. These tools are also useful in increasing patient awareness of the disease and highlighting its nature and severity [7]. This helps the patient to take ownership of their problem, which is a key factor in effective clinical management. Monitoring can also provide additional information to help identify the etiology of the presenting tooth wear [8].

According to several studies, the use of an occlusal splint can be prescribed to alleviate bruxism [24, 25]. However, the effect of maxillofacial physiotherapy on bruxism has been poorly studied [26].

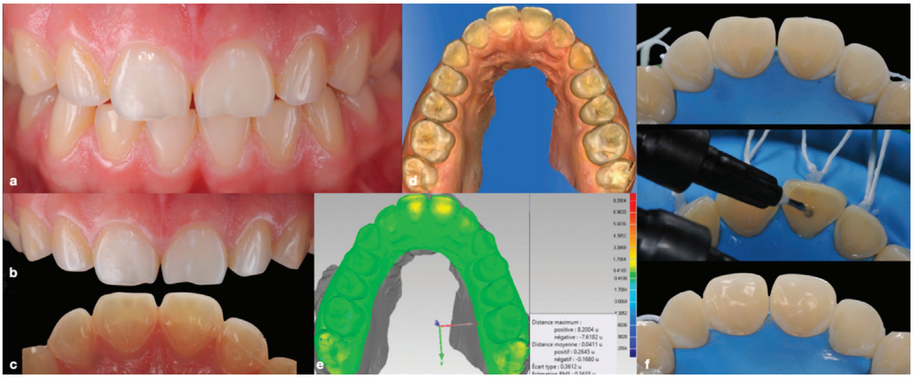


Fig. 1.6 Clinical management of a 16-year-old female patient exhibiting pathologic TW due to bruxism and gastroesophageal reflux
a) and b) Baseline frontal views showing attrition facets
c) Baseline palatal anterior view showing erosion of the palatal surfaces of incisors
d) Baseline intra-oral scan of the upper maxilla
e) Superimposition of the baseline and the 2 years followup intra-oral scans using the Geomagic software (Geomagic Inc, Morrisville, NC, USA) in order to detect tissue loss
f) In this case flowable direct composite was used to protect dentin of the eroded palatal surface of 11 and 21. The patient wears an occlusal nightguard and is followed by a maxillofacial physiotherapist for bruxism and by a psychologist for stress. She also has a treatment for gastroesophageal reflux. Photo courtesy of Prof. A. Mainjot. Geomagic superimposition: J. Oudkerk.

3. Minimally-invasive treatment of generalized severe tooth wear

In addition to preventive approaches in the absence of symptoms and patient demand [27], current recommendations emphasize the need to develop minimally invasive treatment strategies that preserve as much residual tooth tissue as possible with the current trend being to avoid any preparation of tooth tissue («No-Prep») and to work in an additive way [7]. Restorative treatments should also involve the minimum number of teeth necessary to achieve a satisfactory clinical outcome. A variety of techniques have been described in the literature for the treatment of generalized TW: direct techniques using light-cured composites, which is the most commonly reported treatment [16], indirect techniques, or a combination of the two.

In the direct shaping by occlusion (DSO) technique, the new VDO is arbitrarily estimated on the articulator and silicone bite-stops are created in the posterior region to assist in the realization of restorations [28, 29]. Alternatively, a wax-up can be performed and then light-cured direct composites can be molded using a transparent silicone index [30, 31]. The injection technique using flowable direct composite is a method that also uses a transparent silicone index for translating a diagnostic wax-up into composite restorations without the need for tooth preparation [32]. For moderate TW cases, Dietschi et al. proposed a modified full-molding technique to alleviate some of the known shortcomings of this method, namely the index deformation, the time-consuming removal of excess material in the proximal and contact areas, and the possible lack of precision in molding the occlusal anatomy [33]. In essence, a thick plastic translucent tray is subsequently relined with a transparent, low-viscosity silicone material on the wax-up, thereby ensuring optimal detail reproduction. The occlusal embrasures are opened using ultrathin discs and isolated with a small quantity of isolation material (ie, Rubber Sep, Kerr Corporation, Orange, California, USA). However, known limitations of molding techniques are the time-consuming removal of excess, the potential inaccuracy of the anatomy and function of the restoration, and the severity of TW.

Finally, some authors have based the wax-up on an analysis of the occlusal relationships (e.g. using a facial bow and jig) [30], while others have used temporary restorations to test the new VDO before the final direct composite fabrication [34]. The direct technique is particularly minimally invasive and reversible. It allows easy repair of restorations and has been shown to reduce treatment costs [35, 36]. However, it may require ongoing maintenance (e.g. polishing and repairs), especially in patients with bruxism, as the success of restorations depends on the individual patient [37]. Furthermore, the long-term clinical behavior of direct composites, particularly in regard to material wear and color stability, has not been the subject of sufficient investigation. Indeed, systematic research from 2023 highlights the need for more rigorous long-term clinical studies with standardized protocols to better assess the longevity and wear resistance of resin composites, particularly in challenging clinical conditions such as bruxism [38].

With respect to indirect techniques, Vailati first introduced in 2006 the initial minimally invasive protocol, designated as the «three-step technique.» In this technique, the maxillary anterior teeth are restored using the «sandwich technique,» which involves the use of composite palatal veneers in conjunction with glass-ceramic buccal veneers. Posterior teeth are restored with lithium disilicate reinforced glass-ceramic (IPS e.max Press (Ivoclar Vivadent, Schaan, Liechtenstein)) or dispersed filler CAD-CAM composite

(Lava Ultimate (3M Espe, St Paul, MN, USA)) occlusal onlays [39-42]. These multi-step methods require several appointments for the fabrication of mock-ups and provisional restorations to test the new VDO, validate the esthetic results and guide the preparation of tooth tissue for indirect restorations [43]. While indirect techniques are more costly than direct techniques, they permit the utilization of higherperformance materials, particularly in regard to mechanical and aging properties [37].

In 2018 and 2020, Mainjot introduced the One-Step No-Prep technique for the treatment ofgeneralized [20] and localized [44] severe TW, respectively. This technique uses Polymer-Infiltrated Ceramic Network CAD-CAM bonded partial restorations (PICN or "hybridceramics", Vita Enamic, Vita Zahnfabrik, Germany) [45]. Its main feature is that it does notrequire any preparation of the tooth tissue ("No-Prep" technique) and is performed in a single step, i.e. there is no phase with temporary restorations ("One-Step"). This is made possible by the fact that PICNs are composite materials that can be milled to a very thin thickness, bonded in a high-performance manner [46] and easily retouched to adjust proximal and occlusal contact points. The material is also easy to repair in the event of failure. In this way, the technique combines the advantages of direct techniques (minimally invasive, One-Step procedure, easy to repair) and indirect techniques (access to materials that perform better than direct restoration materials). This approach also includes bruxism management by maxillo facial physiotherapist and occlusal analysis for full mouth cases [20]. In the context of localized TW, the technique is associated with a straight-forward orthodontic extrusion (orthodontic-assisted One-Step No-Prep technique). This represents an advancement of the Dahl concept and enables the avoidance of intervention on intact teeth [44].

4. Methodological approaches to the clinical evaluation of restorations

Clinical evaluation of dental restorations is essential because it allows us to assess the effectiveness, durability and safety of the procedures and materials used to restore teeth. The methodological approaches used for this evaluation are varied, focusing on different aspects of the restoration, such as function, esthetics and the health of the surrounding tissues.

Among these approaches, the United States Public Health Service (USPHS) developed several rating scales in 1971, and the one that was finally adopted includes items for color match, cavosurface marginal discoloration, anatomical shape, marginal adaptation, and caries [47]. This scale was frequently adapted by researchers to evaluate modern restorative materials, with the consequence that there are many so called "modified

Ryge criteria" or "modified USPHS". Based on these, a new assessment tool for dental restorations was proposed by Hickel et al. in 2007 and revised in 2010, known as the World Dental Federation (FDI) criteria. The FDI criteria categorize the evaluation of restorations into three groups: esthetic (surface luster, staining, color and anatomical form), functional (fracture of material & retention, marginal adaptation, occlusal wear, approximal contact point & contour, radiographic examination and patient's view) and biological (post-operative sensitivity, caries, tooth integrity, periodontal response, adjacent mucosa and oral health). Each criterion is rated on a scale of 1 to 5, where 1 represents the best performance ('clinically excellent') and 5 the worst ('clinically poor or unacceptable'), particularly score 1 = clinically excellent, score 2 = clinically good, score 3 = clinically satisfactory, score 4 = clinically unsatisfactory (repairable), and score 5 = clinically unsatisfactory (replacement needed). Not all criteria need to be assessed in every case; the selection of relevant criteria depends on the specific clinical situation and the objectives of the evaluation [48]. In contrast, the USPHS criteria scales are more general and have traditionally focused on fewer aspects of restoration performance, often summarized in binary (pass/fail) or categorical terms (such as Alpha, Bravo, Charlie ratings). Recent studies have shown that, when properly calibrated and trained, these methods can assist practitioners in selecting the most appropriate materials and techniques, as well as ensuring optimal follow-up for their patients [49, 50]. However, the FDI criteria provide a more detailed and comprehensive evaluation of dental restorations and allow for a more nuanced assessment of the overall performance of the restoration, which may not be as thoroughly addressed by the USPHS criteria. For example, the FDI criteria evaluate not only the clinical appearance and function of the restoration, but also its biological impact (including tissue response) and patient comfort.

As the FDI criteria are set by the World Dental Federation, they may be more widely recognized and standardized internationally, which can be beneficial for studies seeking wider applicability or for clinicians wishing to align their practices with global standards. A recent published scoping review indicated that, in 2016, 50% of clinicals trials used the FDI criteria [51]. In addition, by separating the assessment into aesthetic, functional and biological categories, the FDI Criteria allow practitioners to evaluate each aspect independently, providing a clearer understanding of where a restoration may excel or need improvement. This can lead to better decision making in clinical practice and research.

Two types of statistics are reported routinely in dental restoration performance studies: percent success, which is a measure of restorations that survive without any adverse effects, and percent survival, which is a measure of all restorations that survive even though they may have exhibited chipping fracture, or they may have been repaired [52]. If the definition of the survival restorations appears to be clear, success used to be assessed differently between studies. Terminologies such as minor chipping, partial chipping, technical complications, and biological complications have crept into the dental terminology, and they have complicated the classification of success and failure of restorations [52]. Success is defined as the intact survival of a prosthesis with acceptable surface quality, anatomic contour, and function, and where applicable, with acceptable esthetics [52]. According to FDI recommendations, the most severe score from the 16 criteria will prevail. Whenever a restoration receives a score of 4 or 5 independent of the specific criteria below, it must be recorded as a failure. They also recommend to combine scores 1, 2 and 3 to only one acceptable score and additionally two or one (merged scores 4 and 5) unacceptable score [53]. Using this classification, only failures that need a repair are considered for success evaluation. To take in account different grades of failure, Heintze proposed in 2011 to distinguish two categories of success, one success category thatexcludes only repaired failures (grade 2 failures) and failures that require replacement (grade 3 failures), and another success category that additionally excludes the minor failures that only need to be polished (grade 1 failures). Recent studies used these two success rates [54-56], enable the distinction of refurbished/polished and repaired failures, which represent different levels of clinical intervention, and easy comparison between studies.

5. Investigation of wear in restorative materials

The intraoral wear behavior of direct and indirect materials utilized in TW treatment remains an understudied area, to the best of our knowledge. In addition, visual clinical evaluation methods, such as the FDI 7a criteria, do not allow accurate and high performance analysis of material wear, however, this information is crucial, especially in patients with bruxism [57]. It is noteworthy that the ideal restorative material should behave like natural tooth tissue in a biomimetic approach.

Indeed, the optimal material is not one that is inherently wear-resistant, as exemplified byzirconia [58, 59]. Instead, it should exhibit a behavior that closely resembles that of the tissue it replaces. This entails the capacity to evolve in conjunction with the patient's occlusion in response to tooth wear and to adapt to errors in occlusal contact point adjustment. Furthermore, the optimal material should exhibit a degree of abrasiveness that is no greater than that of enamel.

A review of the literature revealed that only three studies are currently available on the measurement of intraoral wear of restorative materials, and the measurement methods used vary widely [60-62]. In the first study related to CAD-CAM composites [60], 24 single crowns were performed in different materials (two lithium-based glass-ceramic (IPS e-max CAD and Vita Suprinity), one dispersed filler CAD-CAM composite (Cerasmart (GC) and PICN (Vita Enamic)). The measurement and recording of the crown surfaces using an intraoral scanner were carried out in the short term (6 months). No significant differences were detected between libased glass-ceramic materials and CAD-CAM composites in terms of material and wear induced antagonist [60].

In the second study [61, 62], 12 patients underwent complete rehabilitation with full occlusal coverage restorations (experimental dispersed filler CAD-CAM composite or lithium-based glass-ceramic). Impressions were made and the models were scanned with a laboratory scanner (D810, 3Shape, Copenhagen, Denmark) [63]. At 1 year, the mean material wear for pressed lithium disilicate ceramic was significantly inferior to the CAD-CAM composite [62]. For direct composite, Ning et al. reported results after 5 years of patients with severe tooth wear treated with direct composite restorations made of two different marketed materials. Quantitative wear analysis was performed using intra-oral 3D scans (Lava Cos/True Def, 3M) superimposed with Geomagic software (3D Systems, Morrisville, North Carolina, USA). The findings revealed a notable mean wear on the bearing cusps of molars for the two distinct composite materials [64] . The results showed a mean wear on bearing cusps of molars of -464 ± 185 µm (mean ± SD) and -318 ± 281 µm (mean ± SD) for the two different composite materials. These values are considerably higher than those observed in natural tooth tissue, which underscores one of the limitations of direct composites. Indeed, Lambrechts et al. [6] have demonstrated that the wear of opposing enamel is 15 µm and 29 µm per year under normal circumstances for premolars and molars, respectively. Similarly, Esquivel-Upshaw et al. [65] have reported enamel wear of 40–80 µm per year.

On the other hand, a systematic review of the *in vitro* wear resistance of CAD-CAM composite materials by Laborie et al. indicated that PICN (Vita Enamic) exhibited reduced wear compared to dispersed filler CAD-CAM composites, but greater wear than lithium-based glass-ceramics, which are more abrasive [66]. Most articles also show that PICN would wear the opposing teeth more than dispersed filler CAD-CAM composites, with PICN reported to have a wear pattern similar to that of enamel [66, 67]. In regard to direct composites, an *in vitro* study examined the wear behavior of three commercially available composites (hybrid and nanofiller composites) and demonstrated that all the composites exhibited wear rates between those of enamel and dentin. Indeed, the data demonstrated that the wear ratio between enamel and composites was 2.5. This indicates that, in accordance with the aforementioned paper, patients who undergo full-mouth treatment to restore the vertical dimension will require retreatment after 5-10 years unless protective measures are implemented to reduce material wear [68].

However, if *in vitro* studies are useful, easy to perform, cheaper than clinical studies, and allow accurate analysis of the material surface, they face numerous difficulties in reproducing the oral environment and its variations, which can significantly influence their clinical relevance [63, 69, 70]. Therefore, the development of clinical studies, which allow material clinical wear measurement, is recommended.

Different methods have been reported to assess material wear clinically, and Wulfman et al. have reported an important lack of standardization of wear measurement procedures in clinical studies and an important variation in terms of the performance of the different measurement workflows described [63].

Digital profilometry combined with a matching software is reputed as the best technique for wear measurement in clinical studies [71][72] and is the most often used tool. Replica use should be avoided as much as possible, but this option is only valid for restorations that can be removed and scanned directly [63]. In fact, replicas generate inaccuracies mainly due to the deformation of the impression material, the casting or the presence of positive bubbles on the surface. On the other hand, the use of intraoral scanners is promising for analyzing the wear of restorative materials and dental tissue [73], but further studies are equired to evaluate their accuracy and precision [74].

6. Outstanding questions and future directions

6.1 Risk factors of TW

TW is a multifactorial phenomenon and knowledge of risk factors is crucial to promote diagnosis, prevention strategies, and timely interceptive treatment. A substantial body of research has been conducted on the prevalence and risk factors associated with TW. These factors can be classified as either intrinsic or extrinsic, chemical or mechanical, biological, behavioral, or environmental. However, to the best of our knowledge, no comprehensive review of the literature has been conducted to synthesize the results of these studies. This lack of synthesis makes it challenging for general dental practitioners to gain a comprehensive understanding of the factors that have been identified thus far and to proceed to an accurate diagnosis.

6.2 Holistic approach to TW: relationships with musculoskeletal disorders

As mentioned above, a number of factors and pathologies have been documented to be associated with TW and bruxism [11-13], Indeed, the stomatognathic system is an integral part of the body, which functions as a cohesive whole, with numerous interactions, influences, and impacts between its organs and associated pathologies.

In this context, musculoskeletal disorders (MSDs) are soft-tissue injuries caused by sudden or sustained exposure to repetitive motion, force, vibration, and awkward positions. These disorders can affect muscles, nerves, tendons, joints, and cartilage (https://www.cdc.gov/niosh/programs/msd/). MSDs constitute a major public health issue, with a high morbidity and a significant economic impact on most European countries. They engender direct costs, related to medical expenditure, but also indirect costs, including lost work output, and intangible costs, related to the psychosocial burden [75]. Particularly, neck and low back pain were reported to be one of the most important causes of the global burden of disease worldwide, low back pain being in the top ten for all countries while neck pain was in the top for half of the countries [76]. If 40% of low back pain are reported to be attributed to occupational risks or increased BMI [76], there is no defined risk associated with neck pain.
On the other hand, some MSDs have been reported to be related to body posture [77, 78] and a few studies have shown a correlation between the stomatognathic system and body posture, although this topic is controversial [78-81]. Some authors highlighted a correlation between jaw position and body posture [82-84], or masticatory dysfunction and neck pain [85], while other authors have reported that there is no link between dental occlusion and the entire body [86]. However, a good balance between the masticatory muscles and the head and neck muscles seems to be an important factor for postural stability [87, 88], and some studies have underlined the need to achieve an interdisciplinary approach in complex treatments combining dentists, physical therapists, and posturologists [89-91]. Indeed, following the muscular chains concept [91], the muscular system is composed of groups of muscles, which are connected longitudinally and symmetrically through the fascia and which influence body posture and alignment. Therefore, mechanical tension in masticatory muscles due to bruxism could be transmitted through the body, influencing postural sway and generating musculoskeletal pain. Particularly, one hypothesis is that bruxism has an impact on Musculoskeletal Disorders (MSD) and that reducing bruxism could reduce MSDs. In 2012, the findings of Hellmann et al. [92] supported the assumption of a relationship between jaw clenching and the activity of the neck muscles, while in 1997 Bader et al. [93] noticed, in a sample of 24 bruxers, that 69% of them complained about neck, back, shoulder, or chest pain.
However, there is a lack of data regarding the association between bruxism or TW (as a symptom of bruxism) and MSDs (except localized masticatory muscle pain).

6.3 Awareness of the characteristics of emerging restorative materials for TW

The restorative material properties are of paramount importance with regard to the efficacy of the treatment, particularly over the long term. Nevertheless, the current range of dental composites is extensive and sophisticated, comprising a multitude of materials with diverse properties and applications. In particular, the development of CAD-CAM blocks has been associated with the advent of new polymerization modes, innovative microstructures, and compositions that differ from those of direct light-cured composites. These changes have resulted in significant discrepancies between the various categories of composite materials with regard to mechanical properties, chemical stability, biological properties, bonding properties, and long-term performance probability, particularly in comparison with ceramic materials [45, 94, 95]. Furthermore, the recent and rapid advancements in the domain of CAD-CAM composites have frequently resulted in uncertainty regarding the distinctive attributes of the emerging materials, which have not been fully recognized by practitioners. This confusion is further compounded by the marketing strategies employed by manufacturers and the emergence of ambiguous terminology, such as the use of terms like «nanoceramic materials» or «hybrid ceramics». The majority of practitioners are unaware of the distinctions between a dispersed filler CAD-CAM composite and a PICN CAD-CAM composite. In the majority of cases, they defer to the dental technician in selecting the material, when they should be capable of making an informed decision based on the clinical circumstances and the relative advantages and disadvantages of each material. This is particularly relevant in the field of TW, whereminimally invasive strategies are employed in challenging circumstances. In such cases, CAD-CAM composites may offer a viable solution.

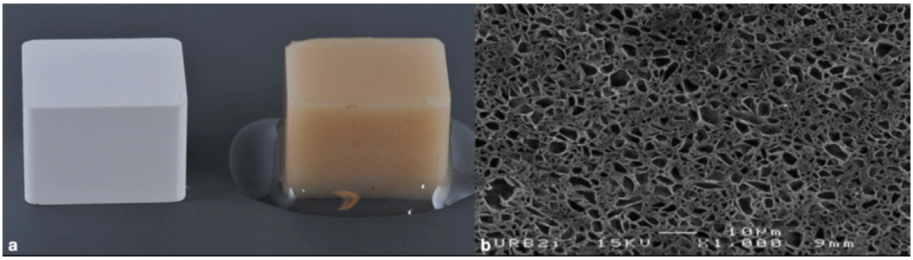


Fig. 1.7 a) A pre-sintered glass-ceramic scaffold infiltrated with monomer, which is secondarily polymerized under high-temperature and high-pressure to produce a polymerinfiltrated-ceramic-network (PICN) block. In PICN, glass-ceramic particles are interconnected creating a double-network material. From: "Recent advances in composite CAD-CAM blocks" Mainjot A., Int J Esthet Dent, 2016
b) Scanning electron microscope observation (1000×magnification) of experimental slipcasted polymer-infiltrated ceramic-network after polishing and etching with hydrofluoric acid for 1 min. Etching leads to glass-ceramic network dissolution and creation of a specific interesting "honeycomb" structure formed by the remaining resin network, which promote bonding. From: "From Artisanal to CAD-CAM Blocks: State of the Art of Indirect Composites" Mainjot A. et al, Journal of Dental Research, 2016.

6.4 Building evidence for the technique to be employed in TW treatment

As previously stated, and in consideration of the extant literature, there is an absence of evidence regarding the optimal technique (direct or indirect) or material (composite or ceramic) for the restoration of worn dentition [7, 16, 96]. Indeed, there is a paucity of studies, particularly those with a long-term follow-up period. The One-Step No-Prep approach, which employs recent PICN materials, has been demonstrated to yield successful short-term clinical outcomes in three pilot cases and to be particularly straightforward and minimally invasive. However, these preliminary results need to be confirmed by a comprehensive study of the various aspects of this protocol, which should be studied over a longer period of time. Additionally, there is a deficit in data concerning the clinical behavior of PICN partial bonded restorations in general. The intraoral wear of the material should be investigated, with particular attention to its role in TW treatment.

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Chapter

2

Objectives

The primary aim of this thesis was to contribute to the assessment of a non-invasive restorative treatment protocol for patients with generalized tooth wear (TW): the One-Step No-Prep technique using polymer-infiltrated ceramic network (PICN) CAD-CAM composite restorations. Additionally, this study sought to contribute to TW diagnosis and to the investigation of the intraoral wear of PICN material.

The strategy was based on the following assumptions presented in the introduction:

- **Tooth wear (TW) is a multifactorial phenomenon**, and understanding the associated risk factors is crucial. However, the literature lacks a comprehensive review that synthesizes findings from various studies to guide clinicians in making informed diagnostic and management decisions.
- **One hypothesis suggests** that bruxism or TW might be linked to several factors and pathologies, such as musculoskeletal disorders (MSDs) or posture. However, the current data on this association are limited, highlighting the need for further research in this area.
- **Publications indicate that there is no consensus** on the optimal technique or material for restoring severely worn dentition, largely due to a scarcity of studies, particularly long-term evaluations. The One-Step No-Prep technique has been noted for its simplicity, but its effectiveness needs to be validated through a comprehensive analysis of the various aspects of this protocol and with a large sample size.
- **PICN materials appear to be well-suited** for the One-Step No-Prep technique due to their properties. However, their clinical performance has been insufficiently studied, particularly in long-term in intraoral conditions. Specifically, data on the wear resistance of PICN materials are lacking, which is crucial information, especially for patients with bruxism.

Therefore, the specific aims of the six work packages of this thesis are as follows:

1. To map and describe factors suspected to be associated with TW in permanent dentition based on quantitative measurement of TW. The secondary objective of this work package is to introduce a TW risk factor checklist for use in clinical practice.
2. To investigate the association between bruxism and MSDs. A secondary objective is to study the association between TW related to bruxism and MSDs.
3. To critically review the global evolution of indirect composites to understand their respective properties and the contribution of new materials to treatment strategies improvement.

To evaluate the One-Step No-Prep technique for full-mouth rehabilitation of worn dentition in a **prospective clinical study**, in particular:

4. To investigate the clinical behavior of PICN restorations and the impact of treatment on patients' oral health-related quality of life (OHRQoL) using the Oral Health Impact Profile-49 (OHIP-49) questionnaire over a two-year period in 7 patients.
5. To evaluate the intraoral wear of PICN CAD-CAM composite restorations over a five-year period using *ex vivo* 3D profilometry analyses.
6. To report the results of up to 9 years of follow-up in 24 patients and to evaluate the influence of restoration thickness on fracture of restorations.

Chapter

3

Risk factors of tooth wear in permanent dentition: A scoping review

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2. Abstract

Background: Tooth wear (TW) prevalence is high and increasing and has important consequences on the patient's quality of life. Knowledge of risk factors is crucial to promote diagnosis, prevention strategies and timely interceptive treatment. Many studies have identified TW risk factors.

Objective: This scoping review aims to map and describe suspected available factors associated with TW in permanent dentition based on quantitative measurement.

Methods: The scoping review was conducted using the PRISMA extension of the Scoping Reviews checklist. The search was conducted in October 2022 from the Medline® (PubMed® interface) and Scopus® databases. Two independent reviewers selected and characterised the studies.

Results: 2702 articles were identified for assessment of titles and abstracts, and 273 articles were included in the review. The results show a need to standardise TW measurement indices and the study design. The included studies highlighted various factors, classified into nine domains: sociodemographic factors, medical history, drinking habits, eating habits, oral hygiene habits, dental factors, bruxism and temporomandibular disorders, behavioural factors, and stress. Results related to chemical TW (erosion) risk factors underline the importance of eating disorders, gastroesophageal reflux and lifestyle, particularly drinking and eating behaviours, which supports developing public health information campaigns and interventions. Besides chemical, this review identifies evidence of several mechanical TW risk factors, such as toothbrushing and bruxism; the influence of this last factor needs to be further explored.

Conclusions: TW management and prevention require a multidisciplinary approach. Dentists are in the first line to detect associated diseases such as reflux or eating disorders. Consequentiy, practitioners' information and guideline diffusion should be promoted, and a TW risk factors checklist (the ToWeR checklist) is proposed to help diagnostic approaches.

KEYWORDS

abrasion, attrition, bruxism, diet, erosion, gastroesophageal reflux.

3. Introduction

Tooth wear (TW) is the loss of dental hard tissues from the surface by means other than dental caries, trauma, or developmental disorders. It has different types: attrition (wear process by direct tooth-to-tooth contact), erosion (dissolution of dental hard tissue caused by non-bacteriogenic acids), abrasion (caused by the sliding or rubbing of abrasive external objects against the tooth surfaces), and abfraction (caused by tensile stress generated from non-axial cyclic occlusal forces) [1]. TW prevalence has been high and increasing, particularly in young patients [2-4]. An earlier study reported that TW affects 68.8% of the population between 16 and 97 years old in the United States, with 9.6% showing extreme TW [5]. In the Netherlands, moderate and severe TW affected 86% of the adult population [6].

In severe TW cases, patients can suffer from dental pain and psycho-social handicap due to impaired aesthetics, masticatory dysfunction, temporomandibular joint disorders, masticatory muscles, and orofacial pain [7, 8], with a significant impact on the oral health-related quality of life [9], requiring complex rehabilitation [10-14]. TW is a multifactorial phenomenon, which can be physiological or pathological [15], and knowledge of risk factors is crucial to promote diagnosis, prevention strategies, and timely interceptive treatment. Moreover, knowledge of TW risk factors and proper clinical screening could detect associated pathologies.

Many studies on the prevalence and related risk factors identified extrinsic or intrinsic, chemical or mechanical, biological, behavioral, or environmental [16]. However, to the best of our knowledge, no review in the literature synthesizes the results of different studies. Therefore, the objective of this scoping review was to map and describe factors suspected to be associated with TW in permanent dentition based on quantitative measurement of TW. The secondary objective of this study was to introduce a TW risk factor checklist for use in clinical practice.

4. Method

4.1. Study design

The scoping review was conducted using the PRISMA-ScR checklist (Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for scoping reviews checklist) [17] (Appendix 1).

4.2. Eligibility criteria

Epidemiological studies, systematic review and meta-analysis on risk factors of tooth wear in permanent dentition were considered in this review. Reviews, case reports, correspondence, editorials, animal studies, anthropological studies, *in vitro* and in situ studies, letters, posters, conference abstracts, personal opinions, comments, and resumes were excluded, as well as studies on dental materials and treatments.

Pubmed (28/10/2022) #1 AND #2 AND #3

#1	#2	#3
Tooth wear OR Dental wear OR Tooth abrasion OR Tooth erosion OR Tooth attrition OR Dental abrasion OR Dental erosion OR Dental attrition OR Occlusal wear OR Occlusion wear OR Molar wear OR Premolar wear OR Canine wear OR Incisive wear OR Erosive tooth wear OR Anterior tooth wear OR Posterior tooth wear OR Enamel wear OR Dentin wear OR Tooth Wear[MeSH Terms] OR Tooth Wear/etiology[MeSH Terms]	Risk factor OR Risk factors OR Cause OR Causes OR Risk OR Risks OR Causality OR Origin OR Reason OR Bruxism OR GERD OR Gastroesophageal reflux OR Soft drink OR Energy drinks OR Fruit juice OR Bulimia OR Anorexia OR Dietary OR Acidity OR Acidic OR Alcoholism OR Drugs OR Brushing OR Toothpaste OR Swimming pool OR Risk[MeSH Terms] OR Risk Assessment [MeSH Terms] OR Carbonated Beverages [MeSH Terms] OR Causality[MeSH Terms]	NOT Temporary dentition NOT Primary tooth NOT Primary teeth NOT Implant NOT Periodontal NOT Periodontitis NOT Dental material NOT Dental materials NOT Restoration NOT Rehabilitation

Scopus (28/10/2022) #1 AND #2 AND NOT #3

#1	#2	#3
TITLE-ABS-KEY (tooth wear) OR TITLE-ABS-KEY (dental wear) OR TITLE-ABS-KEY (tooth abrasion) OR TITLE-ABS-KEY (tooth erosion) OR TITLE-ABS-KEY (tooth attrition) OR TITLE-ABS-KEY (dental abrasion) OR TITLE-ABS-KEY (dental erosion) OR TITLE-ABS-KEY (dental attrition) OR TITLE-ABS-KEY (Occlusal wear) OR TITLE-ABS-KEY (Occlusion wear) OR TITLE-ABS-KEY (Molar wear) OR TITLE-ABS-KEY (Premolar wear) OR TITLE-ABS-KEY (Canine wear) OR TITLE-ABS-KEY (Incisive wear) OR TITLE-ABS-KEY (Erosive tooth wear) OR TITLE-ABS-KEY (ETW) OR TITLE-ABS-KEY (Anterior tooth wear) OR TITLE-ABS-KEY (Posterior tooth wear) OR TITLE-ABS-KEY (enamel wear) OR TITLE-ABSKEY (dentin wear)	TITLE-ABS-KEY (risk factor) OR TITLE-ABSKEY (cause) OR TITLE-ABS-KEY (risk) OR TITLE-ABS-KEY (causality) OR TITLE-ABS-KEY (origin) OR TITLE-ABS-KEY (reason) OR TITLEABS-KEY (bruxism) OR TITLE-ABS-KEY (GERD) OR TITLE-ABS-KEY (gastro-esophageal reflux) OR TITLE-ABS-KEY (soft drink) OR TITLE-ABS-KEY (energy drinks) OR TITLE-ABS-KEY (fruit juice) OR TITLE-ABS-KEY (bulimia) OR TITLE-ABS-KEY (anorexia) OR TITLE-ABS-KEY (dietary) OR TITLE-ABS-KEY (acidity) OR TITLE-ABS-KEY (acidic) OR TITLE-ABS-KEY (drugs) OR TITLEABS- KEY (brushing assessment)	TITLE-ABS-KEY (*In vitro*) OR TITLE-ABS-KEY (case report) OR TITLE-ABS-KEY (animal)

Fig. 1 Electronic databases and search strategy.

4.3. Information sources

The search was conducted in October 2022 from two databases: Medline® (PubMed® interface) and Scopus®. MeSH terms and synonyms related to TW, risk factors and permanent dentition were considered (Figure 1).

4.4. Search strategy

The search query was developed based on TW risk factors in adult (permanent) dentition. The search strategy was adapted to fit each database (Figure 1). The search was limited to publication date and language to ensure publications are from January 1, 2000, in English or French. The reference lists of all identified articles were also screened to identify additional studies for inclusion.

4.5. Selection of source of evidence

After excluding duplicate references, two independent investigators (J.O. and C.G.) selected publications according to the eligibility criteria. The titles and abstracts of the identified articles were assessed. Data extraction differences were discussed and resolved by consensus; otherwise, a third examiner (A.M.) intervened in deciding whether to include or exclude the paper. The full texts of all articles identified for possible inclusion were retrieved and screened by two of the authors (J.O. and A.D.).

4.6. Data charting process

For each study, the following data items were extracted (Appendix 2):

- Paper identification: first author name, title, journal and year of publication
- Information about the study: number of participants (n) and power sample size calculation, age of participants, calibration and number of examiners, TW measurement indexes, studied factors.

Moreover, the significance of outcomes was considered when identified factors significantly promote or decrease TW by univariate and/or multivariate statistical analysis (Appendix 2).

5. Results

5.1 Selection of sources of evidence

The literature search resulted in 3270 manuscripts (Figure 2) and 2702 after removing duplicates. After title and abstract screening, 523 studies were considered for the full-text review. After full-text reading, 250 studies that did not meet the eligibility criteria were excluded. Consequently, 273 studies were included, comprising 246 cross-sectional studies,

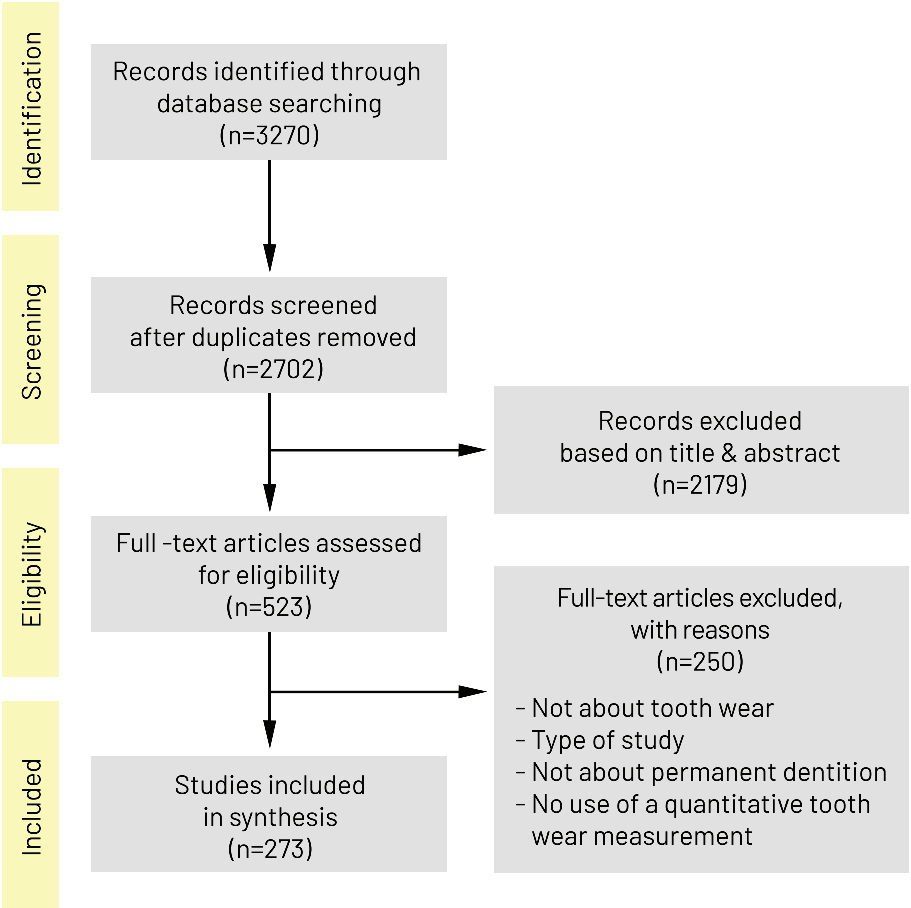

Fig. 2 Flow diagram for study selection according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.

17 longitudinal studies, 10 systematic reviews and 8 meta-analyses. Appendix 1 presents the following data for each of the included studies: (1) authors; (2) titles; (3) journals; (4) years; (5) number of participants and power sample size calculation; (6) age of participants; (7) calibration and the number of examiners; (8) TW measurement indices; and (9) studied factors.

5.2 Characteristics of sources of evidence

In total, 183 studies mentioned that the examiners were calibrated before clinical evaluation, and 35 different TW measurement indices were used. The most commonly used indices were the BEWE index (62 studies) [18], the TWI index (53 studies) [19], and a modified version of TWI (18 studies) [20]. However, 25 studies did not indicate the type of index used.

5.3 Synthesis of results

The geographic distribution of TW studies showed that most studies were conducted in Brazil and Europe (Figure 3). The factors evaluated in the selected studies are presented in Table 1 and classified into nine domains: sociodemographic factors, medical history, drinking habits, eating habits, oral hygiene habits, dental factors, bruxism and temporomandibular disorder (TMD), behavioral factors, and stress. Figure 4 shows that the most studied factors were related to sociodemographic factors (188 studies), medical history (183 studies), drinking (154 studies), and eating habits (141 studies).

5.3.1. Socio-demographic factors

Among all factors associated with TW, the socio-demographic factors were the most frequently studied in this scoping review (68.9% of included studies, n=188) [2-5, 20-149] [150-198]. Sex and age represented 58.6% and 46.9% of studies in this category (Table 1). In particular, age was reported as a statistically significant TW risk factor in 57 out of 128 included articles, and the chance of wearing facets increased with age (Table 1, Appendix 1). However, it must be noted that 109 of 273 studies focused only on young patients (under 20 years old) (Appendix 2), while reported risk factors are not different regarding adolescents and regarding adults [197]. Sex was reported as a statistically significant TW risk factor in 50 out of 160 included articles, most of which showed that males are more affected by TW than women (Table 1, Appendix 2). The type of work seems to significantly influence TW in 12 of 31 studies and education in 12 of 39 studies. Exposure to acidic chemicals and extremely high noise levels seem to be associated with erosion and tooth abrasion, respectively [83, 88, 94]. Managers have shown a significantly higher TW prevalence [38], and unemployed people have significantly higher occlusal wear [40]. A high level of education was negatively correlated with severe tooth wear, whereas children with a father with lower education were reported to exhibit a high risk of TW [2, 199].

5.3.2. Medical history – Medical condition

Medical history was the second most frequently studied factor (67% of included studies; n=183) [2, 3, 5, 22-24, 26-35, 38, 40, 42-44, 47, 49-51, 53, 56-58, 60-64, 68-70, 74, 75, 77, 78, 80, 81, 83, 85, 87, 90-92, 94-96, 98, 101, 102, 104-108, 110, 111, 113, 114, 119-130, 132, 136-138, 140-144, 147, 148, 200-238] [151, 153, 154, 239-241], [155, 156, 242, 243] [(157, 159, 161, 163, 167, 168, 170, 173, 174, 177-179, 181, 182, 186, 189-191, 195, 197, 198, 244-257], and 27 studies were exclusively dedicated to this topic. The influence of the presence of GORD, stomach upset, or heartburn was the most studied factor from this category, with 35.2% of studies included in this scoping review (96 out of 273). This factor significantly influenced TW in 30 of

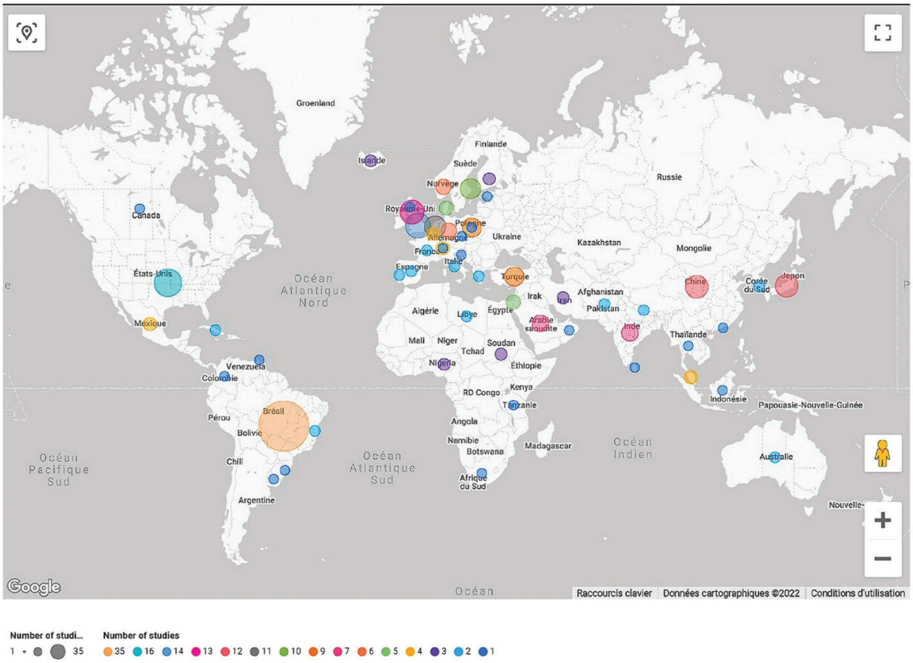

Fig. 3 Geographic map indicates the distribution of TW studies in different countries.

96 studies, and a study showed that patients with GOR had poorer salivary buffering capacity [221]. Saliva composition and oral dryness symptoms were studied in 49 studies, but only nine significantly influence TW (Table 1, Appendix 2); for example, a study of 1944 participants highlighted hyposalivation as a severe erosive tooth wear risk factor [29].

Weight or obesity showed a statistically significant association with TW in eight out of 29 studies, notably in children, as demonstrated in a recent study of 370 young Indian patients [77]. Eating disorders, including a range of psychological conditions that cause unhealthy eating habits, particularly anorexia nervosa, bulimia nervosa, binge eating disorder, pica disorder, rumination disorder, and avoidant/restrictive food intake disorder, were statistically significant TW risk factors in many studies (60.9% of 23 studies). However, most articles did not specify the eating disorder types studied, while anorexia nervosa and bulimia nervosa were specifically evaluated in ten papers. Three studies analyzed the relationship between TW and sleep apnea. TW severity was significantly associated with the apnea-hypopnea index severity in patients treated with an occlusal splint in one study [56]. Moreover, medications such as aspirin or diazepam was significantly associated with developing TW in 9 out of 40 studies. Similarly, vitamin C intake was correlated with TW in seven of the 28 studies (Table 1, Appendix 2). Asthma significantly influences dental wear in seven out of 14 [201], and one

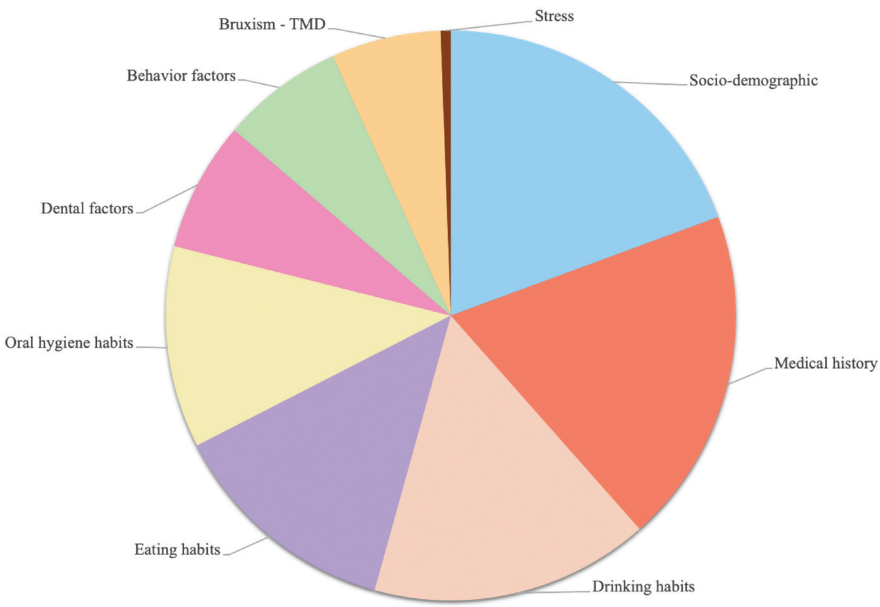

Fig. 4 Percentage of studies dedicated to each domain of factors suspected to influence TW, respectively.

study attributed this influence to cortisol inhaler side effects, which reduce saliva pH [70]. Drug consumption was identified as a risk factor for TW in 4 out of 10 studies (Table 1, Appendix 2). Nixon et al. attributed this effect to bruxism and xerostomia induced by drugs, such as ecstasy, amphetamines, or cocaine [224]. Finally, one study showed that esomeprazole-based medications might be useful in counteracting GORD-related dental erosions progression [237].

5.3.3. Drinking habits

5.3.3.1 Drinks-beverages

Studies on drinking habits were more in the literature, with 56.4% of articles included in this review (Table 1, Appendix 2) [2-5, 22, 24-27, 29-34, 37, 38, 40, 43, 44, 47-49, 51, 53, 54, 57, 60, 61, 66, 68, 70-75, 77-80, 83-85, 87, 90, 91, 94-98, 100, 101, 104, 106-114, 118-127, 129, 130, 132, 136, 138, 139, 142-144, 147, 148, 200, 201, 204-207, 212, 214, 217, 218, 222, 224, 229-232, 235, 258-264] [151] [153-155, 159, 160, 163, 166-168, 170, 174-176, 178-181, 183, 184, 186, 188, 189, 191, 196-198, 240, 244, 245, 250, 265-269].

	Number of studies (n)	n/n tot (%)
1. Socio-demographic factors	**188**	**68.9**
Gender -Sex	*160*	*58.6*
Age	*128*	*46.9*
Education - Parent's education - Father's education - Mother's education Family - Parents' birthplace	*39*	*14.3*
Work - Type of work- Work in factory - Working exposure (acid) - Worker exposed - Smelter workers - Working environment - Occupation - Position Employment - Unemployment - Length of employment - Working years Profession - Parent's employment	*31*	*11.4*
Country - Location - Area of residence -District - Village - Site - Civil state- Migrants	*28*	*10.3*
Socio-economic status - Economic classification - Socio-economic class - Social	*26*	*9.5*
Household income - Family income - Poverty income ratio - Income - Financial class	*19*	*7*
Rural area - Urban area - Rural/Urban resident - Environment - Apartment size	*4*	*1.5*
Dental insurance coverage	*3*	*1.1*
2. Medical history - Medical condition	**183**	**67**
Gastro-Oesophageal-Reflux - Gastric reflux - Reflux - Acid reflux - Sour in mouth- Stomach Upset - Heartburn	*96*	*35.2*
Saliva - pH saliva - Saliva flow rate - Buffering capacity - Saliva viscosity - Oral pH - Salivary consistency- Salivary gland disorder – Hyposalivation - Sjögren's Syndrome – Xerostomia – Oral dryness – Dry mouth	*49*	*17.9*
Vomiting - Regurgitation - Vomit - Repeated vomiting	*40*	*14.7*
Medication - Acid reflux medication - Aspirin - Sleeping medication/Antidepressant - Medicaments - Esomeprazole – Sedatives – Diazepam - Soporifics	*40*	*14.7*
Weight - Obesity - BMI- Waist and hip ratio - Body shape/weight - Overweight - Morbid obesity	*29*	*10.6*

TABLE 1 (continued)	Number of studies (n)	n/n tot (%)
Vitamin C - Vitamin C tablets - Vitamin - Effervescent vitamin C - Vitamin D intake - Multivitamins	28	10.3
Bulimia - Anorexia - Eating disorders - Anorexia nervosa - Purging bulimia	23	8.4
Smoking - Tobacco - Plain Tobacco	20	7.3
General Health - Anamnesis	16	5.9
Asthma	14	5.1
Drugs - Cocaine - Amphetamine - Snuff - Cannabis - Ecstasy - Heroin	10	3.7
Dementia - Psychiatric disorder – Illnesses- Psychological disease	8	2.9
Allergies - Eczema	5	1.8
Indigestion – Digestion problems	5	1.8
Hypertension - Blood pressure - Cardiovascular disorder	5	1.8
Systemic disease – Systemic health	5	1.8
Diabetes	4	1.5
Alcoholism	4	1.5
X-rays irradiation - Radiations - Radiotherapy	3	1.1
Respiratory disorders - Pneumonia	3	1.1
Oesophageal symptoms - Oesophagitis	3	1.1
Height	3	1.1
Iron supplements	3	1.1
Apnea - Sleep - Apnea	3	1.1
Bariatric surgery	3	1.1
Triglycerides - Cholesterol - Fats	2	0.7
Calcium intake	2	0.7
Pregnancies	2	0.7
Ear infection - Hearing problems	2	0.7
Nervous system disorder - Neurological disease	2	0.7
Cerebral palsy	2	0.7
Mouth breathing	1	0.4
T score for BMD femur - T score BMD spine - Z score for BMD femur - Z score BMD spine	1	0.4
Celiac disease	1	0.4
Parkinson's disease	1	0.4
Phosphate - Phosphorus intake	1	0.4
Inattention	1	0.4

TABLE 1 (continued)	Number of studies (n)	n/n tot (%)
Halitosis	1	0.4
Copper intake	1	0.4
HIV	1	0.4
Thyroid	1	0.4
Hormone	1	0.4
Liver	1	0.4
Amylase (saliva)	1	0.4
Urea (saliva)	1	0.4
Albumin (saliva)	1	0.4
Serum	1	0.4
Zinc intake	1	0.4
Potassium (saliva)	1	0.4
Sodium (saliva)	1	0.4
Total protein (saliva)	1	0.4
Hemodialysis	1	0.4
Mild cognitive impairment	1	0.4
Hay fever	1	0.4
Epilepsy	1	0.4
Hiatus Hernia	1	0.4
Urogenital disorder	1	0.4
Rheumatic fever	1	0.4
Snoring	1	0.4
Migraines	1	0.4
Immune system disease	1	0.4
Hyperactivity	1	0.4
Infections	1	0.4
Eye dryness	1	0.4
Chest pain	1	0.4
Proton pump inhibitors	1	0.4

TABLE 1 (continued)	Number of studies (n)	n/n tot (%)
3. Drinking habits	**154**	**56.4**
3.1 Drinks - Beverages		
Soft drinks -Diet Soft drinks— Carbonated beverages - Fizzy drinks - Diet fizzy drinks - Cola - Carbonated drinks - Carbonated soft drinks- Appy fizz	115	42.1
Juices - Fresh juices - Fruit juices - natural fruit juice - Powdered juice - Concentrated juice - Artificial fruit juice- Nectare	71	26
- Citrus juice (Orange, lemon, grapefruit, orange squash)	17	6.2
- Apple juice	8	2.9
- Grape juice	2	0.7
Isotonic beverage - Sport drinks - Isotonic drinks - Red-bull - energy drinks - High energy drink	43	15.8
Tea - Sweetened tea -Herbal tea - Lemon tea- Karkade - Plain tea - Red tea - Fruit tea	30	11
Milk - Milk products - Butter milk	26	9.5
Alcoholic drinks - Alcohol - Alcohol consumption - Alcoholic drinks - Alcoholic mixed drinks	26	9.5
Acidic drink – Acidic beverages in general – Erosive beverages	25	9.2
Coffee - Sweetened coffee - Coffee with milk	18	6.6
Water - Tape water - Mineral water - Carbonated water - Still water - Pure water	17	6.2
Wine - Winemakers	11	4
Iced tea – Still drinks – Non-carbonated drinks	9	3.3
Beer - Ginger beer	8	2.9
Vegetable juice – Tomato juice	6	2.2
Lemonade - fruit lemonade - Lemonade squash	6	2.2
Spirits	4	1.5
Cider - Apple cider	4	1.5
Vinegar drinks	3	1.1
Flavoured milk - Sour milk - Soured milk - Sweetened milk	2	0.7
Low calories drinks	1	0.4
3.2 Drinking behavior	**34**	**12.6**
Drinking before sleep - Night drink - Drink at bedtime - Drink at night	11	4
Holding drinks in mouth, Retention in mouth - Retained drink in mouth	11	4

TABLE 1 (continued)	Number of studies (n)	n/n tot (%)
Straw use	10	3.7
Drinking during meals	6	2.2
Swish before swallow - Swishing	5	1.8
Swallowing - Direct swallow	4	1.5
Drink after sport	3	1.1
Drinking between meals	3	1.1
Glass	2	0.7
Drinking before breakfast	2	0.7
Bottle use	1	0.4
Temperature of drink	1	0.4
Drinks frequency	1	0.4
4. Eating habits	**141**	**51.7**
4.1 Food - Diet - Dietary habit		
Fruits - Fresh fruits - Sweet fruits - Sour fruits - Canned fruit - Acidic fruits	71	26
- Citrus fruit (Lemon - Grapefruit - Oranges - Clementine- Tangerines)	52	19
- Apples	13	4.8
- Bananas - Pineapple - Mango	8	2.9
- Grapes	3	1.1
- Tinned fruit	2	0.7
- Rhubarb	1	0.4
Yoghurt - Yoghurt products - Fruit yoghurt – Dairy products - Cheese	36	13.2
Acidic food- Acidic taste - Sour food	31	11.4
Chewing-gum - Sugar free gum	23	8.4
Sweets - Acidic sweets - Acidic candies - Citrus-flavored sweets - Sour sweet - Sour candy - Lemon sour candy – Candy	20	7
Vinegar - Vinegar dressing- French dressing – Sour taste - Marinades	19	7
Ketchup - Sauce - Tomato sauce - Sweet/Sour sauce - Tartar sauce - Acidic sauce - Mustard – Mayonnaise - Mazza	165.9	
Vegetables - Sour vegetables - Legumes – Grains - Vegetarian diet - Vegetarian	165.9	
Pickles - pickles onions	145.1	
Salt & Vinegar chips - Salt/Vinegar crisps - Crisps or savoury snacks - Snacks - Sour snacks	114	

TABLE 1 (continued)	Number of studies (n)	n/n tot (%)
Biscuits - Biscuits unsweetened - Biscuits sweetened - Cookies - Chocolate - Caramels - Cake - Desserts	10	3.7
Salad lemon - Salad dressing - Salad creams	8	2.9
Spicy food- Spicy curried food	8	2.9
Hard foods	6	2.2
Baobab - Berries - Tubers	4	1.5
Carbohydrate - Beans/ Pasta	4	1.5
Ice cream - Ice lolly - Popsicle	3	1.1
Peppermint - Mint	3	1.1
Omnivores - Non vegetarian - Lacto-ovo-vegetarian - Special diet	2	0.4
Tamarind - Sambar	2	0.7
Jam - Meat	2	0.7
Lemon salt – Salt lemon-blend	2	0.7
Sauerkraut	2	0.7
Sugar/Flour - Sugar sweetened food	1	0.4
Food rich in calcium/phosphate minerals	1	0.4
Olives	1	0.4
Toast/sweet sandwiches	1	0.4
Honey	1	0.4
Stoneground bread	1	0.4
Rasam	1	0.4
Jelly	1	0.4
Relish	1	0.4
Fizzy pop	1	0.4
Curds	1	0.4
4.2 Eating behavior		
Eating occasion - Meal per day - Food frequency	4	1.5
Food taken at night - Night foods	2	0.7
Sucking fruits	2	0.7
Snacking between meals	1	0.4

TABLE 1 (continued)	Number of studies (n)	n/n tot (%)
5. Oral hygiene habits	**105**	**38.5**
Toothbrushing frequency - Brushing frequency	43	15.8
Brushing - Toothbrushing	33	12.1
Toothbrush - Brush bristles hardness - stiff-bristled brush - Toothbrush bristle - manual toothbrush - Electric toothbrush - Toothbrush texture - Replacing toothbrush	32	11.7
Brushing technique - Horizontal brushing - Toothbrushing technique - Brushing method - Toothbrushing pressure - Brushing movement - Horizontal technique - Vertical technique	27	9.9
Toothpaste - Type of toothpaste - Tooth gel - Abrasive dentifrice	17	6.2
Topical fluoride - Fluoridation- Fluoride consumption – Fluoride toothpaste – Fluoride vanishes, gel – Fluoride mouth rinse	14	5.1
Duration of brushing - Toothbrushing duration - Time of brushing	11	4.1
Brushing after eating - Brush after dinner - Brush after breakfast - Brushing after meal	11	4
Mouthwash - Mouth rinse	9	3.3
Brushing teeth after soft drinks - Brushing after acidic foods	5	1.8
Toothbrushing post-vomiting	2	0.7
Dental floss	2	0.7
Brushing before breakfast	1	0.4
Brushing last thing at night	1	0.4
6. Dental factors	**64**	**23.4**
Dental history		
Caries - Caries experience - Dental caries - Decayed - Decay - DMF index	16	5.9
Time of last dental visit - Last dental visit - Dental control - Visiting dentist	10	3.7
Number of teeth - Loss of occlusal contacts - Loss teeth - Missing permanent teeth	9	3.3
Orthodontic treatment	8	2.9
Plaque - Dental plaque - Dental biofilm – Poor oral hygiene	6	2.2
Composition of enamel pellicle - Enamel bioptates - Content in enamel (Ca, Mg)	4	1.5
Periodontal bone loss - Periodontitis	3	1.1
Gingival recession - Gingivitis	2	0.7

TABLE 1 (continued)	Number of studies (n)	n/n tot (%)
Tooth whitening	2	0.7
Dental calculus - Calculus	1	0.4
Filled tooth	1	0.4
Teeth/Gum soreness	1	0.4
Dental problems	1	0.4
Anatomical factors		
Occlusion – Malocclusion	10	3.7
Unilateral chewing- Mastication - Chewing side	7	2.6
Bite force - Occlusal force - Occlusal stress in maximum intercuspation position	6	2.2
Guidance - Canine guidance - Right canine guidance - Left canine guidance - Protrusive guidance	5	1.8
Angle class	4	1.5
Overbite - Deepbite	3	1.1
Type of dentition	2	0.7
Open bite	2	0.7
Anterior contact	2	0.7
Protrusive interferences - Laterality interference	1	0.4
Group function	1	0.4
Edge to edge	1	0.4
Cusp-to-cusp relation	1	0.4
Crowding	1	0.4
Tooth misalignment	1	0.4
Sharp teeth	1	0.4
Tooth position	1	0.4
Overjet	1	0.4
Cross-bite	1	0.4
Facial type	1	0.4
7. Bruxism – Temporo-Mandibular-Disorders	**64**	**23.4**
Bruxism - Sleep bruxism- Tooth grinding - Clenching - Self-reported grinding	52	19
Tenderness in Temporo Mandibular Jaw (TMJ) or masticatory muscles - Fatigue masticatory muscles - Muscles pain – Jaw soreness – Masseter muscle activity	9	3.3

TABLE 1 (continued)	*Number of studies (n)*	*n/n tot (%)*
Occlusal splint - Mouth guard - Bite guard	*7*	*2.6*
TMD pain - TMJ disorder - Musculoskeletal disorder	*7*	*2.6*
Temporal headache - Headache	*6*	*2.2*
Clicking sound during opening mouth - clicking joint	*3*	*1.1*
Facial pain	*2*	*0.7*
Limitation mouth opening	*1*	*0.4*
8. Behavior factors	**37**	**13.6**
Sport		
Swimming - Swimming pool - Swim in chlorinated pool – Chloride	*18*	*6.6*
Sports activity - Physical activity - Sport - Exercise - Competitive sport - Outdoor sport - Running - Training - Cycling	*18*	*6.6*
Time during training - Time expended during competition	*1*	*0.4*
TV/Computer - Computing	*3*	*1.1*
Oral parafunctional habits		
Fingernails - Nail biting - Biting objects - Biting pencil – Grinding substances - Toothpick use – Oral piercings	*11*	*4*
Cheek habits	*1*	*0.4*
Use teeth as tools	*1*	*0.4*
Chewing sticks	*1*	*0.4*
Finger/Thumb sucking	*1*	*0.4*
Pacifier use	*1*	*0.4*
9. Stress	**5**	**1.8**

Tab. 1 List of factors suspected to influence TW in included studies, ranked by domain and number of studies (n) included.

The influence of acidic beverages like soft or carbonated drinks on TW was found in 42.1% of studies; a statistically significant association was found in 32.2% of studies related to this topic (Table 1) [22, 270]. In a study of 3586 American adults, the daily frequency of soft drink consumption was the only factor associated with moderate-to-severe tooth wear compared to socio-demographic factors, acid reflux medication, fruits, fruit juices, and alcoholic drink consumption [259]. This was corroborated by 23 studies on children (Appendix 2). Moreover, a study of 1528 children from South Brazil also found that daily soft drinks consumption was associated with dental erosion [32].

The consumption of fruit juices was a statistically significant TW risk factor in 26% of related studies (Table 1). However, studies reporting more details on the type of fruit juice (citrus, apple, or grapefruit) do not specifically highlight one type of fruit juice. Energy drinks and sports beverages were associated with erosive TW (ETW) in 17 of 43 (39.5%) studies. Regarding tea and coffee consumption, 6 studies on 30 (20%) and 5 studies on 18 (27.8%) showed a significant association with TW, respectively (Table 1). In addition, 53.9% of studies (n =26) showed a significant association between alcohol and TW, making this factor the most significant (Appendix 2). However, one study showed that patients who drank more than 7 alcoholic beverages per week had less TW [125, 271].

Finally, milk consumption showed a significant negative association with the progression of erosive wear in five studies on 26 (19.2%) (Appendix 2). Only one study on 14-year-old-school showed a positive correlation between milk and ETW. However, the authors reported that it could be related to the high consumption of beverages [258]. The intake of milk and milk-based products has been reported to prevent ETW, especially in replacing sweet-carbonated drinks [69].

5.3.3.2 Drinking behavior

The influence of various drinking behaviors on TW, like straw use or drink retention in the mouth before swallowing, was studied in 12.6% of included studies (n=34) [26, 28, 30, 60, 74, 77, 100, 105, 108, 110, 118, 121, 127, 142, 147, 205, 217, 225][173, 184, 194, 244, 250]. Two out of 10 studies related to straw use showed that it decreased the prevalence of erosion [77, 217]. Conversely, drink retention in the mouth significantly increased TW prevalence in 4 out of 11 studies. Moreover, drinking before going to sleep or between meals was reported to promote TW in 5 out of 11 and 2 out of 3 studies, respectively (Table 1, Appendix 2) [28]. However, two out of 6 showed that drinking acidic beverages with meals increased TW compared to drinking these beverages between meals, while the 4 other studies showed no influence [225, 259].

5.3.4. Eating habits

5.3.4.1 Diet

Dietary habits were also found in the literature, and in 51.7% of articles included [2, 4, 24-27, 30, 32, 34, 37-39, 43, 44, 47-51, 53, 54, 57, 60, 61, 68-72, 74, 83-85, 87, 89, 91, 92, 94-97, 101, 104, 106-114, 116, 118-120, 122, 124, 127, 129, 130, 132, 136, 141, 143, 144, 147, 148, 200, 201, 204-207, 212, 216-218, 222, 224-226, 229, 235, 258-261, 264][155, 160, 161, 164, 166, 170, 174-176, 178, 180, 181, 186, 188-191, 193-198, 240, 244, 245, 268, 272-274].

Citrus fruit consumption was reported to increase TW significantly in 19 of 52 studies. Frequent consumption of acidic candies was shown to be a risk indicator for developing erosive lesions in five out of 20 studies (Table 1, Appendix 2). Conversely, the use of vinegar in dietary habits and ketchup or tomato sauce consumption was reported as a statistically significant risk factor for TW in four out of 19 and five out of 16 included articles, respectively (Table 1, Appendix 2). Vegetable consumption showed a significant association with TW in 6 out of 16 studies. This association was shown in a study of 207 individuals who followed a vegetarian diet and showed significantly more ETW than omnivores [27, 116]. Moreover, six out of 23 studies showed that chewing-gum consumption increased the risk of TW. Finally, only two studies of 24 found an association between yogurt and dairy products consumption and wear lesions, whereas El Aidi et al. and Sezer et al. showed that erosive tooth wear was negatively associated with yogurt products [60][194](2 out of 24 studies) (Table 1, Appendix 2).

5.3.4.2 Eating behaviors

Unlike drinking, eating behaviors have rarely been studied (n=6 studies) [2, 28, 58, 113]. Food intake at night and eating frequency showed a positive association with TW in one of two and two of 4 studies, respectively (Table 1, Appendix 2). Moreover, eating acidic food more than six times per day was significantly associated with severe TW in a study of 2924 participants in six Arab countries [2], which confirmed the results of Sayed et al. [124].

5.3.5. Oral hygiene habits

The influence of oral hygiene habits on TW was studied in 38.5% of included studies [2, 5, 20, 24, 26, 30-32, 37, 38, 40, 43, 44, 47, 48, 50, 51, 60, 63, 65, 66, 68, 70-72, 79, 81, 83, 85, 88, 90, 94, 95, 97, 98, 100, 101, 104, 106-108, 110, 111, 113-115, 118-120, 122, 124, 127, 129, 130, 132, 134-136, 138, 142-144, 146-148, 200, 204, 207, 214, 217, 224, 225, 229, 230, 234, 275, 276][150, 152, 159, 160, 166, 167, 170, 173-175, 179, 183-185, 188, 191, 194-196, 198, 268], particularly toothbrushing frequency (15.8% of studies in this category) was reported to be significantly associated with TW in 11 studies out of 43 (Table 1). For example, in a study of 2160 Chinese adults, a daily brushing frequency of ≥ twice a day significantly increased the likelihood of wear lesions [79]. Similarly, brushing duration (3 to 5 minutes) showed a significant association with TW in four out of 11 studies [127]. The type of toothbrush (type of bristles) and toothbrushing (manual or electric) were also found to be TW risk factors in ten out of 32 studies (Table 1).
Brushing technique (high pressure, horizontal movement) was associated with TW in six of 27 studies. In a study of 488 participants, TWI scores were significantly higher in subjects who brushed horizontally than vertically [115]. In addition, abrasive toothpaste promoted TW in four of the 17 studies (Table 1, Appendix 2). Finally, tooth brushing directly after eating was associated with TW in three out of 11, while the five studies on brushing after acid intake did not show an association.

5.3.6. Dental factors

Dental factors in 23.4% of included studies [5, 24, 26, 31, 35, 40, 48, 49, 52, 54, 55, 58, 60, 62, 65, 79-81, 90, 99, 101, 103, 109, 118, 122, 123, 128, 130, 134, 136, 137, 139, 148, 149, 206, 214, 230, 234, 260, 277-282][152, 156, 167, 171, 172, 174-176, 178, 179, 185, 190, 194, 195, 283, 284] showed caries was significantly associated with TW in three out of 16 studies. Five of 9 showed that a low number of teeth on the arches was significantly associated with high occlusal wear. The occlusion type seems to significantly influence TW in four out of ten studies. In a study of patients from general practices in the United States, a class II malocclusion promoted TW, while posterior or anterior open bites decreased TW in children and adolescents but not in adults [52].

5.3.7. Bruxism – Temporo-Mandibular-Disorders (TMDs)

Bruxism and TMD concerned 23.4% of included studies in this review [23, 24, 26, 29-33, 40, 49, 53, 60, 62, 64, 67, 70, 79, 81, 90, 92, 101, 104, 105, 117, 121, 125, 130, 134, 143, 147, 216, 226, 264, 277, 281, 285, 286] [151, 162, 169, 171, 172, 174, 175, 186, 193, 194, 240, 244, 252, 268, 287-289]. Bruxism and tooth grinding/clenching were the most studied factors in this category (52 out of 64 studies) and showed a significant association with TW in 18 studies (34.6% of studies). A study including 2529 subjects showed that self-reported bruxism was a considerable risk factor for high occlusal wear in men [40].

5.3.8. Behavior factors

The relationships between sports or extensive training and TW were analyzed in 18 studies [30, 33, 34, 44, 49, 62-64, 71, 72, 74, 81, 90, 105, 118, 123, 124, 127, 129, 130, 142-144, 147, 206, 212, 214, 217, 219, 229, 230, 264] [173, 174, 179, 184, 189, 194, 195, 290], four of which showed a significant association with TW [33, 63, 64]. Four studies showed that regular swimming in chlorinated pools was correlated with TW (Table 1, Appendix 2). Finally, oral parafunctional habits, such as nail, pencil, and object biting, have rarely been studied [200]. One study in China showed that toothpicks and biting hard objects might be considered risk factors for TW.

5.3.9. Stress

Stress/psychological stress was studied in four articles but was not shown to be a risk factor for TW [45, 93, 124] [240].

6. Discussion

TW is a multifactorial phenomenon, and knowledge of its risk factors is crucial to prevent and intercept this pathology. This scoping review of TW risk factors in permanent dentition showed that various factors and age ranges characterized many studies. The results show a lack of standardization of the TW measurement indexes (35 different indexes were reported) for data analysis and interpretation. Among these indexes, the most frequently used ones were the BEWE index (22,7% of studies) [18], the TWI index (19.4% of studies) [19] and a modified version of TWI (6.6%) [20].

Moreover, many studies did not report how these indexes were standardized, which constitutes a risk of bias (Appendix 2). Other risks of bias include the sample size, which is sometimes very small and in most of the cases not supported by a power calculation, and the type of statistical tests used in analyzing data, which does not always include a multivariate analysis to take into account the confounding factors (43.96% of studies did not report a multivariate analysis). Consequently, the research quality should be improved. The factors analyzed in the 273 included studies were divided into nine categories, presented in decreasing order in terms of their representativeness in this review: sociodemographic factors, medical history, drinking habits, eating habits, oral hygiene, dental factors, behavioral factors, bruxism, and stress. Most factors can be classified into two main groups: mechanical and chemical. Indeed, TW can be engendered by a mechanical effect related to abrasion, attrition, or abfraction of tooth tissues or a chemical effect related to the acidic environment and erosion of tooth tissues. Chemical factors were the most studied and included drinking and eating habits, medical history, and behavioral factors. Drinking habits, such as soft drinks, fruit juice, energy drinks and particularly alcoholic drink consumption, were shown to significantly affect TW in many studies within the limitations of the published articles included in this scoping review. This could be explained by the low pH of the beverages. Regarding alcohol consumption and low alcohol pH [291], Kranzler et al. [292] reported that oral hygiene in alcoholic patients is often deficient, promoting an acidic environment. Interestingly, tea (pH–3-10 depending on the type of tea) and coffee (pH 4,5-5) have also been TW risk factors in some studies. One explanation could be that caffeine, a well-known stimulant, increases muscle activity and bruxism, resulting in attrition [24]. Citrus fruit consumption was shown to be a significant ETW risk factor due to its acidity (pH 0-2), while yogurt products were reported to be protective, probably due to their low acidity (pH 4.5 – 6.8) coupled with a high calcium and phosphate content, which could promote remineralization [60].

The most important risk factors considered in the medical history category were eating disorders and GORD. Gastric acids are reported to ascend to the oral cavity in GORD [293], and eating disorders are associated with vomiting. Dry mouth and diminished saliva production, for example, due to medications or radiotherapy, reduce the capacity to clear and neutralize acids in the mouth, contributing to erosive lesions in some individuals [294]. Some medications can also exhibit a low pH, such as aspirin (acetylsalicylic acid) [147] and cortisol inhalers used in asthma treatment [132]. Swimming has been reported in two studies as a risk factor, one explanation being that the pH of swimming pool water is low. Mechanical factors have been less explored than chemical causes and mainly include oral hygiene habits and bruxism/tooth grinding/clenching. It was demonstrated that the presence of TW was associated with the use of a toothbrush with hard fibers or a horizontal brushing technique. In contrast, an electric toothbrush was reported as a risk factor in two studies, although the phenomenon was not explained [130, 132].

Surprisingly, the association between bruxism and TW, particularly attrition, was not often analyzed in included studies (52 studies, corresponding to 19% of included studies). Eighteen studies reported a significant association between TW and self-reported bruxism. However, these studies' limitations were the diagnostic criteria used for bruxism. These criteria are limited to patient self-reports, which cannot define bruxism. If polysomnography or electromyography cannot be used to confirm the diagnosis in large-sample studies, a clinical examination should be performed to reduce the risk of bias [295].

Moreover, a distinction could also be made between sleep and awake bruxism, which can both lead to TW. The presence of TW is considered a diagnostic criterion for sleep bruxism by the American Academy of Sleep Medicine, consistent with the report of tooth grinding during sleep [264]. Since bruxism and TW are suspected to be associated with sleep apnea [56, 296], mechanical TW diagnosis should lead the dentists or other related specialists to question patients about sleep disorders and should help detect them. However, further research is required in this regard.

Indeed, TW is a multifactorial and complex phenomenon, in which some risk factors can be confounding, promoting the use of multivariate analyses. For example, between BMI and overweight /obesity were shown to be significantly associated to Apnea Hypopnea Index (AHI) [240] and to the consumption of soft drinks, respectively [154].

The analysis of the significant association between different TW risk factors could constitute an interesting research perspective.

6.1 Implication for clinical practice and public health

The analysis of TW chemical risk factors regarding lifestyle, particularly drinking and eating behaviors, highlights the need to develop awareness campaigns and interventions. However, whenever TW chemical risk factors are studied, the research design should also include mechanical risk factors, particularly bruxism. Indeed, patient awareness and early bruxism treatment, including occlusal nightguard and maxillofacial physiotherapy, may significantly reduce TW.

The ToWeR checklist

Medical history	0	1	2	3	4	5	6	7	8	9	10
Eating Disorders - Vomiting	○	○	○	○	○	○	○	○	○	○	○
Gastro-Oesophageal-Reflux-Disease (GORD)	○	○	○	○	○	○	○	○	○	○	○
Drugs (cocaine, heroin)	○	○	○	○	○	○	○	○	○	○	○
Asthma	○	○	○	○	○	○	○	○	○	○	○
Smoking	○	○	○	○	○	○	○	○	○	○	○
Medication (aspirin, diazepam, ...)	○	○	○	○	○	○	○	○	○	○	○
Vitamin C intake	○	○	○	○	○	○	○	○	○	○	○
Overweight	○ Yes			○ No							
Dry mouth - Hyposalivation	○	○	○	○	○	○	○	○	○	○	○

Drinking habits	0	1	2	3	4	5	6	7	8	9	10
Consumption of : Alcohol (wine, beer, alcohol mixed)	○	○	○	○	○	○	○	○	○	○	○
Soft drinks (coke, sodas, ...)	○	○	○	○	○	○	○	○	○	○	○
Energy drinks, sport drinks	○	○	○	○	○	○	○	○	○	○	○
Tea	○	○	○	○	○	○	○	○	○	○	○
Coffee	○	○	○	○	○	○	○	○	○	○	○
Fruits juices	○	○	○	○	○	○	○	○	○	○	○
Retention of beverages in mouth	○	○	○	○	○	○	○	○	○	○	○
Drinking before sleep	○	○	○	○	○	○	○	○	○	○	○

Eating habits	0	1	2	3	4	5	6	7	8	9	10
Consumption of: Citrus fruits (lemon, grapefruit, orange)	○	○	○	○	○	○	○	○	○	○	○
Tomato sauce	○	○	○	○	○	○	○	○	○	○	○
Vegetables	○	○	○	○	○	○	○	○	○	○	○
Fruits	○	○	○	○	○	○	○	○	○	○	○
Sweets, acidic, candies	○	○	○	○	○	○	○	○	○	○	○
Vinagar-based alimentation	○	○	○	○	○	○	○	○	○	○	○
Chewing gum	○	○	○	○	○	○	○	○	○	○	○

Oral hygiene habits	0	1	2	3	4	5	6	7	8	9	10
Duration of brushing (>3 minutes)	○	○	○	○	○	○	○	○	○	○	○
Hard toothbrush bristles use	○	○	○	○	○	○	○	○	○	○	○
Toothbrushing > twice per day	○	○	○	○	○	○	○	○	○	○	○
Horizontal brushing technique	○	○	○	○	○	○	○	○	○	○	○
Abrasive toothpaste use	○	○	○	○	○	○	○	○	○	○	○

Behavior factors	0	1	2	3	4	5	6	7	8	9	10
Sport practicing	○	○	○	○	○	○	○	○	○	○	○
Swimming	○	○	○	○	○	○	○	○	○	○	○

Bruxism	0	1	2	3	4	5	6	7	8	9	10
Tooth grinding clenching reporting	○	○	○	○	○	○	○	○	○	○	○

Fig. 5 The ToWeR (Tooth Wear Risk factor) checklist. This checklist summarises the main health and lifestyle risk factors identified in this scoping review, (1) that is, factors analysed in a minimum of 10 studies and (2) shown, after statistical analysis, to be positively associated with TW in a minimum of 15 % of these studies. Risk factors in bold were found to be significantly associated with TW in more than 30% of the included studies on this factor. Sociodemographic and dental factors were not included as they cannot be modified by patient information and care.

By diagnosing and analyzing TW etiology, dentists are the first line to help diagnose associated diseases, such as reflux or eating disorders. Therefore, practitioner information and guideline diffusion are crucial and should be promoted. The ToWeR (Tooth Wear Risk factor) checklist is proposed to help them in the diagnostic and management of TW risk factors. It summarizes the main health and lifestyle risk factors identified in this scoping review (Figure 5). In that objective, it was decided to include only factors 1) analyzed in a minimum of 10 included studies and 2) shown, after statistical analysis, to be positively associated with TW in a minimum of 15% of these studies. Risk factors in bold were found to be significantly associated with TW in more than 30% of the included studies on this factor. Socio-demographic and dental factors were not included since they cannot be modified by patient information and care. The ToWeR checklist can be used to monitor the evolution of risk factors at every recall visit and raise the awareness of the adult or adolescent patient. However, it does not constitute an exhaustive document about TW risk factors and further research is needed to validate this tool or to make it evolve.

Finally, research results should encourage specialists in public health to develop appropriate policies and therapeutic education programs. Indeed, TW is an important dental problem with consequences for patient well-being and quality of life. Since it is partly related to lifestyle evolution, it represents an important issue for future generations.

7. Conclusion

This scoping review maps an important amount of heterogenous studies analyzing a large variety of factors suspected to be associated with TW. Chemical factors were the most studied and included drinking and eating habits, medical history, and behavioral factors, while the association between bruxism and TW was not often analyzed in included studies.

Further research is needed to confirm the association between TW and the many factors identified in this review, and more particularly longitudinal studies are required to assess if those factors are real risk factors for TW incidence. This will need to involve multidisciplinary research teams in health care in order to define the role of the dentists in the diagnostic and prevention of TW and related disorders.

In that objective, research quality about TW risk factors shoud be improved by: (1) promoting large sample sizes as a function of power calculation, (2) standardizing the use of one TW measurement index, (3) improving bruxism diagnosis, (4) using appropriate statistical analysis tests and methods for the important confounding factors and TW causes.

8. Author contribution

Julie Oudkerk contributed to conceptualisation, methodology, data curation, formal analysis and writing original draft; Charlotte Grenade contributed to data curation, formal analysis and reviewed the manuscript; Anoushka Davarpanah contributed to data curation, formal analysis and reviewed the manuscript; Alain Vanheusden contributed to formal analysis and reviewed the manuscript; Sandrina Vandenput contributed to conceptualisation, validation data curation and reviewed the manuscript; Amélie K. Mainjot contributed to conceptualisation, methodology, data analysis, writing original draft and supervision. All authors gave final approval and agree to be accountable for all aspects of the work.

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10. Conflict of interest statement

The authors declare no potential conflicts of interest with respect to the authorship and/or publication of this article.

11. Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Appendix A : Identify the report as a scoping review.

SECTION	ITEM	PRISMA-ScR CHECKLIST IYEM	Reported on page #
TITLE			
Title	1	Identify the report as a scoping review	1
ABSTRACT			
Structured summary	2	Provide a structured summary that includes(as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	1
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	1-2
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	2
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	4
Information sources	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	4
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	4-5
Selection of sources of evidence	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review	5
Data charting process	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data	5

		charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators	
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	5
Critical appraisal of individual Sources evidence	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence;describe the methods used and how this information was used in any data synthesis (if appropriate).	/
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	5
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	5-6
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	6
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	/
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	Appendix 2
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	6-13
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	13
Limitations	20	Discuss the limitations of the scoping review process.	13-15
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	13-15
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	/

Appendix 1: Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist

3

Appendix B

	First authors	Titles	Journals	Year
1	Ab Halim, N.	General and erosive tooth wear of 16-year-old adolescents in Kuantan, Malaysia: prevalence and association with dental caries.	BMC Oral Health	2018
2	Abanto, J.	Associated factors to erosive tooth wear and its impact on quality of life in children with cerebral palsy.	Spec Care Dentist	2014
3	Abdullah, N. F.	Knowledge, attitude, and practice of tooth wear among adults in Bertam, Penang.	Int J Prosthodont	2016
4	Abe, S.	Tooth wear in young subjects: a discriminator between sleep bruxers and controls?	Eur Arch Paediatr Dent	2009
5	Abu-Ghazaleh, S. B.	The prevalence and associated risk factors for tooth wear and dental erosion in 15- to 16-year-old schoolchildren in Amman, Jordan.	Scientific World Journal	2013

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
Y 598	16	Y 1	TWI (Smith and Knight), BEWE	Gender, ethnic group, parents' education level, household income.
Y 60	6 to 14	Y 1	Modified O Brien Index	Age, gender, dental caries, cerebral palsy, **frequency of soft drink intake between meals**, frequency of juice intake between meals, **daily intake of powdered juice**, daily of juice in box, **reported gastroesophageal reflux**, family income.
Y 349	18 to 65	NS NS	NS	Frequent consumption of carbonated beverages, frequent intake of acidic food, frequent intake of sour fruit, biting fingernails, bruxism, brushing with pressure, toothbrush, saliva, smoking, milk, using soft-bristled toothbrush, food rich in calcium/phosphate minerals.
NS 130	19 to 44	Y 3	Johansson et al.	Gender, age, bruxism, anamnesis.
Y 1602	15 and 16	Y 1	Modified Tooth Wear Index (Bardsley et al)	**Gender, oranges**, apples, canned fruit, yoghurt, **ketchup**, salad lemon, vinegar, tomato sauce, pickles, cheese, salt and vinegar chips, spicy food, lemon salt, olives, fresh juice, concentrated juice, fizzy drinks, diet fizzy drinks, red bull, tap water, flavored milk, milk, sweetened tea, herbal tea, **coffee (sweetened)**, lemonade, lemon with honey, plaque, bruxism, TMJ, nail biting, brushing, toothpaste, mouth-wash, general health, asthma, stomach upset, indigestion, acidic taste, chewing gum, vegetarian, vitamin C tablets, **dental visit last year**.

	First authors	Titles	Journals	Year
6	Aguiar, Y. P.	Association between dental erosion and diet in Brazilian adolescents aged from 15 to 19: a population-based study.	J Dent	2014
7	Ahmed, H.	Factors associated with Non-Carious Cervical Lesions (NCCLs) in teeth.	JCPSP	2009
8	Aidi, H. E.	Factors associated with the incidence of erosive wear in upper incisors and lower first molars: a multifactorial approach.	Br Dent J	2011
9	Akinola, M. A.	Gastroesophageal reflux disease: prevalence and Extraesophageal manifestations among undergraduate students in Southwest Nigeria.	BMC Gastroenterol	2020
10	Al-Dlaigan, Y. H.	Dental erosion in a group of British 14-year-old school children. Part II: Influence of dietary intake.	Int J Paediatr Dent	2001

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
Y 675	15 to 19	Y 2	O'Sullivan Index	Gender, age, family income, ethnicity, fruits, soft drink, diet/light soft drink, yogurt, artificial fruit juice, isotonic beverage, natural fruit juice, ice tea, energy drink, milk, flavored milk, coffee, coffee with milk, pickles, mustard, ketchup, vinegar.
Y 95	40 to 59	NS NS	TWI (Smith and Knight)	Gender, age, toothbrush, toothpaste, handedness brushing, type of brush, brushing technique, angle classification, guidance, bruxism.
Y 572	10 to 12	NS NS	Lussi et al.	Diet, acidic whey-based drinks, carbonated soft drink, fruit lemonade, lemonade squash, energy/sport drink, **alcoholic mixed drink**, milk products, yoghurt products, sour vegetables, chewing gum, direct swallow, straw, bite force, anterior contact, **tooth grinding**, vitamin.
Y 668	15-18, 19-22 and 23	Y NS	TWI (Smith and Knight)	GERD.
NS 418	14	Y NS	TWI (Smith and Knight)	**Apples (consumption & frequency), oranges (consumption & frequency), bananas (consumption & frequency), grapes,** salad dressing, **vinegar (consumption & frequency), tomato ketchup (consumption & frequency),** pickles, **yoghurt (consumption & frequency), vitamin C tablets (consumption & frequency), orange squash drinks, apple juice (consumption & frequency), orange juice, cola drinks (consumption & frequency), fizzy drinks (consumption & frequency), sport drinks (consumption & frequency), milk (consumption & frequency), tea (consumption & frequency), coffee frequency**, chocolate, **spirits (consumption & frequency), wine frequency, beer (consumption & frequency), cider.**

	First authors	Titles	Journals	Year
11	Al-Dlaigan, Y. H.	Vegetarian children and dental erosion.	Br Dent J	2001
12	Al-Dlaigan, Y. H.	Is there a relationship between asthma and dental erosion? A case control study.	Community Dent Oral Epidemiol	2002
13	Al-Dlaigan, Y. H.	Dental erosion in a group of British 14-year-old, school children. Part III: Influence of oral hygiene practises.	J Public Health Dent	2002
14	Al-Hammadi, S.	The prevalence of tooth wear among a group of yemeni adults.	Journal of Oral Research	2020
15	Al-Khalifa, K. S.	The Prevalence of Tooth Wear in an Adult Population from the Eastern Province of Saudi Arabia.	Clin Cosmet Investig Dent	2020
16	Allred, R.	Tooth Wear in Patients Undergoing Sleep Studies: A Blinded Observational Study.	Med J (Ft Sam Houst Tex)	2021

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
NS 418	14	Y 1	TWI (Smith and Knight)	**Gender**, vegetarian, fizzy drinks, bananas, grapes, yoghurt, vinegar, salad dressing, vitamin-C tablets, wine, oranges, sport drinks, coffee, pickles, beer, cider, spirits.
NS 60	11 to 18	Y 1	TWI (Smith and Knight)	**Asthma**, indigestion, vomiting, heartburn, stomach problems, hay fever, eczema, epilepsy, allergies, migraines, hearing problem, medication, orange squash, apple juice, orange juice, cola, sport drinks, apples, oranges, bananas, grapes, salad dressing, vinegar, tomato ketchup, yoghurt, vitamin C tablets, saliva, **soft drinks, carbonated beverage, fresh fruits**.
Y 418	14	Y 1	TWI (Smith and Knight)	**Brushing teeth last thing at night**, type of toothbrush, time of brushing, teeth, brushing teeth after meals, circular movements, anything to clean between the teeth, type of toothpaste, brushing teeth three times a day, brushing teeth once a day, attending a dentist every six months, replacing toothbrush every 3 months.
Y 600	20-50	Y 1	TWI (Smith and Knight)	**Age, gender,** location, educational achievement primary, frequency of acidic drinks and foods consumption, khat chewing, pipe smoking, cigarette smoking, masticatory muscle tenderness, masticatory muscle pain.
Y 340	18-40	Y 2	TWI (Smith and Knight), BEWE	Age, gender, education, occupation, frequency of brushing, type of toothbrush, fluoride toothpaste, fluoride aids, number of dental visits.
NS 107	Mean 36	NS 1	TWI (Smith and Knight)	Apnea, BMI, cigarettes, vaping, chewing tobacco, beer, wine, liquor, coffee, diet soda, non-diet soda, sweet tea, unsweet tea, juice, energy drinks, caffeine pills, candy, sugary foods, acidic fruits, GERD, acid reflux, anxiety, post-traumatic stress disorder, headaches, TMD.

	First authors	Titles	Journals	Year
17	Al-Majed, I.	Risk factors for dental erosion in 5-6-year-old and 12-14-year-old boys in Saudi Arabia.	Community Dent Oral Epidemiol	2002
18	Al-Zwaylif, L. H.	Type and timing of dietary acid intake and tooth wear among American adults.	J Public Health Dent	2018
19	Alaraudanjoki, V.	Influence of intrinsic factors on erosive tooth wear in a large-scale epidemiological study.	Int Dent J	2016
20	Ali, A. S. T.	Association Between Cervical Abrasion, Oral Hygiene Practices and Buccolin-gual Dimension of Tooth Surfaces: A Cross-Sectional Study.	J Pharm Bioallied Sci	2022
21	Alvarez Loureiro, L.	Erosive tooth wear among 12-year-old schoolchildren: a population-based cross-sectional study in Montevideo, Uruguay.	Braz Dent J	2015

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
Y 354	5 to 15	Y 1	NS	**Drinks taken at night, frequency of night drink, frequency of food taken at night**, frequency of brushing, **duration of drinks in mouth, frequency of vomiting**, illnesses related, family income, father's education, **erosive potential of food taken at night**.
NS 3586	Over 18	Y 2	TWI (Smith and Knight)	Fruits, fruit juices, alcoholic drinks, **soft drinks**, fruits from meals, fruits from snacks, fruit juices from meals, fruit juices from snacks, alcoholic drinks from meals, alcoholic drinks from snacks, **soft drinks from meals**, soft drinks from snacks.
NS 1944	Adults	Y 7	BEWE	**Gender, GERD symptoms, onset of GERD symptoms, alcoholism, heavy alcohol consumer**, pregnancies, **sleep bruxism, saliva, juices or soft drinks for quenching thirst**, juices or soft drinks during meals, soft drinks.
Y 366	Above 20	Y 1	NS	**Age, gender,** soft toothbrush, **horizontal method of cleaning**, fluoride toothpaste, frequency of cleaning, time of brushing, frequency of changing toothbrush, use of other oral hygiene aid.
Y 1136	12	Y 2	BEWE	**Gender, socioeconomic status,** mother' education level, school, soft drinks, yoghurt, drink of the end of sports, **swish before swallow**, how to drink, bruxism, **brushing frequency**, swimming, respiratory disorders, Gastro-esophageal disorders.

	First authors	Titles	Journals	Year
22	Alvarez-Arenal, A.	The role of occlusal factors in the presence of noncarious cervical lesions in young people: A case-control study.	Nutrients	2019
23	Alves, L. S.	Dental erosion among 12-year-old schoolchildren: a population-based cross-sectional study in South Brazil.	J Oral Sci	2015
24	Alves Mdo, S. D.	Tooth wear in patients submitted to barietric surgery.	Acta Odontol Scand	2012
25	Alwaheidi, H. A. A.	The interrelationship between xerogenic medication use, subjective oral dryness, and tooth wear.	J Dent	2021
26	Amato, M.	Tooth wear Is frequent in adult patients with celiac disease.	Niger J Clin Pract	2017
27	Anderson, S.	Evidence That Daily Vinegar Ingestion May Contribute to Erosive Tooth Wear in Adults.	J Med Food	2021
28	Antunes, L. A.	Sports drink consumption and dental erosion among amateur runners.	Pediatr Dent	2017

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
Y 140	18 to 29	Y NS	TWI (Smith and Knight)	**Age**, chewing side, angle's malocclusion classification, overbite, overjet, crossbite, protrusive guidance, right canine guidance, left canine guidance, **protrusive interferences**, right laterality interferences, left laterality interferences, laterality interferences in non-working side, laterality interferences in working side, **bruxism**, frequency of brushing, brush bristles hardness, brushing technique, soft drinks, acidic/ citrus fruits, vomiting/ gastroesophageal reflux.
Y 1528	12	Y 1	BEWE	**Gender**, socioeconomic status, school, **soft drinks**, orange, **lemon**, Gastro-oesophageal disorders, asthma, weight status; brushing frequency, bruxism.
NS 125	Adults	Y NS	BEWE	**Bariatric surgery**, obesity, reflux, vomiting.
NS 3578	Above 18	Y 2	Modified version of TWI (Smith and Knight)	**Sex, age, race/ethnicity**, education, power income ratio, **dental insurance coverage**, soft drinks intake, GERD medication, xerogenic medication use, amount of saliva in mouth, mouth feels dry when eating.
NS 65	Over 18	NS 2	TWI (Smith and Knight)	Celiac disease.
NS 22	Adults	NS NS	BEWE	Vinegar.
Y 108	Adults	Y NS	Eccles et al.	Sex, age, **running frequency**, number of years of sports activity, time during training, **time expended during competition**, sports drinks, work in factory, swim in chlorinated pool, acidic drinks, brushing after eating, stiff-bristled brush, toothpaste, vomiting, regurgitation, **GERD**, bulimia, anorexia, xerostomia, radiotherapy, hemodialysis,

	First authors	Titles	Journals	Year
29	Arnadottir, I. B.	Dental erosion in Icelandic teenagers in relation to dietary and lifestyle factors.	J Dent	2003
30	Ashour, A. A.	Association between gastric reflux, obesity, and erosive tooth wear among psychiatric patients.	Medicine (United States)	2022
31	Atalay, C.	Evaluation of tooth wear and associated risk factors: A matched case-Control study.	Niger J Clin Pract	2018
32	Awad, M. A.	Prevalence, severity, and explanatory factors of tooth wear in Arab populations.	J Dent	2019
33	Aznar, F. D.	Dental wear and tooth loss in morbid obese patients after bariatric surgery.	Arq Bras Cir Dig	2019
34	Bachanek, T.	Prevalence of dental erosion among 18-year-old adolescents in the borderland districts of Lviv (Ukraine) and Lublin (Poland).	Ann Agric Environ Med	2018
35	Bairappan, S.	Impact of asthma and its medication on salivary characteristics and oral health in adolescents: A cross-sectional comparative study.	Spec Care Dentist	2020

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
NS 278	Mean 18	Y 2	Lussi et al.	**Male**, gastric reflux, sports activity, water following sport, carbonated drink following sport, soft drinks following sport, fruit juice following sport, recall of soft drinks between meals, recall of soft drinks with meals, biting nail/cheek habits, sugar-free gum, asthma.
NS 223	19-30, 31-63	Y 1	NS	Age, gender, BMI, **consumption of soft drinks, type of psychiatric illness**, citrus fruit consumption, **chronic vomiting or bulimia**, consumption of vitamin C, **gastric reflux**, smoking.
Y 50	18 to 65	Y 2	TWI (Smith and Knight)	**Tooth brushing frequency**, brushing technique, brushing immediately after acidic foods, toothbrush, citrus fruits, soft drinks, fruit juice, sport drinks, citrus-flavored sweets/gum, **saliva, acidic foods**.
Y 2924	18 to 35	Y NS	BEWE	Sex, **age**, country, **education, frequency of tooth brushing**, GERD, eating fruits, fruit and vegetables juice, **soft drinks**, cheese, **eating occasions**, isotonic drinks.
Y 100	Adult	Y 1	Index IDD	Morbid obesity, morbid obesity operated with surgery, **age**, gender, race, education, financial class, hypertension, diabetes, triglycerides, cholesterol, smoking, alcoholism, age, BMI, waist and hip ratio, **loss teeth**.
NS 254	18	Y NS	BEWE	**District, gender**, rural area, urban area.
Y 50	12-15	Y NS	NS	**Asthma.**

	First authors	Titles	Journals	Year
36	Bandodkar, S.	A study to evaluate psychological and occlusal parameters in bruxism.	Journal of Oral Biology and Craniofacial Research	2022
37	Bardolia, P.	Prevalence and risk indicators of erosion in thirteen- to fourteen-year-olds on the Isle of Man.	Caries Res	2010
38	Bardsley, P. F.	Epidemiological studies of tooth wear and dental erosion in 14-year-old children in North-West England. Part 1.	Br Dent J	2004
39	Bartlett, D. W.	The association of tooth wear, diet and dietary habits in adults aged 18-30 years old.	J Dent	2011
40	Bartlett, D. W.	Prevalence of tooth wear on buccal and lingual surfaces and possible risk factors in young European adults.	J Dent	2013
41	Basha, S.	Association between soft drink consumption, gastric reflux, dental erosion, and obesity among special care children.	Spec Care Dentist	2020

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
Y 60	Under 30	NS NS	Attrition index (Ekfledt et al.)	**Bruxism.**
Y 629	13-14	Y 4	Bardsley et al.	**Gender,** age, fizzy drinks, flavoured water, fruit juice, milk, water, fruit, yoghurt, ice cream, chewing gum, toothbrushing, **fizzy drinks frequency**.
Y 2385	14	Y 1	Modified version of TWI (Smith and Knight)	**Gender, fluoridation, fluoridation brushing.**
NS 1010	18 to 30	Y 3	TWI (Smith and Knight)	**Carbonated drinks, apples, orange juice**, grapefruit, lemon juice, lemons, fruit juice, orangeade, pickles, **heartburn**, beer, wine, spirits, drinking from a glass, **swilling**.
NS 3187	18 to 35	Y 10	BEWE	Age, gender, country, area of residence, education, **occupation/socio-economic class**, brushing frequency, toothbrush, brushing movement, brush before breakfast, brush after breakfast, interval breakfast to brushing, brush after lunch, brush after dinner, **soporifics/ antidepressants**, chewing-gum, **heart burn/ reflux, vomiting, fresh fruit; fruit/veg juice**, isotonic/energy drinks, soft drinks.
NS 350	6-12 13-16	Y 1	NS	**Age**, gender, socioeconomic status, BMI, **consumption of soft drinks**, intellectual disability, autistic disorder, cerebral palsy, Down's syndrome, deafness, or blindness or both, others with syndromes involving multiple disabilities, citrus fruit consumption, **chronic vomiting and bulimia, gastric reflux**.

	First authors	Titles	Journals	Year
42	Berbesque, J. C.	Sex differences in Hadza dental wear patterns: a preliminary report.	Hum Nat	2012
43	Bernhardt, O.	Risk factors for high occlusal wear scores in a population-based sample: results of the Study of Health in Pomerania.	Int J Prosthodont	2004
44	Borcic, J.	The prevalence of non-carious cervical lesions in permanent dentition.	J Oral Rehabil	2004
45	Brandt, L. M. T.	Relationship between Risk Behavior for Eating Disorders and Dental Caries and Dental Erosion.	Scientific WorldJournal	2017
46	Brusius, C. D.*	Dental erosion among South Brazilian adolescents: A 2.5-year longitudinal study.	Community Dent Oral Epidemiol	2018
47	Buchhardt, J.	The Influence of Steroid Hormones on Tooth Wear in Children and in Adolescents.	J Clin Med	2022
48	Buczkowska-Radlinska, J.	Prevalence of dental erosion in adolescent competitive swimmers exposed to gas-chlorinated swimming pool water.	Clin Oral Investig	2013
49	Caglar, E.	Dental erosion among children in an Istanbul public school.	J Dent Child (Chic)	2005
50	Cavalcanti, A. L.	Risk behaviors for eating disorders among Brazilian female adolescents.	Open Dentistry Journal	2020

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
Y 126	Over 15	NS NS	Modified TWI (Smith & Knight)	Age, **sex**, honey, baobab, berries, **meat, tubers**
Y 2529	20-79	Y 8	Attrition index (Ekfledt et al.)	Age, **gender**, open bite, cross-bite, **edge-to-edge,** angle class, **cusp-to-cusp relation**, angle class, **loss of natural occlusal support areas**, tenderness in TMJ or masticatory muscles, **bruxism**, marital status, **unemployment**, soft drink, fruit juice, heartburn, toothbrushing frequency, crowding. Gender, fluoridation, fluoridation brushing.
NS 1002	10 to 65	NS 1	TWI (Smith and Knight)	Age.
Y 850	15-18	Y 2	O'Sullivan et al.	Age, family income, eating disorder, BMI.
Y 801	12	Y 1	BEWE	**Gender**, socio-economic status, school, dietary habits, soft drinks frequency, juice frequency, orange frequency, lemon frequency, gastro-oesophageal disorders, asthma, brushing frequency.
NS 984	10 and 18	NS NS	Wetselaar et al.	**Gender, age, BMI**, High SES, orthodontic treatment, **testosterone**, oestradiol, SHBG (hormone), **FT (hormone)**.
NS 62	14 to 16	NS NS	Lussi index	Swimming, dietary acids, gender, acidic medicines, brushing.
NS 85	11	NS 1	O'Sullivan et al.	Medical history (asthma, gastric diseases), dental history (caries, orthodontic treatments), brushing, fruit, fruit yogurt, swimming, orange juice, carbonated beverages.
Y 200	15-18	Y 2	O'Sullivan et al.	**Eating disorder.**

	First authors	Titles	Journals	Year
51	Carpenter, G.	Composition of enamel pellicle from dental erosion patients.	Caries Res	2014
52	Carvalho, A. L.	Prevalence of bruxism and emotional stress and the association between them in Brazilian police officers.	Braz Oral Res	2008
53	Chadwick, R. G.*	Maxillary incisor palatal erosion: no correlation with dietary variables?	J Clin Pediatr Dent	2005
54	Chan, A. S.	A systematic review of dietary acids and habits on dental erosion in adolescents.	Int J Paediatr Dent	2020
55	Chaturvedi, P.	Assessment of tooth wear among glass factory workers: Who 2013 oral health survey.	JCDR	2015
56	Chellappa, L. R.	Prevalence and dependency of tobacco use among tribal gypsies in Thoothukudi district - A cross sectional study.	J Family Med Prim Care	2021
57	Chikte, U. M.	Patterns of tooth surface loss among winemakers.	Sadj	2005
58	Chu, C. H.	Dental Erosion and Caries Status of Chinese University Students.	Oral Health Prev Dent	2015

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
NS 60	18 to 65	Y 1	BEWE	**Composition of enamel pellicle**, saliva, orange/tangerines/clementines, grapefruit, rhubarb, lemons, orange juice/ grapefruit juice, lemon juice, other fruit juice/juice cocktails, carbonated/fizzy drinks, sports drinks/lucozade, beer/lager/cider, white wine/red wine, vinegar, french dressing, salt/ vinegar crisps, acidic sweets.
NS 394	Mean 35.5	NS NS	Johanson et al.	Stress, type of work.
NS 251	11 to 13	NS 2	Oilo et al.	Fluoride toothpaste, fluoride mouthrinse **toothbrushing, fizzy water**, hiatus hernia, achlorhydia, eating disorder, asthma, medication, eating, method of drinking, bedtime, special diet, fruit juice, flavoured fizzy drinks, sports drinks, herbal teas, alcohol, salad creams, dressings or vinegar, yoghurts, fruits.
/	/	Systematic review	/	Dietary acids and habits.
NS 936	20 to 69	Y NS	Eccles	**Age, gender.**
NS 164	1-80	NS 1	NS	**Tobacco.**
NS 36	26 to 53	NS NS	Eccles	Winemakers, gender, fruit, citrus fruit, brushing, smoking.
NS 600	18 to 21	Y 3	BEWE	Fluoride toothpaste, fluoride mouthwash, sour snacks, fruit juice, carbonated beverages, sports drinks, brushing, dental problems, gender, **tooth misalignment**.

	First authors	Titles	Journals	Year
59	Chuajedong, P	Associated factors of tooth wear in southern Thailand.	J Oral Rehabil	2002
60	Correa, M. C.	Salivary parameters and teeth erosions in patients with gastroesophageal reflux disease.	Arq Gastroenterol	2012
61	Correr, G. M.	Influence of diet and salivary characteristics on the prevalence of dental erosion among 12-year-old schoolchildren.	J Dent Child (Chic)	2009
62	Cunha-Cruz, J.	Tooth wear: Prevalence and associated factors in general practice patients.	Community Dent Oral Epidemiol	2010
63	Deery, C.	The prevalence of dental erosion in a United States and a United Kingdom sample of adolescents.	Pediatr Dent	2000
64	Delwel, S.	Oral function of older people with mild cognitive impairment or dementia.	J Oral Rehabil	2018
65	de Queiroz Gonçalves, P. H. P.	Dental erosion' prevalence and its relation to isotonic drinks in athletes: a systematic review and meta-analysis.	Sport Sciences for Health	2020
66	Di Fede, O.	Oral manifestations in patients with gastro-oesophageal reflux disease: a single-center case-control study.	J Oral Pathol Med	2008
67	Diraçoğlu, D.	Relationship between maximal bite force and tooth wear in bruxist and non-bruxist individuals.	Archive of Oral biology	2011

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
NS 506	Mean 32	Y NS	TWI (Smith and Knight)	**Sex, age**, occupation, systemic diseases, medication, **number of teeth**, clicking sound during mouth opening, sour in the mouth, facial pain and tenderness, bruxism, chewing habit, brushing, tooth position, sports, fruit juice, **carbonate**, hard food, **alcohol**, sour food, **sour fruit**.
NS 60	17 to 60	NS NS	Eccles	Gender, age, **GERD**, diet, medication, oral hygiene, saliva.
NS 389	12	Y 2	O'Sullivan	Gender, diet, hygiene habits, acidic beverages, soft drinks, candies, acidic fruits, fruits, **acidic drugs**.
NS 1295	18 to 93	Y NS	NS	Age, gender, race/ethnicity, angle's malocclusion, open bite, orthodontic treatment, occlusal splint, periodontal bone loss, missing permanent teeth.
NS 129	11 to 13	Y 2	O Brien Index	Sex, site, carbonated drinks, fruit, still drinks, fresh fruit, spicy foods, heartburn, regurgitation, vomit, stomachache, sour taste, teeth grinding.
Y 348	Mean 83	NS 1	Wetselaar et al.	Dementia, Mild cognitive impairment.
/	/	Systematic review – Mera-analysis	/	Isotonic drinks in athletes.
NS 200	19 to 78	Y 1	TWI (Smith and Knight)	GERD.
NS 29	Mean 35.2	NS 1	Bartlett	Bruxism, maximal bite force.

	First authors	Titles	Journals	Year
68	Dugmore, C. R.*	Asthma and tooth erosion. Is there an association?	Int J Paediatr Dent	2003
69	Dugmore, C. R.*	A multifactorial analysis of factors associated with dental erosion.	Br Dent J	2004
70	Dugmore, C. R.	The prevalence of tooth erosion in 12-year-old children.	Br Dent J	2004
71	Duran-Cantolla, J.	Frequency of obstructive sleep apnea syndrome in dental patients with tooth wear.	J Clin Sleep Med	2015
72	Dynesen, A. W.	Salivary changes and dental erosion in bulimia nervosa.	Oral Surg Oral Med Oral Pathol Oral Radiol Endod	2008
73	Ekfeldt, A.	Dental status and oral function in an adult group of subjects with thalidomide embryopathy - A clinical and questionnaire study.	Acta Odontologica Scandinavica	2009
74	El Aidi, H.*	Dynamics of tooth erosion in adolescents: a 3-year longitudinal study.	J Dent	2010
75	El Aidi, H.*	Multifactorial analysis of factors associated with the incidence and progression of erosive tooth wear.	Caries Res	2011

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
NS 1753	12 and 14	Y 1	O Brien Index	Asthma, medications.
NS 1149	12 and 14	Y 1	TWI (Smith and Knight)	Age, apples, oranges, grapefruit, tomato sauce, chocolate, sweets, chips with vinegar, **decay, calculus, fruit other than apple and citrus, fruit juice, fizzy pop**, orthodontic anomaly.
NS 1753	12	Y 1	O Brien Index	**Gender, ethnic group**, deprivation, **caries experience.**
NS 30	Mean 58.5	NS NS	NS	**Obstructive Sleep Apnea Syndrome**, BMI, Age, Gender.
NS 20	18-33	NS NS	Larsen et al.	Saliva flow rate, **bulimia**, vomiting, acidic drinks. Fruits, cakes, sweets, desserts, medication, **age**.
NS 31	45-49	NS NS	Ekfeldt et al. /	Gender, tobacco, use of teeth as tools, regurgitation, age, occupation, education, oral parafunctions, dietary habits, vomiting.
Y 656	10 to 12	Y 2	Lussi et al.	**Age, socio-economic status, gender.**
Y 656	10 to 12	Y 2	Lussi et al.	Diet, acidic whey-based drinks, carbonated soft drink, ice tea, fruit lemonade, lemonade squash, fruit juice, mineral water, tap water, tea, **alcoholic mixed drink**, yoghurt drink/ breakfast drink, milk products, yoghurt products, acidic fruit, sweet fruit, **sour vegetables**, pickled vegetables, cheese, sweet sandwich spreads, spreads/salads, sour candy, ice lolly, chewing gum, red sauces, white/yellow sauces, saliva, swishing, swallow, straw, tooth brushing, plaque, bite force, canine guidance, anterior contact, **tooth grinding**, gender, socio-economic status, tooth brush, vitamin, energy/sports drink.

	First authors	Titles	Journals	Year
76	Ellis, A. W.	Dental erosion as an indicator of gastroesophageal reflux disease.	Gen Dent	2022
77	El Karim, I. A.	Dental erosion among 12-14 year old school children in Khartoum: a pilot study.	Community Dent Health	2007
78	Emodi-Perlman, A.	Prevalence of psychologic, dental, and temporomandibular signs and symptoms among chronic eating disorders patients: A comparative control study.	Journal of Oraofacial Pain	2008
79	Entezami, S.	Tooth wear and socioeconomic status in childhood and adulthood: Findings from a systematic review and meta-analysis of observational studies.	J Dent	2021
80	Evaristo-Chiyong, T.	Factors related to the presence of dental erosion and abrasion in Peruvian adults.	Journal of Oral Research	2021
81	Farahmand, F.	Gastroesophageal reflux disease and tooth erosion: A cross-sectional observational study.	Gut and liver	2013
82	Fathima, F.	Association of occlusal wear facets in patients with temporomandibular disorders.	Bioinformation	2020
83	Flueraşu, M. I.	The correlation between sleep bruxism, salivary cortisol, and psychological status in young, Caucasian healthy adults.	Cranio	2021

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
Y 80	18-85	NS NS	BEWE	**Age**, race, sex, obstructive sleep apnea, **GERD**, BMI.
NS 157	12-14	Y 1	TWI (Smith and Knight)	Oral hygiene habits, vomiting, GORD, dietary habits, acidic food, citrus fruit juice, **carbonated drinks**, herbal drinks (hibiscus), citrus fruit, yoghurt, cheese, Baobab and Tamarind (traditional food), **school type**, gender.
NS 79	18 to 35	NS 2	Johansson et al.	**Eating disorders**, Bulimia nervosa, anorexia nervosa, eating disorder not overwise specified, limitation of mouth opening, chewing gum, Oral habits (biting nails, biting hard foreign bodies, bruxism.
/	/	Systematic review – Meta-analysis	/	Socioeconomic status.
Y 153	18-65	NS 2	BEWE	Gender, **age**, saliva pH, saliva flow rate, industrial beverages, non-industrial beverages, coffee-like beverages, alcoholic drinks, nausea and vomiting, regurgitation (reflux), **asthma, oral habits**, type of bristles, amount of toothpaste, toothbrushing frequency, force applied while brushing.
NS 112	43 to 12	NS NS	Aine Erosion Index	GERD.
NS 98	26-40	Y 1	TWI (Smith and Knight)	Temporo-mandibular-disorder.
NS 60	Mean 23.1	NS NS	NS	**Bruxism**.

	First authors	Titles	Journals	Year
84	Frese, C.	Effect of endurance training on dental erosion, caries, and saliva.	Scand J M	2015
85	Friedman Rubin, P.	Potential orofacial hazards of resistance training: A controlled comparative study.	The Journal of Cranio-mandibular & Sleep Practice	2017
86	Fukayo, S.	Different dental caries patterns among smelter workers with dental erosion.	J Occup Health	2001
87	George, R.	Dental erosion and dentinal sensitivity amongst professional wine tasters in South East Queensland, Australia.	Scientific World Journal	2014
88	Gillborg, S.	Tooth wear in Swedish adults-A cross-sectional study.	J Oral Rehabil	2020
89	Giraudeau, N	The contribution of teledentistry in detecting tooth erosion in patients with eating disorders.	Digit Health	2021
90	Goller Bulut, D.	Ultrasonographic evaluation of jaw elevator muscles in young adults with bruxism and with and without attrition-type tooth wear: A pilot study.	The Journal of Craniomandi-bular & Sleep Practice	2018
91	Goller Bulut, D.	Ultrasonographic evaluation of jaw eleva-tor muscles in young adults with bruxism and with and without attrition-type tooth wear: A pilot study.	Cranio	2020

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
NS 35	Over 18	Y 2	BEWE	Gender, age, socio-economic status, height, body weight, oral hygiene regime, running, swimming, cycling, **sports activity**, beverage, saliva.
NS 99	Over 18	Y 1	Lobbezoo et al.	Age, sports activity, weight, **training**, bruxism.
NS 350	Over 29	Y 2	Eccles et al.	Smelter workers, age, brushing, dental plaque, dental calculus, gingivitis, periodontitis.
NS 25	22 to 66	Y NS	TWI (Smith and Knight)	**Wine**, brushing, **age**.
Y 1000	20-89	Y 8	BEWE	**Age, gender,** toothbrushing, acidic drinks, **fruit**.
Y 50	Over 16	Y 1	BEWE	Age, gender, education, employment, restrictive anorexia nervosa, purging-type anorexia nervosa, bulimia with vomiting, bulimia with other compensatory behaviors, hyperphagia bulimia, drugs, antidepressants, vomiting, dry mouth, citrus consumption, acidic food.
NS 60	Mean 46.7	Y 2	TWI (Smith and Knight)	Gender, age, **bruxism**
NS 60	Mean 46.7 (group 1)	Y 1	TWI (Smith and Knight)	Age, gender, **masseter muscle thickness, temporal muscle thickness.**

	First authors	Titles	Journals	Year
92	Gonzalez-Aragon Pineda, A. E.	Relationship between erosive tooth wear and beverage consumption among a group of schoolchildren in Mexico City.	Clin Oral Investig	2019
93	Gonzalez-Aragon Pineda, A. E.	Prevalence of erosive tooth wear and associated factors in a group of Mexican adolescents.	J Am Dent Assoc	2016
94	Gonzalez-Aragon Pineda, A. E.*	Prevalence, Incidence, and Progression of Erosive Tooth Wear and Their Respective Risk Factors Among Schoolchildren in Mexico City.	Pediatr Dent	2020
95	Goswami, U.	Asthma, long-term asthma control medication and tooth wear in American adolescents and young adults.	J Asthma	2021
96	Gurgel, C. V.	Risk factors for dental erosion in a group of 12- and 16-year-old Brazilian schoolchildren.	Int J Paediatr Dent	2011

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
Y 512	11 to 14	Y 1	BEWE	Beverages, pure water, natural fruit juices (pure or with water), milk, hot beverages (coffee or infusions), soft drinks (**sweet carbonated drinks**, fruit-based drinks, sports drinks, energy drinks), demographic information (sex and age), habits related to the consumption of drinks, food (citrus fruits, yogurt, caramels, and chewing gum), dental hygiene, vitamin C chewable tablets, gastroesophageal reflux, vomiting, saliva.
Y 417	14 to 19	Y 1	Lussi Index	Fruit juice, nectar or juice concentrate, **sweet carbonated drinks**, sport drinks, water, carbonated water, energy drinks, milk, tea, tooth brushing, **xerostomia**, medication, vitamin C, **age**.
NS 424	11-14	Y 1	BEWE	Citrus fruits, **acidic beverages**, condiments/ dressings, caramels, dairy products, keeping acidic drinks in the mouth, consumption of sweet carbonated drinks or fruits juice before going to bed, sucking lemon, frequent consumption of medications, consumption of vitamin C chewable tablets, effervescent tablet consumption, gastroesophageal reflux, frequent vomiting, saliva flow rate, stimulated saliva, saliva buffer capacity, poor oral hygiene, toothbrushing frequency, amount of time before brushing after meals, malocclusion requiring treatment.
NS 2186	13-29	Y 2	TWI (Smith and Knight)	Sex, age, race/ ethnicity, education, poverty income, dental insurance, **GERD medication, asthma diagnosis**, soft drinks.
NS 414	12 and 16	Y 2	O Brien Index	Disease, diabetes, asthma, gastric disorders, vomit, medicaments, vitamin C tablets, fruit juice, carbonated drink, sport drink, milk, coffee, tea, water, yogurt, fruits, vinegar, ket-chup, sweets, acidic drink bedtime, hold drink, swimming.

	First authors	Titles	Journals	Year
97	Hamasha, A. A.	Risk indicators associated with dental erosion among Jordanian school children aged 12-14 years of age.	Int J Paediatr Dent	2014
98	Harłukowicz, K.	Prevalence and determinants of extrinsic origin dental erosion among children and adolescents from Wrocław.	Dent Med. Probl.	2017
99	Hasheminejad, N.	The association between beverage consumption pattern and dental problems in Iranian adolescents: a cross sectional study.	BMC Oral Health	2020
100	Hasheminejad, N.	Meal patterns and the quality of breakfast and snacks in relation to adolescents' dental health in southeast of Iran.	Nutr Health	2022

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
NS 3812	12-14	Y 1	TWI (Smith and Knight)	**Medical condition, asthma, corticosteroid inhaler, heart burn, indigestion, acid taste in the mouth, oral dryness**, eye dryness, **vomiting**, ear infection, **headaches**, stomach disease, neurological and psychological disease; **vitamin C, iron tonics (syrup), antacid drugs, clenching or grinding day/ night, pain or fatigue of the jaw muscles**, use of mouth guard, toothpaste, tooth gel, **mouth wash**, professionally applied fluoride, home-applied fluoride, brushing, **vomiting, carbonated drink, fruit juice, usual drinking method**, vegetarian, **drinking habits, drinking habits at bedtime**, orange, **lemon**, apple, **tinned fruit, curry spicy food**, yogurt, tomato, ketchup, mayonnaise, natural fruit juice, diluted fruit juice, **carbonated drinks, sports drinks, coffee with sugar, herbal tea**, red tea with sugar, milk, vinegar, sour candies, pickles, cheese.
NS 240	12 to 18	NS NS	Lussi et al., Sullivan et al., BEWE;	Age, gender, **toothbrushing**, orange juice, apple juice, vegetables juices, **cola, energy/ sport beverages, carbonated** and non-carbonated beverages, vitamin C, cocoa, milk, yogurt, herbal tea, oranges, apples, **bananas, ketchup**, mustard, vinegar dressing, sauerkraut, pickles, chewing gum, **acidic vegetables**, swimming.
NS 600	12	Y 1	TWI (Smith and Knight)	Plaque, milk beverages, milk derivatives, yoghurt drinks, tea beverages, **sweetened soft beverages**, natural fruit juice, other hot beverages, gender, toothbrush.
NS 600	12	Y 1	TWI (Smith and Knight)	Sex, breakfast quality, snack quality, snack frequency.

	First authors	Titles	Journals	Year
101	Hasselkvist, A.	Association between soft drink consumption, oral health, and some lifestyle factors in Swedish adolescents.	Acta Odontologica Scandinavica	2014
102	Hasselkvist, A.	Dental erosion and soft drink consumption in Swedish children and adolescents and the development of a simplified erosion partial recording system.	Swed Dent J	2010
103	Hasselkvist, A.*	A 4-year prospective longitudinal study of progression of dental erosion associated to lifestyle in 13-14 year-old Swedish adolescents.	J Dent	2016
104	Hasselkvist, A.*	Prevalence and progression of erosive tooth wear among children and adolescents in a Swedish county, as diagnosed by general practitioners during routine dental practice.	Heliyon	2021
105	Hermont, A. P.	Tooth erosion and eating disorders: a systematic review and meta-analysis.	PLoS One	2014
106	Hermont, A. P.	Acidic food choice among adolescents with bulimic symptomatology: a major risk factor for erosive tooth wear?	Eat Weight Disord	2021

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
NS 197	13-14, 18-19	Y 1	Johansson et al.	Gender, carbonated soft drink, sweets, chips/cheese doodles, soured milk, sweetened milk, juice/ fruit drinks, TV/Computer, physical activity, toothbrushing, parents' birthplace, fresh fruit; syrup-regular, breakfast meals, mouth breathing, GOR, BMI.
NS 1580	5-6, 13-14, 18-19	Y 1	Johansson et al.	**Age, gender**, drinking habits, **carbonated soft drinks, juices, still drinks, sport drinks**.
Y 227	13-14	Y 1	Johansson et al. And Simplified Erosion Partial Recording System	Age, gender, oral hygiene, GOR, **intake medicines**, general health, **retaining acidic soft drinks in the mouth**, physical activity, screen-viewing habits, body height/weight, born outside, dietary, **water, acidic soft drinks, milk**, yogurt, **sour milk, tea, coffee**, sweets, **sour sweets**, chewing gum, ice cream, popsicle, biscuits, snacks, cheese, dried and fresh fruits, **still drinks, sport drinks, juice, alcoholic beverages (wine, beer, cider, alcopop), dry mouth**.
NS 2363	7-19	Y NS	Johansson et al.	Gender, age.
/	/	Systematic review/ Meta-analysis	/	Eating disorder.
Y 62	15-18	Y 1	O'Sullivan index	**Vomiting, citrus fruits**, non-citric fruits, **ketchup, diet soda**, sugared soda, yogurt, Fruit drink mix, citric fruit juice, non-citric fruit juice.

	First authors	Titles	Journals	Year
107	Holbrook, W. P.	The Basic Erosive Wear Examination (BEWE) applied retrospectively to two studies.	Clin Oral Investig	2014
108	Huew, R.	Dental erosion and its association with diet in Libyan schoolchildren.	Eur Arch Paediatr Dent	2011
109	Huew, R.	Dental erosion among 12-year-old Libyan schoolchildren.	Community Dent Health	2012
110	Isaksson, H.	Prevalence of dental erosion and association with lifestyle factors in Swedish 20-year-olds.	Acta Odontol Scand	2014
111	Janson, G.	Tooth-wear patterns in subjects with Class II Division 1 malocclusion and normal occlusion.	Am J Orthod Dentofacial Orthop	2010
112	Jastaniyah, N.	The relationship between overweight/obesity and dental erosion among a group of Saudi children and adolescents.	Indian J Dent Res	2019
113	Jász, M.	Dental Erosion and Its Relation to Potential Influencing Factors among 12-year-old Hungarian Schoolchildren.	Oral Health Prev Dent	2022
114	Jensdottir, T.	Relationship between dental erosion, soft drink consumption, and gastroesophageal reflux among Icelanders.	Clin Oral Investig	2004

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
NS 2251	6, 12, 15	NS NS	BEWE Lussi index	GOR, acidic drinks, saliva, **gender**, age, **country districts**.
Y 3014	12	Y 1	TWI (Smith and Knight	Dietary intake, carbonated drinks, sports drinks, squashes, **fruit-based sugary drinks**, natural unsweetened fruit juices, sugar-free carbonated drinks, carbonated water, milk, flavoured milk, **sugared tea with milk**, tap or bottled water, **fruit**.
Y 791	12	Y 1	TWI (Smith and Knight	**Gender**, socioeconomic status, mother's education, father's education.
NS 494	20	NS 1	Hasselkvist et al, Eccles and Johansson et al.	Saliva, **BMI, soft drinks**, fruit juice (sweetened), fruit juice, fruit, main meals, chewing gum, physical activity, water, sport drinks, too-thbrushing, gastric reflux, perceived healthy, medication, caries.
NS 310	Mean G1 : 13.51 G2 :13.44 G3 : 13.17	Y 1	TWI (Smith and Knight) modified	Occlusion.
Y 370	4-18	Y 1	Smith and Knight modified by O'Brien	**Overweight**, BMI, age, gender, Mother educational level, father educational level, socioeconomic status, **carbonated drinks**, noncarbonated drinks, **frequency of night** drink intake, straw, low-calorie drinks.
NS 579	12	Y 1	BEWE	**Location, gender, carbonated soft drinks, education level of the mother**, tooth-brushing, fresh fruits, tea with sugar, non-carbonated fruit juices, sweets/candys.
NS 80	19 to 22	NS 2	Lussi et al.	GERD, soft drinks, **carbonated beverages**, milk-based beverages, pure fruit juices, juices from concentrate, energy or sport drinks, age, gender, **Coca-Cola consumption**.

	First authors	Titles	Journals	Year
115	Jiang, H.	The prevalence of and risk factors for non-carious cervical lesions in adults in Hubei Province, China.	Communiy Dent Health	2011
116	Johansson, A. K.	Eating disorders and oral health: A matched case-control study.	European Journal of oral Sciences	2012
117	Jokstad, A.	Wear of teeth due to occupational exposure to airborne olivine dust.	Acta Odontol Scand	2005
118	Jonsgar, C.	Sleep bruxism in individuals with and without attrition-type tooth wear: An exploratory matched case-control electromyographic study.	J Dent	2015
119	Jordão, H. W. T.	The association between erosive tooth wear and gastro-oesophageal reflux-related symptoms and disease: A systematic review and meta-analysis.	J Dent	2020
120	Kamal, Y.	Obesity and tooth wear among American adults: the role of sugar-sweetened acidic drinks.	Clin Oral Investig	2020
121	Kanaan, M.	Non-biological and Biological Risk Indicators for Tooth Wear Outcomes in Adults.	Caries Res	2022
122	Kanaan, M.	Tooth wear and oral-health-related quality of life in dentate adults	J Dent	2022

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
Y 2160	35 to 74	Y 4	TWI (Smith and Knight)	**Location**, gender, **age**, ethnic, education, **toothbrushing, family income**, soft drinks, fruit juices, mastication, **bruxism**.
NS 54	10 to 50	Y 1	Johansson et al.	**Eating disorder.**
NS 191	18 to 33, 34 to 44, over 44	NS NS	Hugoson et al.	Number of remaining teeth, occluding pairs, clenching habits, carbonated soft drinks, gastro-oesophageal reflux, airborne olivine exposure, **age**.
Y 16	19.9 to 28.5	Y 5	Carlsson et al.	Sleep bruxism, saliva, dietary habits, general and oral health, headache, facial pain, muscles pain, dryness mouth.
/	/	Systematic review – Meta-analysis	/	Gastro-oesophageal reflux.
Y 3541	12-19	Y 2	Modified index of TWI (Smith and Knight)	**Sugar-sweetened acidic drinks**, sugar-sweetened non-acidic drinks, non-sugar-sweetened acidic drinks, **non-sugar-sweetened non-acidic drinks**, BMI
Y 570	Over 18	Y 2	BEWE	**Age, gender,** region of residence, education completed, **patient's occupation**, tooth-brushing, toothbrush, toothpaste, medical condition, medication, DPSI, use of rigid occlusal splint, acidic beverage consumption frequency, acidic beverage consumption method.
Y 570	Over 18	Y 2	BEWE	**Gender, grinding or clenching teeth, age, secondary education level, oral health, medical conditions (eating disorders, gastro esophageal reflux disease, chronic alcoholism, obesity, medications, acidic beverages.**

	First authors	Titles	Journals	Year
123	Kapagiannidou, D.	Association between polysomnographic parameters of sleep bruxism and attrition-type tooth wear.	J Oral Rehabil	2021
124	Karki, S.	Different risk factors for erosive tooth wear in rural and urban nepal: A national study.	International Journal of Environmental Research and Public Health	2021
125	Kataoka, K.	Association Between Self-Reported Bruxism and Malocclusion in University Students: A Cross-Sectional Study.	J Epidemiol	2015
126	Khayat, N.	The Prevalence of Temporomandibular Disorders and Dental Attrition Levels in Patients with Posterior Crossbite and/or Deep Bite: A Preliminary Prospective Study.	Pain Research and Management	2021
127	Kim, H. D.	Associations between occupational health behaviors and occupational dental erosion.	J Public Health Dent	2003
128	Kim, H. D.	Occupational exposure to acidic chemicals and occupational dental erosion.	J Public Health Dent	2006
129	Kirthiga, M.	Dental Erosion and its Associated Factors In 11-16-Year-Old School Children.	J Clin Pediatr Dent	2015
130	Kitagawa, K.	Effect of masseter muscle activity during wakefulness and sleep on tooth wear.	Journal of Prosthodontic Research	2022

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
NS 63	Over 18	NS 1	Lobbezoo et al.	Bruxism, gender, age.
Y 1137	5-6, 12 and 15	Y 2	BEWE	**Location, age**, gender, **school type**, ethnic group, fizzy drinks consumption, fruits consumption, toothbrushing frequency, use of toothpaste, **use of charcoal**, use of miswak, BMI, **waist-hip ratio**, waist-height ratio.
NS 1503	18-19	NS 5	TWI (Smith and Knight)	Bruxism, malocclusion, BMI, gender, orthodontic treatment, oral habits, temporal headache, biting fingernail/pens/pencils, biting mucosa of cheeks/lips, and gum chewing.
NS 310	11-49	Y 1	Lobbezoo et al.	Age, temporomandibular disorders, disc displacement, mixed temporomandibular disorders, **deep bite**.
Y 943	15 to 63	NS 1	Modified ten Cate's criteria	Age, Workers (acid exposure), wearing masks, gargling, length of employment, gender.
Y 951	18 to 65	Y 3	Modified ten Cate's criteria	**Workers (acid exposure)**, age, gender, length of employment, income, work type, factory size, position, **wear mask**, brushing, vomiting, smoking status, alcohol consumption, acid food preference, gastritis history.
NS 2000	11 to 16	Y 1	O'Sullivan index	Age, gender, **school type**, candy, jelly, appy fizz, lemon soda, fanta, coke, mazza, fruits (orange, lemon, or grapes), night foods.
Y 15	Mean 71.69	NS 1	TWI (Smith and Knight)	Age, number of remaining teeth, masseter muscle activity, bruxism.

	First authors	Titles	Journals	Year
131	Kitasako, Y.	Age-specific prevalence of erosive tooth wear by acidic diet and gastroesophageal reflux in Japan.	J Dent	2015
132	Kitasako, Y.	Multifactorial logistic regression analysis of factors associated with the incidence of erosive tooth wear among adults at different ages in Tokyo.	Clin Oral Investig	2017
133	Kitasako, Y.	Erosive Tooth Wear Among Different Tooth Types and Surfaces in Japanese Adults 15 to 89 Years Old.	Oral Health Prev Dent	2017
134	Kitasako, Y.	The prevalence of non-carious cervical lesions (NCCLs) with or without erosive etiological factors among adults of different ages in Tokyo.	Clinical Oral Investigations	2021
135	Korkmaz, E.	Cross-Sectional Analysis of Prevalence and Aetiological Factors of Dental Erosion in Turkish Children Aged 7-14 Years.	Oral Health Prev Dent	2020

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
NS 1108	15 to 89	Y 2	TWI (Smith and Knight) and Fares et al.	Gastro-oesophageal reflux, **acidic drinks (carbonated drink, fruit juice), vinegar drinks, acidic fruits (apple, orange, grapefruit, lemon)**, systemic disease, eating disorders, age.
NS 1108	15 to 89	Y 2	TWI (Smith a nd Knight) and Fares et al.	Age, dietary habit, **grapefruit, orange fruit, apple, foods in sweetened vinegar, carbonated drinks, sports drinks, energy drinks, vinegar drink, citrus juice**, drink at bedtime, **acidic drinks per day**, health condition, **repeated vomiting, heartburn, gastroesophageal reflux**, oral health condition, frequent oral dryness, oral hygiene, **texture type of toothbrush**, brushing pressure.
NS 1108	15 to 89	Y 2	TWI (Smith and Knight) and Fares et al.	Age.
NS 1108	15 to 89	Y 2	TWI (Smith and Knight) and Fares et al.	**Carbonated soft drinks, citrus juice, orange fruit, tooth brushing pressure,** bruxism,
Y 473	7-14	Y 1	O'Sullivan index	Sex, **age**, socioeconomic status, education level of father, education level of mother, systemic disease, **BMI**, duration of gestation, birth weight, swimming in the pool, regular sporting habits, drinks with straw, **drinks slowly with glass**, drinks quickly, keeping drinks in the mouth, beverage consumption with meals, **beverage consumption between mealtimes**, beverage consumption before bedtime, irregular consumption, fruit consumption (bite), **fruit consumption (suck)**, previous dentist visits, visiting dentists regularly, frequency of toothbrushing, technique of toothbrushing, timing of toothbrushing, toothbrush replacement, mouthwash use, **dental floss use**.

	First authors	Titles	Journals	Year
136	Kosalram, K.	An investigation of risk factors associated with tooth surface loss: a pilot study.	J Oral Rehabil	2014
137	Kovacevic, M.	Tooth abrasion in workers exposed to noise in the Montenegrin textile industry.	Ind Health	2006
138	Kumar, S.	Prevalence and risk factors for dental erosion among 11- to 14-year-old school children in South India.	J Oral Sci	2013
139	Kunzel, W.	Dental erosion in Cuban children associated with excessive consumption of oranges.	Eur J Oral Sci	2000
140	Lai, Z. Y.	Prevalence of non-carious cervical lesions and associated risk indicators in middle-aged and elderly populations in Southern China.	Chin J Dent Res	2015

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
NS 80	25 to 85	NS 2	Wetselaar's index	**Cardiovascular disorders, drug use, gastrointestinal disorders, musculoskeletal disorders**, medications, nervous system disorders, urogenital disorders, respiratory disorders, immune system disorders, thyroid, blood pressure, smoking, operations, diabetes, rheumatic fever, liver, infections, allergies, Coffee, soft drinks, sweets, hard foods, water, acidic food, tea, alcohol, lemons, **health, finances, daily hassles total** score, environment, practical, social, family, work, saliva.
NS 225	Mean G1 : 33,1 G2 : 42,5	NS 1	Grippo et al.	**Worker exposed, gender**, demographic factor, socioeconomic factor, tooth brushing habits, career length, marital status, apartment size, number of apartment dwellers, bathroom in the apartment, family income.
Y 605	11 to 14	Y 1	O'Sullivan index	Location of school, gender, **socio-economic status**, type of diet, **type of school, brushing**, fruits, biscuits, **lemon**, jam, **sweets, soft drinks carbonated**, non-carbonated soft drinks, straw, direct swallow, both ways, snacks with soft drinks, medical diseases, medicine consumption, vitamin C, sports.
Y 1010	12	Y 1	Modified index of TWI (Smith and Knight)/ Eccles et al./ Lussi et al.	Location, **gender**, vegetables, pineapple, oranges, grapefruit, citrus.
Y 768	35 to 74	Y 1	TWI (Smith and Knight)	**Age, gender, location of residence, marriage, education level, monthly income, occupation**, brushing, **toothpicks, tooth brushing method**, dental floss, **bruxism**, chewing on one side, **biting hard objects**, fruit, carbohydrate and **vinegar beverages**, recurrence of gastric acid, xerostomia, experience of visiting dentists.

	First authors	Titles	Journals	Year
141	Lechien, J. R.	Laryngopharyngeal reflux, gastro-oesophageal reflux and dental disorders: A systematic review.	PLoS One	2020
142	Li, H.	Dietary factors associated with dental erosion: a meta-analysis.	PLoS One	2012
143	Li, Y.	Association between gastro-oesophageal reflux disease and dental erosion in children: A systematic review and meta-analysis.	J Dent	2022
144	Li, W.	Prevalence of dental erosion among people with gastroesophageal reflux disease in China.	J Prosthet Dent	2017
145	Lim, S. N.	Prevalence and risk factors of erosive tooth wear among young adults in the Singapore military.	Clinical Oral Investigations	2022
146	Liu, B.	Tooth wear in aging people: an investigation of the prevalence and the influential factors of incisal/occlusal tooth wear in northwest China.	BMC Oral Health	2014
147	Liu, J. W.	The Prevalence of Erosive Tooth Wear and Related Risk Factors in 6- to 12-Year-Old Students.	Oral Health Prev Dent	2021
148	Lurie, O.	Bruxism in military pilots and non-pilots: tooth wear and psychological stress.	Aviat Space Environ Med	2007

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
/	/	Systematic review and Meta-analysis	/	Gastroesophageal reflux disease, laryngo-pharyngeal reflux.
/	/	Meta-analysis	/	Soft drinks, sport drinks, juice, vitamin C, milk, yoghourt.
/	/	Systematic review and Meta-analysis	/	Gastro-oesophageal reflux disease.
NS 51	18 to 70	Y 1	TWI (Smith and Knight)	GERD, sex, age, education, grains and legumes, milk per day, yoghurt, **carbonated beverages**, smoking.
Y 1296	18-25	Y 1	BEWE	Gender, age, **education**, combat fitness, **GERD, caries susceptibility, TMD symptoms**, brush frequency, **brush hardness, acidic food, acidic drinks**, hard food, rinsing after meal habits, nightguard wear.
NS 704	40 to 50	Y 1	TWI (Smith and Knight)	Bruxism, **hard or acidic foods**, parafunctional activity, working environment (acid gas), clicking of the temporomandibular joint, stiffness or fatigue of the masticatory muscles, acid reflux.
NS 1469	6-12	Y 3	BEWE	**Age, gender, family-social factors, nationality, oral hygiene habits, frequency of eating acid flavouring, frequency of eating sauerkraut, frequency of drinking soft drinks, unilateral mastication, bruxism, brush teeth immediately after acidic diet.**
NS 57	Mean 25,8	NS 2	Modified from Magnusson et al.	Psychological stress, **work** (military pilots).

	First authors	Titles	Journals	Year
149	Lussi, A.*	Progression of and risk factors for dental erosion and wedge-shaped defects over a 6-year period.	Caries Res	2000
150	Lussi, A.*	Erosive tooth wear and wedge-shaped defects in 1996 and 2006: cross- sectional surveys of Swiss army recruits.	Swiss Dent J	2015
151	Machado, C. A. L.	The impact of erosive tooth wear related to masticatory quality in an indigenous Brazilian population: A cross-sectional study.	Int Orthod	2022
152	Mafla, A. C.	Prevalence and Extrinsic Risk Factors for Dental Erosion in Adolescents.	J Clin Pediatr Dent	2017
153	Maharani, D. A.	Dental Caries and the Erosive Tooth Wear Status of 12-Year-Old Children in Jakarta, Indonesia.	Int J Environ Res Public Health	2019
154	Manarte, P.	Dental erosion in alcoholic patients under addiction rehabilitation therapy.	Med Oral Patol Oral Cir Bucal.	2009

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
NS 204	26 to 30, 46 to 50	Y 2	Lussi et al.	Age, fruits, citrus fruits, fruit juice, apple juice, vegetables, yoghurt, toothpaste, **toothbrushing**, hardness of toothbrush bristles, drug usage, gastric regurgitation, X-ray irradiation, salivary gland disorders, **environmental acid exposure**, hypersensitivity of the teeth, saliva.
NS 417	18 to 25	Y 2	Lussi et al.	Age, education, general medical problems (reflux), medication, oral hygiene habits, **erosive beverages (including alcohol), foodstuffs, brushing, brush immediately after eating**.
NS 197	12-60	NS NS	BEWE	**Age**, sex, masticatory function, meats, fruits, **vegetables**, soft drinks, fruit juice, **orange, banana, apple, lemon**, energy drinks, sweets.
Y 384	10 to 15	Y 2	O'Sullivan index	**Age**, sex, **socio-economic status, fruit juices and frequency**, artificial fruit juices and frequency, carbonated drinks and frequency, **beverages and frequency**, salt-lemon-blend and frequency, **snacks with artificial lemon taste and frequency**, sour candies and frequency, **alcohol and frequency, medication intake**, asthma treatment.
Y 696	12	Y 1	BEWE	Age, **gender**, place of birth, **frequency of soft drinks**, frequency of citrus tea/drinks containing lemon, frequency of fruit juice, **frequency of chewing gum**, frequency of vitamin C supplement drink, frequency of tooth brushing, caregiver, **education of father, education of mother**, parent dental knowledge.
NS 50	24 to 67	Y 1	Eccles et al.	Gender, **age, civil state, academic education, employment status, daily alcohol intake, years of alcohol daily consumption**, heroin, cocaine, **smoking habits, drink before breakfast**, drink before sleeping, vomits, **gastroesophageal reflux, brushes teeth, mouthwash.**

	First authors	Titles	Journals	Year
155	Manevski, J.	Dental aspects of purging bulimia.	Vojnosanitetski Pregled	2020
156	Mangueira, D. F.	Association between socioeconomic factors and dental erosion in Brazilian schoolchildren.	American Association of Public Health Dentistry	2009
157	Margaritis, V.	Multicenter study to develop and validate a risk assessment tool as part of composite scoring system for erosive tooth wear.	Clin Oral Investig	2021
158	Marro, F.	Erosive tooth Wear in special Olympic athletes with intellectual disabilities.	BMC Oral Health	2019
159	Marro, F.	The Influence of Behavioural and Socio-demographic Risk Indicators on Erosive Tooth Wear in Flemish Adolescents, Belgium.	Caries Res	2018
160	Marro, F.*	Associated risk factors with quantitative erosive tooth wear progression.	J Dent	2022
161	Massignan, C.	Socio-economic characteristics, acid drinking patterns and gastric alterations associated with erosive tooth wear in children: a cross-sectional study.	Eur Arch Paediatr Dent	2020

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
NS 60	18-35	NS NS	BEWE	**Purging bulimia**.
Y 983	6 to12	Y 1	O'Sullivan index	Family income, parental educational status, type of school, gender, age, type of dentition.
NS 121	15-21	Y NS	BEWE	Soft drinks, **energy drink, juices consumption, erosive drink kept in the mouth**, erosive drink for quenching thirst between meals, unstimulated saliva secretion, **stimulated saliva secretion**.
NS 232	9 to 62	Y 3	BEWE	**Athletes with Down syndrome**, athletes with intellectual disable.
NS 613	13 to 17	Y 3	BEWE	**Education**, gender, socio-economic status, use toothpaste, use mouthwash, use manual toothbrush, use electric toothbrush, brushing frequency, brushing duration, drinking soft drinks and fruit juices before brushing, drinking soft drinks and fruit juices just after brushing, eating cookies or chocolate or candies just ager brushing, **frequency soft drinks**, drinking time of soft drinks, use straw for soft drinks, holding liquid (soft drinks), fruit juices frequency, drinking time of fruit juices, use straw for fruit juices, holding liquid (fruit juices), chewing gum, sugar-free chewing gum.
Y 70	15	Y 2	BEWE	Gender, parental education, reflux or vomiting, dietary acidic intake, age.
Y 1085	8-10	Y 4	O'Sullivan index	Gender, age, **head of the household education, sports drinks**, acid juice/soda, chewing gum, vomiting, gastric upsets, vomiting after overeating, DMFT, DAI index.

	First authors	Titles	Journals	Year
162	Mathew, T.	Relationship between sports drinks and dental erosion in 304 university athletes in Columbus, Ohio, USA.	Caries Res	2002
163	McGuire, J.	Erosive tooth wear among children in the United States: relationship to race/ethnicity and obesity.	Int J Paediatr Dent	2009
164	Medeiros, T. L. M.	Prevalence and risk indicators of non-carious cervical lesions in male footballers.	BMC Oral Health	2020
165	Methuen, M.	Prevalence of erosive tooth wear and associated dietary factors among a group of Finnish adolescents.	Caries Res	2022
166	Mijuskovic, M.	Tooth wear and gingival recession in 210 orthodontically treated patients: a retrospective cohort study.	Eur J Orthod	2018

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
NS 304	18 to 28	Y 1	Lussi index	Age, sex, **race**, sports, dental history, gastric disorders, sports drinks (frequency, quantity), cola drinks, soft drinks, fruit juices, lemonade, coffee, plain tea, lemon tea, wine, beer, alcoholic drinks, apple cider, citrus fruits, tomatoes, hard cheese, curried foods, spicy foods, vinegar, pickles salad with dressing, yogurt, peppermint, sweet and sour sauce, tartar sauce, sour candy, meals per day, snacking/drinking between meals, eating disorders, medications, **iron supplement**, vitamin C, multivitamins, chest pain, acidic taste, dry mouth, **health problems**, heart-burn, regurgitation, vomiting, sharp teeth, diet: strict vegetarian, lacto-ovo-vegetarian, nonvegetarian, swimming, toothbrushing, toothpaste, **tooth whitening**, clenching and grinding habit, orthodontic treatment.
NS 1962	13 to 19	Y NS	TWI (Smith and Knight)	**Gender, age, race/ethnicity,** income, dental coverage, BMI, **last dental visit**.
NS 45	18-49	Y 1	Mockers and modified by Viera et al.	Education level, years of a sports activity, **daily training time**, occupation, **toothpaste**, brushing immediately after meals, dry mouth, gastroesophageal reflux, medication, **lemon water intake while fasting**, parafunctional habits, **previous orthodontic treatment**, malocclusion, bite alteration.
NS 328	15-17	Y 1-2	BEWE	**Gender**, location, erosive drinks, fruits or berries, **erosive products**.
NS 210	Mean 13,8	Y 2	Carlsson et al.	**Age**, gender, **time point (gingival recession)**, angle class I, angle class II, **angle class III**.

	First authors	Titles	Journals	Year
167	Milosevic, A.	Epidemiological studies of tooth wear and dental erosion in 14-year-old children in North West England. Part 2: The association of diet and habits.	Br Dent J	2004
168	Moazzez, R.	The association of acidic reflux above the upper oesophageal sphincter with palatal tooth wear.	Caries Res	2005
169	Moazzez, R.	Dental erosion, gastro-oesophageal reflux disease and saliva: how are they related?	J Dent	2004
170	Moazzez, R.	Oral pH and drinking habit during ingestion of a carbonated drink in a group of adolescents with dental erosion.	J Dent	2000
171	Mohamed, R. N.	Dental Erosion Prevalence and Its Association With Obesity Among Children With and Without Special Healthcare Needs.	Oral Health Prev Dent	2021
172	Morita, K.	Association between salivary alpha-amylase and subjective and objective oral parafunctions in community-dwelling elderly individuals.	J Dent Sci	2020

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
Y 2385	14	Y 1	Modified version of TWI (Smith and Knight)	District, clenching/ grinding, fizzy drink, Stomach upsets/ vomiting, sport drinks, fresh oranges, apples, grapefruit, tinned fruit, yoghurt, tomato ketchup, brown/other sauce, salad dressing, vinegar, baked beans/pasta shapes, pickled onions, other pickles, relishes, stoneground bread, cheese, salt and vinegar crisps, curry/spicy food, low calorie fizzy drinks, sports/ high energy drink, mineral water, still water, tea or coffee, beer/lager/cider, alcopop, spirit, squash, natural juice, alcohol, wine, milk, diluted fruit juice/squash, fizzy mineral water, herbal/lemon tea, normal tea, brushing, general health, medication, exposure to stomach acid, satisfaction body shape/weight.
NS 31	Mean 43,2	NS 1	Modified version of TWI (Smith and Knight)	Acidic reflux.
NS 104	18 to75	Y 1	Modified version of TWI (Smith and Knight)	**Gastroesophageal reflux**, saliva.
NS 11	10 to 16	NS NS	TWI (Smith and Knight)	Oral pH, **carbonated drinks (method and speed)**, fruit, fruit juice, orange cordial or squash, **sport drink, acidic crisps**.
Y 1200	6-16	Y 1	NS	Age, gender, **BMI, consumption of soft drinks**, citrus fruit consumption, **chronic vomiting or bulimia**, consumption of vitamin C, **gastric reflux**, type of disability.
NS 319	Over 65	NS NS	TWI (Smith and Knight)	**Saliva alpha-amylase**.

	First authors	Titles	Journals	Year
173	Mota-Veloso, I.	Effects of attention deficit hyperactivity disorder signs and socio-economic status on sleep bruxism and tooth wear among schoolchildren: structural equation modelling approach.	Int J Paediatr Dent	2017
174	Mulic, A.	Dental erosive wear among Norwegian wine tasters.	Acta Odontol Scand	2011
175	Mulic, A.	Dental erosive wear and salivary flow rate in physically active young adults.	BMC Oral Health	2012
176	Mulic, A.	Protein profiles of individuals with erosive tooth wear.	Pesquisa Brasileira em Odontopediatria e Clinica Integrada	2020
177	Muller-Bolla, M.	Dental erosion in French adolescents.	BMC Oral Health	2015
178	Mwangi, C. W.	Relationship between malocclusion, orthodontic treatment, and tooth wear.	Am J Orthod Dentofacial Orthop	2009

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
Y 851	6 to 12	Y 2	TWI (Smith and Knight)	Sex, **age, bruxism**, bequivalized monthly household income, **mother's schooling, father's schooling**, hyperactivity reported by parents, hyperactivity reported by teachers, inattention reported by parents, inattention reported by teachers, ever finger/thumb sucking, bit nails/objects, used pacifier, used bottle, currently use medication.
NS 18	24 to 56	Y 4	Visual Erosion Dental Examination (Mulic et al.)	**Wine tasters** (frequency of wine tasting, number of years in the occupation, number of wine tasting sessions, oral hygiene habits after wine tasting), gastro-esophageal reflux, medication, orange/apple/grapefruit juices, carbonated beverages, oranges, grapefruit, apples, toothbrushing (duration, frequency), fluoride consumption, time of last dental visit.
Y 220	18 to 32	Y 1	Visual Erosion Dental Examination (Mulic et al.)	Gastro-esophageal reflux, medication, orange/apple/grapefruit juices, carbonated beverages, oranges, grapefruit, apples, **toothbrushing (duration**, frequency), fluoride consumption, time of last dental visit, **saliva, gender**, age.
NS 267	18	Y 1	VEDE system	Sex, protein profiling in saliva.
Y 339	14	Y 1	BEWE	Socio-economic category, area of residence, sex, dental biofilm, carious lesions, fluoride toothpaste, dentist control, acidic beverage, energy/sports drinks, acidic sweets, acid fresh fruits, retained drink in the mouth after drinking, vitamin C.
NS 307	30-31	Y 1	Hooper index	**Sex**, orthodontic treatment, acidic drinks, acidic food.

	First authors	Titles	Journals	Year
179	Nagarajappa, R.	Tooth wear among tobacco chewers in the rural population of Davangere, India.	Oral Health Prev Dent	2012
180	Nahas Pires Correa, M. S.	Prevalence and associated factors of dental erosion in children and adolescents of a private dental practice.	Int J Paediatr Dent	2011
181	Nasir, E. F.	Dental Erosion Among Secondary School-children: Sudan.	Scientific Journal of King Faisal University	2021
182	Nayak, S. S.	Dental erosion among 12-year-old school children in Belgaum city: a cross sectional study.	Pak Peds Journal	2009
183	Nijakowski, K.	Regular Physical Activity and Dental Erosion: A Systematic Review.	Applied Sciences (Switzerland)	2022
184	Nijakowski, K.	Regular Physical Activity as a Potential Risk Factor for Erosive Lesions in Adolescents.	Int J Environ Res Public Health	2020
185	Nixon, P. J.	Tooth surface loss: does recreational drug use contribute?	Clin Oral Investig	2002

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
NS 208	35 to 44	Y 1	TWI (Smith and Knight)	**Tobacco, plain tobacco, pan masala with tobacco**.
NS 232	2 to 20	NS NS	Modified version of O'Brien index	Age, **gender**, type of dentition, soft drink, **frequency of soft drink**, type of soft drink, temperature of soft drink, juice, frequency of juice, sports drink, **milk**, tea, usual drinking method (swallows, straw), citrus fruits, **frequency of citrus fruit**, acidic sauces/ dressings, acidic candies, **frequency of acidic candy**, vomiting, gastroesophageal disorders, type of toothbrush, tooth-brushing, mouth rinse, tooth grinding.
Y 483	Mean 12.4	NS 1	TWI (Smith and Knight)	**Soft drink, hibiscus drink, tooth brushing frequency,** gender, class, type of water, topical fluoride, non-bacterial acids.
NS 220	12	Y 2	Modified version of TWI (Smith and Knight)	Gender, brushing, **citrus fruits, curds, pickle, ketchup, lemon, vinegar, Tamarind, Sambar**, Rasam, spicy curried food, fruit juice, fruit drinks, squash, **lemon juice**, milk, tea, carbo-nated/ non-carbonated beverages, coffee, **butter milk**, regurgitation, **vomiting**.
/	/	Systematic review.	/	Physical activity.
NS 155	15 -18	NS NS	BEWE	**Sports activity, isotonic drinks**, fruit juices, carbonated drinks, tendency to hold the drink in the mouth, brushing method, gastric disorders, **gender**, special diet.
NS 13	18 to 23	Y 1	TWI (Smith and Knight)	Frequency of acidic fruit, frequency of fizzy drink, known bruxism, xerostomia, regurgi-tation, competitive sport, tobacco, alcohol, cannabis, **amphetamines, ecstasy, cocaine**.

	First authors	Titles	Journals	Year
186	Nota, A.	Correlation between Bruxism and Gastro-oesophageal Reflux Disorder and Their Effects on Tooth Wear. A Systematic Review.	J Clin Med	2022
187	O'Toole, S.	Timing of dietary acid intake and erosive tooth wear: A case-control study.	J Dent	2017
188	O'Toole, S.*	Randomised Controlled Clinical Trial Investigating the Impact of Implementation Planning on Behaviour Related to The Diet.	Sci Rep	2018
189	Offen, E.	Do oral piercings cause problems in the mouth?	Evid Based Dent	2022
190	Oginni, A. O.	Non-carious cervical lesions in a Nigerian population: abrasion or abfraction?	Int Dent J	2003
191	Okunseri, C.	Erosive tooth wear and consumption of beverages among children in the United States.	Caries Res	2011
192	Okunseri, C.	The relationship between consumption of beverages and tooth wear among adults in the United States.	J Public Health Dent	2015
193	Olaide Savage, Kofoworola	A national survey of tooth wear on facial and oral surfaces and risk factors in young Nigerian adults.	European journal of dentistry	2018

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
/	/	Systematic review	/	Bruxism, gastroesophageal reflux.
Y 600	18 to 66	Y 1	BEWE	**Total acid intake**, fruit with meals, **fruit between meals**, fruit with meals, **acidic drinks between meals, acidic drinks with meals**, brush within 10 min of acid intake, duration of fruit, **duration of acidic drink, alternate drinking habits, gender**, age.
NS 60	25 to 70	Y 1	BEWE	Acidic diet, eating disorder, age, gastro-esophageal reflux, xerostomia, bruxism, requiring antibiotic pre-medication prior to dental treatment, current pregnancy.
/	/	Systematic review	/	Oral piercings.
NS 106	20 to 80	NS NS	TWI (Smith and Knight)	Brushing technique, toothbrush, frequency of brushing.
NS 1314	13 to 19	Y NS	Modified version of TWI (Smith and Knight)	**Age**, gender, **race/ ethnicity**, apple juice, fruit drinks, grape juice, milk, orange/grapefruit juice, other juice, soft drinks, tomato/vegetable juice.
NS 3773	Over 20	Y NS	Modified version of TWI (Smith and Knight)	**Age, gender, race/ ethnicity, education**, annual family income, apple juice, fruit drinks, grape juice, milk, orange/ grapefruit juice, other juice, soft drinks, tomato/vegetable juice.
NS 1349	18 to 35	Y NS	BEWE	**Geopolitical zones of country, age**, gender, area of residence, **education, occupation, brushing frequency**, manual toothbrush, electric tooth-brush, chewing stick, **brush movement** (various motion, horizontal, vertical, circular), **brush after breakfast**, brush before breakfast, brush after lunch, brush after dinner, snoring, sleeping medication/antidepressant, **smoking**, chewing-gum, fresh fruits, fruit/vegetable juice, isotonic/energy drinks, soft drinks, dairy products, acidic foods.

	First authors	Titles	Journals	Year
194	Olley, R. C.	The relationship between incisal/occlusal wear, dentine hypersensitivity and time after the last acid exposure *in vivo*.	J Dent	2015
195	Oltramari-Navarro, P. V.	Tooth-wear patterns in adolescents with normal occlusion and Class II Division 2 malocclusion.	Am J Orthod Dentofacial Orthop	2010
196	Otsu, M.	Factors affecting the dental erosion severity of patients with eating disorders.	BioPsycho Social Medicine	2014
197	Özgöz, M.	Relationship between handedness and toothbrush-related cervical dental abrasion in left- and right-handed individuals.	Journal of Dental Sciences	2010
198	Paszynska, E.	Parotid salivary parameters in bulimic patients a controlled clinical trial.	Psychiatr Pol	2015
199	Paszynska, E.	Risk of Dental Caries and Erosive Tooth Wear in 117 Children and Adolescents' Anorexia Nervosa Population-A Case-Control Study.	Front Psychiatry	2022
200	Pedrao, A. M. N.	Erosive Tooth Wear and Dietary Patterns: A Clinical Study.	Oral Health Prev Dent	2018
201	Penoni, D. C.	Factors Associated with Noncarious Cervical Lesions in Different Age Ranges: A Cross-sectional Study.	European Journal of Dentistry	2021

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
NS 350	19 to 34	Y 1	BEWE	**Acidic beverages**.
NS 165	Mean G1 : 13,9 G2 : 14,3	Y NS	Modified version of TWI (Smith and Knight)	**Normal occlusion, Malocclusion: class II**
NS 79	17 to 47	NS 2	NS	Age, **vomiting** (Anorexia nervosa, bulimia nervosa), water consumption before vomiting, post-vomiting oral hygiene: oral rinsing post-vomiting, **toothbrushing post-vomiting, acidic foods**, acidic beverages, citrus fruit, **sugar-sweetened food (candy, gum),** eating disorder duration.
NS 488	Mean 33,7	Y 1	TWI (Smith and Knight)	**Gender**, age, daily tooth-brushing, **toothbrushing technique (Horizontal method)**, toothbrushing frequency, **duration toothbrushing**.
NS 95	Mean G1 : 21,2 G2 : 27,4 G3 : 25,5	NS NS	TWI (Smith and Knight)	**Vomiting (Bulimia nervosa)**, fluoxetine medication.
NS 117	12-18	Y 2	BEWE	**Anorexia nervosa, anorexia nervosa with purging episodes.**
NS 207	35 to 74	Y 2	BEWE	**Vegetarian, laco-ovo vegetarians, omnivores**, sex, age.
NS 501	Over 15	Y 13	NS	**Age, sex, acidic diet intake, number of teeth, harmful toothbrushing habits**.

	First authors	Titles	Journals	Year
202	Pergamalian, A.	The association between wear facets, bruxism, and severity of facial pain in patients with temporomandibular disorders.	J Prosthet Dent	2003
203	Picos, A.	Factors associated with dental erosions in gastroesophageal reflux disease: a cross-sectional study in patients with heartburn.	Med Pharm Rep	2020
204	Polat, Zülfikar	Evaluation of the relationship between dental erosion and scintigraphically detected gastroesophageal reflux in patients with cerebral palsy.	Turk J Med Sci	2013
205	Provatenou, E.	Erosive Tooth Wear and Related Risk Factors in 8- and 14-Year-Old Greek Children.	Caries Research	2016
206	Przybyszewska-Pardak, S.	Assessment of dental condition in young polish adults using the BEWE index.	Family Medicine and Primary Care Review	2020
207	Quintella, M. C. M.	Relationship between bariatric surgery and dental erosion: a systematic review.	Surg Obes Relat Dis	2020
208	Racki, D. N. D. O.	Is Toothbrush Bristle Stiffness Associated with Erosive Tooth Wear in Adolescents? Findings from a Population-Based Cross-Sectional Study.	Caries Research	2021
209	Rafeek, R. N.	Tooth surface loss in adult subjects attending a university dental clinic in Trinidad.	Int Dent J	2006

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
NS 84	Mean 29,1	Y NS	Johannson et al.	**Age**, gender, bruxism.
NS 263	Over 20	Y NS	BEWE	**Age**, sex, **intrinsic factors (GERD)**, acidic drinks, citric fruits, bruxism, **salivary buffering capacity, salivary pH**.
NS 37	Mean 12,1	NS 1	O'Sullivan	**Gastroesophageal reflux (GERD)**.
Y 329 263	8 and 14	Y 2	BEWE	**Gender**, caries-free, decayed missing filled surface index, toothbrushing, toothbrushing frequency, pool swimming, awareness of tooth grinding, **preference for sour taste (lemon or vinegar), lemon-flavored sour candy, lemon-flavored sour candy frequency**, fruit juice, fruit juice frequency, **soft drink frequency, soft drink prolonged retention in mouth**.
NS 260	17-19.1	Y 1	BEWE	Gender.
/	/	Systematic review.	/	Bariatric surgery.
Y 1197	15-19	Y 2	BEWE	**Sex**, age, **socioeconomic status, toothbrush bristle stiffness**, toothbrushing frequency, toothbrushing after meals, soft drink consumption, citric fruit consumption
NS 155	16 to 73	NS NS	Kelly et al.	**Age**, toothbrushing frequency, vomiting, **gastric reflux, parafunction, citrus fruit**, fruit juices, **soft drinks**, sports drinks, **alcohol**, yoghurt, **chewing gum**, dinner mints, **effervescent vitamin C, vegetarian diet**.

	First authors	Titles	Journals	Year
210	Raj, A.	Evaluation of Dental Status in Relation to Excessive Horizontal and Vertical Overlap in North Indian Population.	J Pharm Bioallied Sci	2021
211	Ramsay, D. S.	Tooth wear and the role of salivary measures in general practice patients.	Clin Oral Investig	2015
212	Ramirez, V.	Relationship between intrinsic and extrinsic factors with Erosive Tooth Wear in adults: a cross-sectional study.	Braz Oral Res	2022
213	Ratnayake, N.	Risk indicators for tooth wear in Sri Lankan adolescents.	Caries Res	2010
214	Rauber, B. F.	Predictors of dental erosions in patients evaluated with upper digestive endoscopy: a cross-sectional study.	Odontology	2020

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
NS 600	13-50	NS NS	NS	**Occlusion**.
Y 1323	16 to 97	Y NS	NS	**Gender, age**, salivary consistency, resting salivary flow, stimulated salivary flow, resting salivary pH, stimulated salivary pH, salivary buffering capacity, milk, coffee, acidic beverage, alcohol, chew tobacco use, tooth-brushing frequency, medications affecting saliva, **dry mouth, number of teeth present**.
Y 553	18-46	Y 2	BEWE	**Age**, sex, low educational level, medium educational level, sport practice, aerobic sports, watersport, walking/skating, no exercise, tobacco smoking, smokes at least once a day, **alcohol drinking currently**, diabetes, arterial hypertension, obesity, pneumonia, asthma, depression, cancer, hiatal hernia, GERD, gastric ulcer, chronic gastritis, **esophagitis, difficulty to swallow**, sensation of acidity, reflux feeling, nausea/vomiting, indigestion or discomfort, nighttime cough, rejection of food, eating large quantities of food, obsession with the physical, **anorexia**, bulimia, **vitamin C**, vitamin C once a day, aspirin, once a day, water, sparkling water, fruit/artificial juices, soft drink, black tea, green tea, coffee, mate/herbal infusion, wine, fruits, chocolates, dairy products.
Y 1200	17	Y 1	Modified version of TWI (Smith and Knight)	**Father's occupation, mother's education**, use of mouth washes, **chewing vitamin C tables, oranges, apples, sauce, coca cola, ginger beer**, natural fruit juices, method of drinking fruit juice, straw, glass.
Y 235	Over 18	Y 1	BEWE	Sex, age, BMI, dental prosthesis, preserved teeth, heartburn, regurgitation score, reflux esophagitis, GERD, hiatal hernia, antidepressants, proton pump inhibitors, chocolate intake.

	First authors	Titles	Journals	Year
215	Rodriguez, J. M.	*In vivo* measurements of tooth wear over 12 months.	Caries Res	2012
216	Roesch-Ramos, L.	Dental erosion, an extraesophageal manifestation of gastroesophageal reflux disease. The experience of a center for digestive physiology in Southeastern Mexico.	Rev Esp Enferm Dig	2014
217	Rusyan, E.	The association between erosive tooth wear and diet, hygiene habits and health awareness in adolescents aged 15 in Poland.	Eur Arch Paediatr Dent	2022
218	Saerah, N. B.	Associated factors of tooth wear among Malaysian 16-year-olds: a case-control study in Kota Bharu, Kelantan.	Community Dent Health	2012
219	Samman, M.	Dental Erosion: Effect of Diet Drink Consumption on Permanent Dentition.	JDR Clin Trans Res	2022
220	Sanhouri, N. M.	Tooth surface loss, prevalence, and associated risk factors among 12-14 years school children in Khartoum State, Sudan.	Community Dent Health	2010

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
NS 63	Mean 39,1	NS NS	TWI (Smith and Knight)	**Heartburn, regurgitation, vomiting**, acid taste in mouth, soft drink, holding/swirling drinks in mouth, method of drinking soft drinks, alcohol consumption, history of eating disorder, clenching, grinding, TMJ disorder-related symptoms, age, gender, parafunction.
NS 60	Mean 50.92	NS NS	Erosion Index of Eccles	Esophagitis, age, gender, **carbohydrates**, fats, **spicy food**, citrus, **coffee**, alcohol, smoking, acid reflux, non-acid reflux, DMF index, **halitosis**, good oral hygiene, poor oral hygiene.
NS 2639	15	Y 18	BEWE	Place of residence, **gender**, education level of the mother, education level of the father, working status of the mother, working status of the father, systemic health, toothbrush type, time between meal and toothbrushing, fluoride rinse or gel, fruits, fruit juices, **fruit teas, isotonic drinks, carbonated drinks, energy drinks, marinades.**
NS 576	16	Y 1	TWI (Smith and Knight)	Gender, monthly household income, carbonated sport drinks, years of drinking orange juices, hydration of saliva in seconds, viscosity of saliva, pH of saliva, Caries experience, pool swimming.
Y 2368	21-60	NS NS	TWI (Smith and Knight)	**Gender, age, race/ethnicity**, education, marital status, ratio of family income to poverty, beverage consumption.
NS 1138	12 to 14	Y 2	Modified version of TWI (Smith and Knight) by Millward	**Brushing after vomiting, swimming, vomiting, mouth dryness, grapefruit, mango, karkade, gongolaise, gender, school, grapefruit juice**.

	First authors	Titles	Journals	Year
221	Sawlani, K.*	Factors influencing the progression of noncarious cervical lesions: A 5-year prospective clinical evaluation.	J Prosthet Dent	2016
222	Sayed, M. E.	Tooth Wear Patterns among Khat and Shammah Users in Jazan City, Kingdom of Saudi Arabia: A Cross-sectional Survey.	J Contemp Dent Pract	2017
223	Schierz, O.	Association between anterior tooth wear and temporomandibular disorder pain in a German population.	J Prosthet Dent	2007
224	Schlenz, M. A.*	Intraoral scanner-based monitoring of tooth wear in young adults: 12-month results.	Clin Oral Investig	2022
225	Sehgal, H. S.	Tooth wear in patients treated with HIV anti-retroviral therapy.	BMC Oral Health	2019
226	Seong, J.	Clinical enamel surface changes following an intra-oral acidic challenge.	J Dent	2015
227	Serra-Negra, J. M.	Tooth wear and sleep quality: A study of police officers and non-police officers.	Cranio	2018

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
NS 29	Mean 60,3	NS 2	NS	Acidic foods, acidic beverages, acidic sauces, gastric reflux, dry mouth, hyposalivation medicine, brush more than 1x/day, medium or hard brush, brus rigorously, horizontal brushing, grind or nail bite, **absolute occlusal stress in maximum intercuspation position (MIP), relative occlusal force in MIP**, relative occlusal force in protrusion, relative occlusal force on working side, relative occlusal force on nonworking side.
NS 236	Mean 42,68	Y 2	Johansson et al.	**Oral habits**, gender, acidic drink, acidic food, fruits, grains, vegetables, **systemic disease, brushing times per day, brushing technique, toothbrush**, parafunctional habits, stress, acid reflux, **age, drink frequency, food frequency, grains frequency.**
Y 646	35 to 44	Y 3	NS	TMD pain, bruxism.
NS 109	Mean 21.0	Y 1	NS	Sex, nightguard, consumption of chewing gum, acidic food, acidic drinks.
NS 93	20 to 90	NS 1	Ekfeldt et al.	HIV, smoking, TMJ Disorder, Bite guard therapy, **clenching day**, clenching night, psychiatric disorder, anti-retroviral therapy, **sex**, Jaw soreness, Headaches, Teeth/gum soreness, **alcoholic beverage per week**.
NS 20	Over 18	Y 4	NS	Acidic soft drink.
NS 144 142	18 to 71	Y 1	Johansson et al.	**Age**, gender, marital status, **profession**, general health, suffering from illness, psychological counseling, consumes alcoholic beverages.

	First authors	Titles	Journals	Year
228	Sezer, B.	Relationship between erosive tooth wear and possible etiological factors among dental students.	Clin Oral Investig	2022
229	Shah, P.	The prevalence of cervical tooth wear in patients with bruxism and other causes of wear.	J Prosthodont	2009
230	Shrestha, D.	Prevalence and Associated Risk Factors of Tooth Wear.	JNMA J Nepal Med Assoc	2018
231	Sierpinska, T.	Copper deficit as a potential pathogenic factor of reduced bone mineral density and severe tooth wear.	Osteoporos Int	2014
232	Sierpinska, T.	Enamel mineral content in patients with severe tooth wear.	IJOPRD	2013
233	Silva, M. A.	Gastroesophageal reflux disease: New oral findings.	Oral Surg Oral Med Oral Pathol Oral Radiol Endod	2001

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
NS 126	21-34	Y 2	BEWE	Age, **gender**, mother's educational status, **father's educational status, acidic foods, dairy products (yoghurt/cheese), fruit juice**, acidic drinks, carbonated drinks, drinking with straw, sport drinks, tea/coffee, **milk, alcohol, swimming in pools**, toothbrushing, **usage of fluoride-containing toothpaste, type of toothbrush**, usage of electrical toothbrush, bruxism, **dental visits**, DFMT.
NS 119	Mean 48.7	Y 2	TWI (Smith and Knight)	**Bruxism**, carbonated drinks, **acidic food, acidic drink, parafunction**.
Y 364	15 to 75	NS NS	BEWE	**Age, duration of brushing, method of brushing, swishing of soft drink, tobacco chewing**, gender, dietary habits, frequency of taking sour food, frequency of taking soft drinks, frequency of taking hard food, vomiting, **reflux**, parafunctional habit.
NS 50	Mean 47,5	NS NS	TWI (Smith and Knight)	Age, gender, number of teeth, height, wright, BMI, BMD (Bone mineral density) femur, T-score for BMD femur, Z-score for BMD femur, **BMD spine, T-score for BMD spine, Z-score for BMD spine**, Calcium intake, **zinc intake**, copper intake, phosphorus intake, vitamin D intake, **enamel bioptates**, saliva, serum.
NS 50	Mean 49,5	NS NS	TWI (Smith and Knight)	**Content of Zn in enamel bioptates, content of Cu in enamel bioptates**. content of Ca in enamel bioptates, content of Mg in enamel bioptates.
NS 31	Mean 37,1	Y 1	Eccles et al.	GERD.

	First authors	Titles	Journals	Year
234	Silva, M. R. G.	Is the consumption of beverages and food associated to dental erosion? A cross-sectional study in Portuguese athletes.	Science and Sports	2021
235	Skalsky Jarkander, M.	Dental erosion, prevalence and risk factors among a group of adolescents in Stockholm County.	Eur Arch Paediatr Dent	2018
236	Smith, W. A.	The prevalence and severity of non-carious cervical lesions in a group of patients attending a university hospital in Trinidad.	J Oral Rehabil	2008

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
NS 110	13 to 62	Y 1	BEWE	Gender, age, race, sport practice, duration of training, **swimmers who consume energy drinks, athletes who do not consume energy drinks**, years of swimming practice, energy drinks, number of daily meals, acidic taste, dry mouth, heartburn, regurgitation, vomiting, sharp teeth, type of diet, **frequency of daily tooth brushing**, toothpaste brand, tooth whitening, bruxism, **orthodontic treatment**, cola, other sodas, fruit juice, lemonade, coffee, plain tea, lemon tea, ice tea, **red wine**, green wine, beer, other alcoholic drinks, citrus food, tomatoes, cheese, curry food, spicy food, vinegar, pickles, salad with dressing, yoghurts, peppermint, sweet and sour sauce, tartar sauce, sour candy, number of daily meals, snacks/ drinks between meals, non-vegetarian diet, iron supplement, vitamin C, multivitamins.
Y 1071	15 to 17	Y 2	Johansson et al.	**Coca-cola or other soft drinks**, juice or sport drinks, juice at breakfast, **juice or sport drink as thirst quencher after exercise, fruit, apple**, citrus fruits, computing, exercise frequency, reflux, intake of fluoride tablets, tooth brushing frequency, tooth brushing before or after breakfast, chewing-gum, mouthwash (with or without fluoride), **age, gender**.
NS 156	16 to 73	Y 2	NS	**Age**, gender, **gastric reflux, heartburn, headaches, bruxism, clinking joint, occlusal splint, tooth brushing, toothbrush type, swimming**, lived near a beach, outdoor sports, **vegetarian food, citrus fruits, soft drinks, alcohol, yoghurt, effervescent vitamin C, chewing-gum, frequency of intake of citrus fruits, frequency soft drinks, sport drinks frequency, alcohol frequency, effervescent vitamin C frequency, guidance**, group function, canine guidance.

	First authors	Titles	Journals	Year
237	Smits, K. P. J.	Vegetarian diet and its possible influence on dental health: A systematic literature review.	Community Dent Oral Epidemiol	2020
238	Soares, L. G.	Prevalence of bruxism in undergraduate students.	Cranio	2017
239	Souza, G. L. N.	Association of facial type with possible bruxism and its related clinical features in adolescents: A cross-sectional study.	Int Orthod	2020
240	Stangvaltaite-Mouhat, L.	Erosive Tooth Wear among Adults in Lithuania: A Cross-Sectional National Oral Health Study.	Caries Res	2020
241	Struzycka, I.	Prevalence of erosive lesions with respect to risk factors in a young adult population in Poland-a cross-sectional study.	Clin Oral Investig	2017
242	Suyama, Y.	Dental erosion in workers exposed to sulfuric acid in lead storage battery manufacturing facility.	Bull Tokyo Dent Coll	2010
243	Tahmassebi, J. F.	Impact of soft drinks to health and economy: a critical review.	Eur Arch Paediatr Dent	2020
244	Takehara, J.	Correlations of noncarious cervical lesions and occlusal factors determined by using pressure-detecting sheet.	J Dent	2008
245	Truin, G. J.	Caries trends 1996-2002 among 6- and 12-year-old children and erosive wear prevalence among 12-year-old children in The Hague.	Caries Res	2005

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
/	/	Systematic review.	/	Vegetarian diet.
Y 253	18 to 30	Y 1	Johansson et al.	Age, **sex**.
Y 448	12-19	Y 1	NS	Facial type.
Y 1397	35 to 74	Y 1	NS	**Age, gender**, education, residency, fluoride level in drinking water, toothbrushing frequency, using fluoridated toothpaste, fruits, juice, soft drinks, oral health, general health, reflux, dry mouth.
Y 1869	18	Y 2	BEWE	**Gender, place of residence (city, village), gastroesophageal reflux, eating disorder**, allergy, **asthma**, fruit, fruit juices, fruit teas, **isotonic drinks**, carbonated beverages, energizing drinks, pickles, **acidic solids and liquids, toothbrush used, asthma**.
NS 40	Mean 42,4	NS NS	Occupation dental health by Japan Dental Association	Sulfuric acid gases exposition, **working years**.
/	/	Systematic review.	/	Soft drinks.
NS 159	Mean 36,2	NS 1	TWI (Smith and Knight)	**Age**, frequency of toothbrushing, hardness of bristles, toothbrushing strike, **toothbrushing pressure**, bruxism, **occlusal force, occlusal contact area, occlusal pressure**.
NS 832	6 and 12	NS 2	Van Rijkom et al.	Socio-economic status, **gender**, frequency of toothbrushing, fluoride gel of varnishes.

	First authors	Titles	Journals	Year
246	Tschammler, C.	Erosive tooth wear and caries experience in children and adolescents with obesity.	J Dent	2019
247	Tsiggos, N.	Association between self-reported bruxism activity and occurrence of dental attrition, abfraction, and occlusal pits on natural teeth.	J Prosthet Dent	2008
248	Uhlen, M. M.	Self-induced vomiting and dental erosion—a clinical study.	BMC Oral Health	2014
249	Vainionpaa, R.	Erosive tooth wear and use of psychoactive substances among Finnish prisoners.	BMC Oral Health	2019
250	van Rijkom, H. M.	Prevalence, distribution, and background variables of smooth-bordered tooth wear in teenagers in the hague, the Nether-lands.	Caries Res	2002
251	Van't Spijker, A.	Occlusal wear and occlusal condition in a convenience sample of young adults.	J Dent	2015
252	Vargas-Ferreira, F.	Prevalence of tooth erosion and asso-ciated factors in 11-14-year-old Brazilian schoolchildren.	J Public Health Dent	2011
253	Venugopal, A.	Occurrence of tooth wear in controlled and uncontrolled diabetic patients - An observational study.	Journal of Advanced Pharmacy Education and Research	2017

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
Y 223	4 to 17	Y 1	BEWE	Caries, **weight, background**, native, migrant, **frequency of erosive beverages**, tooth-brushing, **toothbrush**, age, snacks, BMI, snacks.
NS 102	Mean 44,6	Y 2 *Ex vivo*	Johansson et al.	**Bruxism**.
NS 72	Mean 27,7	Y 1	Visual Erosion Dental Examination (VEDE)	**Eating disorder**, self-induced vomiting, daily intake of acidic beverages.
NS 100	Mean 34,6	Y 1	BEWE	Alcohol, smoking, snuff, drogues, decayed, **filled tooth**, missing teeth, age. DMFT.
NS 345 400	10 to 13 15 to 16	Y 2	Lussi et al.	Gender, vomiting, acidic fruits, **acidic drinks**, dairy drinks, toothbrushing frequency, bristle hardness, brushing immediately after meals, **swishing carbonated drinks**.
NS 28	24,7	NS NS *Ex vivo*	NS	Canine Angle class II, anterior guidance, hori-zontal overbite, self-reported grinding.
Y 944	11 to 14	Y 2	Peres et al.	Gender, ethnics, **age**, household income (BMW), mother's schooling, father's schooling, GERD, consumption of acid drinks, dental caries, **enamel hypoplasia**.
NS 50	20 to 90	NS NS	NS	Random blood sugar (RBS) level, age, uncon-trolled diabetic, gender.

	First authors	Titles	Journals	Year
254	Vered, Y.	Dental erosive wear assessment among adolescents and adults utilizing the basic erosive wear examination (BEWE) scoring system.	Clin Oral Investig	2014
255	Verhoeff, M. C.	Parkinson's disease, temporomandibular disorder pain and bruxism and its clinical consequences: a protocol of a single-centre observational outpatient study.	BMJ Open	2022
256	Vieira Pedrosa, B. R.	Prevalence of Erosive Tooth Wear and Related Risk Factors in Adolescents: An Integrative Review.	J Dent Child (Chic)	2020
257	Wan Nik, W. N.	Gastro-oesophageal reflux disease symptoms and tooth wear in patients with Sjogren's syndrome.	Caries Res	2011
258	Wang, G. R.	Relationship between dental erosion and respiratory symptoms in patients with gastro-oesophageal reflux disease.	J Dent	2010
259	Wang, P.	The prevalence of dental erosion and associated risk factors in 12-13-year-old school children in Southern China.	BMC Public Health	2010

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
Y 245 255	15 to 60	Y 15	BEWE	Gender, **age**, origin, education, employment, lifetime parotid gland inflammation, lifetime exposure to radiation (head, neck tumors), frequency of reflux, vomiting, exposure to acidic vapors at the workplace, frequency of consumption of sedatives, sleeping, antiallergy, drugs, **acidic foods**.
Y NS	Over 18	NS NS	Wetselaar's index	Composition of saliva, Parkinson's disease.
/	/	Systematic review.	/	Lifestyle, diet, sociodemographic, economic factor, gender, acidic foods, beverages, GERD.
Y 33	20	NS NS	Modified version of TWI (Smith and Knight)	Sjögren's Syndrome, GORD.
NS 88	20 to 73	Y 1	Modified version of TWI (Smith and Knight)	**GERD with respiratory symptoms**, medical history, dietary history, dental history, oesophageal symptoms, GERD, oral hygiene habits.
Y 774	12 to 13	Y 2	O'Sullivan	Gender, age, socio-economic status, **occupation and education levels of parents**, oral hygiene habits, **frequencies of ingesting beverage types**, acidic drink intake, special drinking habits, general health, vitamin C supplements, frequency of swimming.

	First authors	Titles	Journals	Year
260	Wei, Z.	Prevalence and Indicators of Tooth Wear among Chinese Adults.	PLoS One	2016
261	Westergaard, J.	Occupational exposure to airborne proteolytic enzymes and lifestyle risk factors for dental erosion—a cross-sectional study.	Occup Med (Lond)	2001
262	Wiegand, A.	Occupational dental erosion from exposure to acids: a review.	Occup Med (Lond)	2007
263	Wild, Y. K.	Gastroesophageal reflux is not associated with dental erosion in children.	Gastro-enterology	2011
264	Wilder-Smith, C. H.*	Longitudinal study of gastroesophageal reflux and erosive tooth wear.	BMC Gastroenterol	2017
265	Wilder-Smith, C. H.*	Quantification of dental erosions in patients with GERD using optical coherence tomography before and after double-blind, randomized treatment with esomeprazole or placebo.	Am J Gastroenterol	2009
266	Yadav, N. S.	Alliance of oral hygiene practices and abrasion among urban and rural residents of Central India.	J Contemp Dent Pract	2012

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
Y 720	36 to 74	Y 2	BEWE	Gender, **age, frequency of acidic drinks and foods, drinking before sleep**, holding drinks in mouth, drinking water during meals, frequency of tea consumption, frequency of swimming in summer, taking vitamin C, taking aspirin, Gastroesophageal reflux disease, gastricism, clenching teeth automatically, bruxism, **unilateral chewing, frequency of tooth brushing, frequency of changing toothbrushes, social-economic class**, duration of tooth brushing, **toothbrush bristle**, horizontal brushing.
NS 425	18 to 67	Y 2	Larsen et al.	**Exposed to proteolytic enzymes, exposed to acids**, grinding substances, **exposed to organic solvents**, sugar/flour, **wine, lemon tea**, fruit intake, soda pop intake, **abrasive dentifrice**, digestion problems, tablets containing acetylsalicylic acid, **age**, gender.
/	/	Systematic review.	/	Exposure acids.
Y 59	9 to 17	NS 1	Simplified Tooth Wear Index	GER, **sport drinks**, drinking, water from bottle, **milk temperature**, eating mints, **eating chocolate, citrus, or sour candies**.
NS 72	Mean 33.8	Y NS	BEWE	pH, reflux episodes, acidic reflux episodes, proximal reflux, esomeprazole treatment.
NS 30	18	NS 1	Lussi et al.	Esomeprazole treatment for GERD.
NS 1045	18 to 59	Y 1	Modified version of TWI (Smith and Knight)	**Age, rural/urban resident, material used**, frequency of brushing, **type of toothbrush, duration of brushing,** gender, toothbrush/finger.

	First authors	Titles	Journals	Year
267	Yang, C.	Dental Erosion in Obese Patients before and after Bariatric Surgery: A Cross-Sectional Study.	J Clin Med	2021
268	Yanushevich, O. O.	Prevalence and Risk of Dental Erosion in Patients with Gastroesophageal Reflux Disease: A Meta-Analysis.	Dent J (Basel)	2022
269	Yu, T.	Prevalence and Associated Factors of Tooth Wear in Shanghai.	Chin J Dent Res	2021
270	Zhang, J.	The prevalence and risk indicators of tooth wear in 12- and 15-year-old adolescents in Central China.	BMC Oral Health	2015
271	Zhang, Q.	Occlusal tooth wear in Chinese adults with shortened dental arches.	J Oral Rehabil	2014

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
Y 62	/	NS NS	BEWE	Bariatric surgery.
/	/	Meta-Analysis	/	Gastroesophageal reflux disease.
Y 1806	12, 15 and over 18	Y 1	BEWE	**Age, frequency of toothbrushing, frequency of consumption of carbonated drinks, GERD, frequency of changing toothbrush, methods of toothbrushing, alcoholic drinks consumption, pickled vegetables consumption, type of toothbrush**, xerostomia, **hard food consumption**.
Y 720	12 and 15	Y 2	BEWE	Gender, **age, social-economic class, frequency of brushing, duration of brushing**, toothbrush bristle, toothbrushing method, fluoride toothpaste, accumulated use time, toothbrush, frequency of changing toothbrush, fruit juices/ soft drinks/acid food, taking drinks before sleep, **holding drinks in mouth**, drinking with straw, **drinking immediately after sport**, dry mouth, frequency of tea consumption, **eating hard food**, vitamin C supplements, **taking aspirin**, taking amphetamine, **taking diazepam, reflux**, vomiting, eating disorder, gastroesophageal reflux disease, gastricism, xerostomia, **frequency of swimming in summer**, clenching teeth automatically, sleep bruxism, **chewing habits**.
Y 150	Mean 58.2	Y 1	Modified version of TWI (Smith and Knight)	Shortened dental arches, **age**, gender, place of residence, **posterior occluding pairs**.

	First authors	Titles	Journals	Year
272	Zhang, S.	Dental caries and erosion status of 12-year-old Hong Kong children.	BMC Public Health	2014
273	Zwier, N.	Saliva parameters and erosive wear in adolescents.	Caries Res	2013

Table 2 Studies included in this scoping review (n=273): First authors, titles, journals, year, number of participants (n) and power sample size calculation, age of participants (year), tooth wear (TW) measurement index used, factors studied and risk of bias. The factors shown to be positively associated with TW after

Power sample size calculation/ Number of participants (n)	Age of participants	Calibration/ Number of examiners	Tooth wear measurement index	Studied factors
Y 600	12	Y 3	BEWE	Gender, place of birth, frequency of soft drinks, frequency of citric tea/ drinks, **frequency of fruit juice, frequency of chewing gum**, frequency of vitamin C supplement drinks, **frequency of toothbrushing**, caretaker, education of father, education of mother, parent's dental knowledge, **caries experience**.
NS 88	49	NS NS	Lussi modified by Van Rijkom	pH, buffer capacity, **flow (ml/min)**, albumin, amylase, CA-6, Total protein, calcium, phosphate, urea, sodium, **chloride**, potassium.

statistical analysis are in bold. The factors shown to be negatively associated with TW are in italic.
NS: not specified. Y: Yes.
*Indicates longitudinal studies.

Chapter

4

Bruxism as a new Risk Factor of Musculo-Skeletal Disorders?

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1. Abstract

Objectives: Musculoskeletal disorders (MSDs), particularly neck and low back pain, constitute a major public health issue worldwide with a heavy morbidity and economic impact. However, the relationships between the stomatognathic system and MSDs are subjected to debate, data sorely lacking. The study objective was to investigate the association between bruxism (BR) and MSDs. Secondary objective includes the study of the association between tooth wear (TW) and MSDs.

Methods: This is a cross-sectional study on 425 participants frequenting a university dental clinic. The presence of MSDs was evaluated with the standardized Nordic questionnaire. The sleep and awake BR assessments were based on clinical examination and self-report. TW was measured with the BEWE index. Socio-demographic factors, medical history, life habits and stress were analyzed as potential confounding variables.

Results: 91% of patients reported at least one MSD during the preceding 12 months and 78.8% were diagnosed as bruxers. In multivariate analyses, BR was associated with a 5-fold increased risk of prevalent MSD (OR=5.88 (2.7-12.5), $p<0.0001$). Regarding TW, for a one-point increase in anterior BEWE score, the risk to present an MSD was increased by 53% (OR=1.53 (1.12-2.08), $p=0.0076$). Moreover, BR was independently associated with neck, shoulder, upper back, low back, hip & thigh and knee MSDs. Anterior TW was independently associated with neck, low back and hip & thigh MSDs, and global TW with knee MSDs.

Conclusions: BR and TW were shown to be associated with MSDs. The cause-and-effect relationships between those factors needs to be analyzed to optimize prevention and therapeutic care.

Clinical significance: Results suggest that the body is a whole, a balanced muscular system, where every part constitutes a link of the chain. MSDs management and prevention may require a multidisciplinary team approach and future perspectives include defining the dentist's role in this context, particularly with respect to BR diagnostic and treatment.

KEYWORDS

Tooth wear, BEWE index, Nordic questionnaire, Neck pain, Back pain, Sleep bruxism.

2. Introduction

Musculoskeletal disorders (MSD) are soft-tissue injuries caused by sudden or sustained exposure to repetitive motion, force, vibration, and awkward positions. These disorders can affect the muscles, nerves, tendons, joints and cartilage [1]. According to the WHO [2], MSDs affect around 1,71 billion persons worldwide and constitute a major public health issue. Studies on the prevalence of MSDs in healthy adult populations are lacking but a systematic review and meta-analysis on the prevalence of work-related MSDs in secondary industries showed that MSDs of the back, shoulder and neck are very common, with mean 12-month prevalence values ranging from 47 to 60% [3]. In the study of Wijnhoven, 39% of men and 45% of women reported chronic musculoskeletal pain in any body region [4]. MSDs are associated with a huge morbidity and have a significant economic impact increasing with population, while young people are also affected [2]. They engender not only direct costs, related to medical expenditure, but also indirect costs, including lost work output, as well as intangible costs, related to the psychosocial burden [5]. Particularly, neck and low back pain were reported to be one of the most important causes of the world global burden of disease in 2016, low back pain being in the top ten for all countries, while neck pain in the top for half of the countries [6]. In 2019, low back pain was in the top ten of the diseases, which engendered the highest amount of years lived with disability (YLDs), while other MSDs ranked the 19th cause out of 369 [7]. If 40% of low back pain are reported to be attributed to occupational risks or increased BMI [6], data about neck pain risk factors are lacking.

On the other hand, following the international consensus, bruxism (BR) is defined as "a repetitive masticatory muscle activity that is characterized by clenching or grinding of the teeth and/or by bracing or thrusting of the mandible, and that is specified as either sleep BR or awake BR, depending on its circadian phenotype" [8]. In healthy individuals, BR should not be considered as a disorder, but rather as a behavior that can be a risk (and/or protective) factor for certain clinical consequences [8]. Indeed, in some individuals this behavior may have positive consequences for the bruxer and reduce the likelihood of a negative health outcome (e.g., being the last episode of respiratory arousals, so as to prevent the collapse or restore the patency of the upper airway whilst asleep) [8]. On the other hand, BR is a sign of certain clinical conditions and symptoms as it has been reported to be associated (without a causal relationship) with various factors and pathologies, such as obstructive sleep apnea, gastro-esophageal reflux, headache or temporo-mandibular disorders (TMDs), such as localized masticatory muscle pain [9-15]. TW (loss of dental hard tissues from the surface by means other than dental caries, trauma or development disorders) particularly mechanical TW, may be an indicator of sleep and awake BR [8]. TW is promoted by changing lifestyles, particularly chemical erosion, which is favored by acidic food/drinks (like sodas) and gastroesophageal reflux (GER) [16, 17], while mechanical wear is often related to the presence of BR, which engenders attrition (from surface TW due to friction) and abfraction (loss of tooth tissue near the junction with gingiva due to mechanical stress) [8] [18]. TW is reported to have a high and increasing prevalence, particularly in young patients [19-22] [23]. An earlier study reported that TW affects 68.8% of the population between 16 and 97 years old in the United States, with 9.6% showing extreme TW [24]. In the Netherlands, moderate and severe TW affected 80% and 6% of the adult population, respectively [22]. In severe TW cases, patients can suffer from dental pain and psycho-social handicap due to impaired esthetics, masticatory dysfunction, TMDs, masticatory muscles, and orofacial pain due to BR [25, 26], with a significant impact on the oral health-related quality of life [27], requiring complex rehabilitation [28-32].

In 2012, the findings of Hellmann et al. [33] supported the assumption of a relationship between jaw clenching and the activity of the neck muscles, while in 1997 Bader et al. [34] noticed, in a sample of 24 bruxers, that 69% of them complained about neck, back, shoulder, or chest pain. However, there is a lack of data regarding the association between BR or TW (as a symptom of BR) and MSDs (except localized masticatory muscle pain). Consequently, the objective of this cross-sectional study was to investigate the association between BR and MSDs. A secondary objective was to study the association between tooth wear (TW) related to BR and MSDs.

3. Materials and methods

3.1. Study design

The protocol of this cross-sectional study was approved by the Ethics Committee of the University Hospital Center (CHU) of Liege and was conducted in accordance with the guidelines set out in the Declaration of Helsinki as revised in 2000, and all applicable local regulations and standards (file: B707201629113, approved 25/03/2019) and was registered on the ClinicalTrials.gov database (Identifier NCT02150226). Participants in this study underwent a clinical examination and completed self-administered questionnaires.

3.2. Participants and settings

3.2.1. Settings

The study was carried out on patients from the Institute of Dentistry, University Hospital, Liège, Belgium. Between April 2019 and December 2019, any patient with the eligible criteria visiting the dentists appointed as clinical evaluators was asked to participate in the study. Moreover, dental students, dental assistants and dentists working at the Institute of Dentistry and fulfilling the eligible criteria were also asked to participate in the study.

3.2.2. Inclusion/exclusion criteria

Patients were eligible to participate in the study if they were between 18 and 80 years old, had a minimum of 8 teeth with dental tissue in occlusion (minimum 1 tooth per sextant), mastered the language of the survey questionnaires (French), and had the mental capacities necessary to participate in the study. Patients were excluded if they were visiting for a painful dental emergency, were under orthodontic treatment (or had it completed less than 2 months before) or were wearing a one-piece bimaxillary orthodontic retainer (post class 2 treatment). Inclusion was validated after consent signature.

3.2.3. Evaluators

The clinical evaluators were 4 experienced dentists, who are trained clinical researchers of the department of fixed prosthodontics, Institute of Dentistry, University Hospital, Liège, Belgium, and 2 postgraduate students. Evaluators were trained by means of group sessions. After the clinical evaluation, a self-administered questionnaire was given to the participants, while the researchers remained at their disposal for any information during the filling out of the forms.

3.2.4. Participant incentives

The participants received no financial compensation.

3.3. Data collection

3.3.1. Musculoskeletal disorders (MSDs)

The French version of the Nordic questionnaire [35] was used to evaluate the presence of MSDs. The standardized Nordic questionnaire is a validated tool to evaluate the musculo-skeletal health in the context of occupational health [36]. It includes data collection about MSDs confounding factors (see below) and MSDs self-report in 9 regions of the body: neck, shoulder, upper back, low back, hip and thigh, knee, ankle and foot, elbow and wrist and hand. Particularly, it focuses on the reporting of MSDs symptoms presence during the past 7 days, 12 months, and whole life, as well as on the consequences on the patient's professional and leisure activities. In the present study, only data about the presence of MSDs during the past 12 months were used, i.e. answers to the following question for each body region: "In the last 12 months, have you had any problems (aches pain, discomfort) in the following body region: yes or no" (the questionnaire includes filling information and a figure, which shows the different body regions). Moreover, in addition to questions of the Nordic questionnaire, reported pain level in each body region was self-reported on a 10-point scale.

3.3.2. Bruxism (BR)

The presence of sleep and/or awake BR was based on clinical inspection and self-report with a questionnaire. Particularly, sleep BR was assessed according to the criteria of the American Academy of Sleep Medicine, and the patient was categorized as sleep bruxer if he/she fulfilled at least two criteria: A) reporting of tooth grinding during the night (including the presence of grinding noise reported by bed partner); B) the presence of at least one clinical sign among the following: presence of attrition wear facets on the teeth (mechanical TW); transitory pain or fatigue on waking felt in the jaw muscles; temporal headaches on waking; and jaw locking on waking related to teeth grinding during sleep [37] [23]. For awake BR, AASM criteria were adapted, and the criteria A was defined as clenching and/or bracing/thrusting the teeth at work or when concentrating on a specific task, clenching and/or bracing/thrusting the teeth, playing with muscles bracing teeth, and tooth grinding during the day. Before answering the questionnaire, the clinical evaluator made the patient aware of what is meant by clenching and bracing/thrusting, most easily defined as the teeth touching not for swallowing purposes, and as increased levels of masticatory muscle activity without tooth contacts, respectively [38].

In addition, a masticatory muscles examination was carried out to complete information about BR symptoms in the studied population:

- Masseteric hypertrophy: The presence of jaw asymmetry at rest, important muscle volume increase (around 3 times) when clenching, or concavities on the lower edge of the mandibular bone at the place of muscle insertion (called gonial eversion, visible on the panoramic radiograph if available), was recorded. The presence of nodules (muscle contraction) on muscle palpation was also recorded.
- Pain on palpation: Pain on palpation, by applying a 1kg pressure approximatively, with three fingers (index, major and annular) and going through the whole muscle, was recorded for both pairs of the masseters, temporal and sternocleidomastoid muscles. During that examination, teeth were in occlusal contact but without clenching. For pressure application, the evaluators were trained using a scale. The presence of muscular tension in the sternocleidomastoid muscles was also evaluated.

3.3.3. Tooth wear (TW)

3.3.3.1 TW evaluation

The Basic Erosive Wear Examination index (BEWE) [39] was used to quantify TW. Two cumulative scores were calculated: the global score (as presented by Bartlett et al.) [39] and the anterior score, the latter considering only sextants 2 and 5.

3.3.3.2 TW type determination

TW was assessed as being mechanical and/or chemical. The presence of mechanical TW was recorded in the presence of attrition facets eventually associated with the presence of other BR clinical signs, such as tooth cracks/fractures, linea alba, exostoses, crenated tongue, masseteric hypertrophy or pain on masticatory muscle palpation [37][38]. The presence of chemical TW was recorded in the presence of dental erosion surfaces (concave, cuneiform or flat lesions) eventually associated with the presence of chemical TW risk factors related to nutrition habits (e.g. consumption of acidic food/drinks), general diseases (e.g. gastro-esophageal reflux presence), medications and environmental factors, which were recorded in a questionnaire.

3.3.4. Confounding factors

3.3.4.1 Socio-demographic data

The self-administered questionnaire included the collection of data about the patients' age, sex, socio-professional status, level of education and perception of income level.

3.3.4.2 Nordic questionnaire related data

The general information part of the Nordic questionnaire includes data collection about the body mass index (BMI), work schedules and physical workload (light, average, heavy or very heavy) of the patients.

3.3.4.3 Medical data

Data were collected about participants' medical background, particularly about factors reported to be associated with BR, TW or MSDs. Those data included the presence of cervical trauma history, motor or neuronal disorders, sleep apnea diagnostic and gastro-esophageal reflux.

3.3.4.4 Life habits

Life habits in terms of smoking and physical activity (at least 2h30 of moderate activity or 75 minutes of intense activity per week) were recorded. The regular use of an occlusal night-guard was also recorded.

3.3.4.5 Stress

The level of stress was measured using the Perceived Stress Scale 14 (PSS14) developed by Cohen et al., 1983 [40]. The questionnaire consists of 14 items. Each patient was asked to rate the frequency of his/her stress feelings on a 5-point Likert scale from a score of 0 "never" to a score of 4 "very often". For items 4-7, 9, 10 and 13, the scale was reversed (score 0; very often and score 4; never). The total score is calculated by summing the scores of the 14 items.

3.4. Data management

Data were collected, stored and processed in the Department of Fixed Prosthodontics, Institute of Dentistry, University Hospital, Liege, Belgium. Patients were identified by their inclusion number in order to preserve their privacy. Data encoding was double-checked, and database quality was verified by a data manager. Only the data manager and the statisticians have unrestricted access to the database.

3.5. Statistical analyses

3.5.1. Sample size

In order to determine the number of subjects to be included in the present study, a power calculation based on the width of the confidence interval for a proportion was performed. Specifically, as there was no data available on the prevalence of musculoskeletal disorders and associated BR/TW, the power calculation was performed using a proportion of 50%. This proportion, thus, allows the sample size to be maximized. The precision was set at 5%, so the sample size was 385 subjects.

3.5.2. Statistical analysis

The results are expressed as median and interquartile range (P25-P75) due to skewed distribution. Normality was investigated by comparing means and medians, investigating graphically histograms and Q-Q plots and performing the Shapiro-Wilk test. Categorical variables are summarized using numbers and frequencies (%). The association between BR and each MSD/presence of at least one MSD was investigated using a Chi-square test or Fischer's exact test if the conditions of application were not met while the association between the global (resp. anterior) TW and each of the musculoskeletal disorders (MSDs)/ presence of at least one MSD was analyzed using a non-parametric Kruskal-Wallis test. Same analyses were performed between each of the MSDs/presence of at least one MSD and the following confounding factors: age, BMI, stress, sex, perception of income receipt, tobacco, physical activity, gastro-esophageal reflux, cervical trauma history, motor neurone disorders, occlusal nightguard wearing, sleep apnea, work schedules and workload. A multivariate binary logistic regression was then performed to test the association between global TW (resp. anterior and bruxism) and each MSD/presence of at least one MSD, controlling for significant confounding factors. The results will be presented as an odds ratio (OR) with the corresponding 95% confidence interval (95% CI). A Firth correction was applied when necessary. The association between the clinical signs of BR and being a bruxer or not was tested using the Chi-square test or Fisher's exact test. The results were considered significant at the 5% uncertainty level ($p < 0.05$). Calculations were always performed on the maximum number of observations available. The statistical software used was SAS 9.4 (for Windows).

4. Results

A total of 425 patients (41.1% men and 58.9% women) were included in the study between April and December 2019. The median age (P25-P75) was 38 (26-54) years.

4.1. Prevalence of MSDs and BR- BEWE TW scores

Results about the prevalence of awake and sleep BR and BEWE cumulative scores for global and anterior TW are presented in Table 1. The median (P25-P75) global BEWE score in the sample was 7 (5-10) and the median anterior score was 4 (2-4). The TW etiology was mainly mechanical: only 1.9% of the sample had only chemical TW, while 67.0% had only mechanical TW and 28.5% had both (only 2.6% did not show TW). Results about the prevalence of MSD and related pain levels (distinguishing the 9 regions of the body of the Nordic questionnaire) are presented in Table 2. The most often reported MSDs were neck and lower back pain (65.0 and 60.3% of the studied sample, median pain level of 5 on 10), while 91 % of the participants reported at least one MSD.

Bruxism	n tot	Global (%)	Awake Bruxism n (%)	Sleep Bruxism n (%)	Sleep ad Awake Bruxism n (%)
	425	321 (75.5)	303 (71.3)	178 (41.9)	160 (37.7)

Tooth Wear BEWE score	n tot	Global score (P25 - P75)	Antérior score (P25-P75)
	421	7 (5-10)	4 (2-4)

Tab 1 Prevalence of BR (distinguishing awake and sleep BR) and BEWE cumulative scores expressed as median and interquartile range (P25-P75) for global and anterior TW.

	MSD - Prevalence n (%) n tot = 423	Median pain level (P 25-P75) n tot = 423
At least 1 TMS	386 (91.0)	NA
Neck	275 (65.0)	5 (3-7)
Lower back	255 (60.3)	5 (3-6.5)
Upper back	187 (44.2)	5 (3-6)
Shoulder	183 (43.3)	5 (3-6)
Knee	147 (34.8)	4 (3-6)
Wrist/Hand	120 (28.4)	5 (3-6)
Ankle/Foot	101 (23.9)	5 (3-6)
Hip/Thigh	98 (23,2)	5 (3-7)
Elbow	48 (11.3)	4 (2-6)

Tab 2 Prevalence of Musculo-skeletal disorders (MSD) and related pain levels (distinguishing the 9 regions of the body analyzed in the Nordic questionnaire) expressed as median and interquartile range (P25-P75).

4.2. BR diagnostic criteria

Results about the prevalence of the different BR diagnostic criteria in the studied population are presented in Table 3. Patients fulfilling at least one criteria A and one criteria B were categorized as bruxers (awake and/ or sleep). The association between the bruxers population and other BR clinical signs related to masticatory muscles (see 2.3.1.1) is also presented. All those clinical signs were shown to be significantly more present in the bruxers population, except masseter muscle hypertrophy and gonial eversion (Table 3).

BR Diagnostic Criteria A	n tot	Yes; n (%)
Tooth grinding-awareness (by night)	425	85 (20.0)
Tooth grinding-sound (by night)	424	78 (18.7)
Feeling of tooth clenching (upon awakening)	422	145 (34.3)
Tooth clenching (during activity)	424	260 (61.4)
Jaw muscle clenching (by day)	424	189 (44.6)
Feeling of tooth clenching (by day)	423	210 (49.3)

BR Diagnostic Criteria B	n tot	Yes; n (%)
Abnormal tooth wear (presence of attrition facets; BEWE≥1)	425	415 (97.6)
Jaw muscle pain or fatigue (upon awakening)	425	125 (29.4)
Temporal pain (upon awakening)	423	84 (19.9)
Jaw locking (upon awakening)	425	27 (6.4)
Jaw muscle pain or fatigue (by day)	425	130 (30.6)
Temporal pain (by day)	425	92 (21.6)

Other BR clinical signs	n tot	Yes; n (%)	Prevalence in the BR population (%)	Association with BR diagnostic (p value)
Jaw asymmetry	417	92 (21.7)	25.6	0.00019*
Masseter muscle hypertrophy	425	94 (22.7)	24.4	0.14
Gonial eversion	416	154 (37.0)	34.7	0.087
Nodules in the masseter	403	171 (42.4)	47.2	0.0008*
Pain on masseter muscle palpation	422	164 (38.9)	44.8	<.0001*
Pain on temporal muscle palpation	422	104 (24.6)	29.8	<.0001*
Pain on sterno-cleido-mastoid muscle palpation	422	190 (45.0)	50.2	0.0002*
Sterno-cleido-mastoid tension	421	253 (60.1)	63.8	0.0059*

Tab 3 Prevalence of the different bruxism (BR) diagnostic criteria examined in the studied population (patients fulfilling at least one criteria A and one criteria B were categorized as bruxers) and prevalence of other BR clinical signs related to masticatory muscles in the bruxers population specifically, with results of statistical analysis. * Indicates that a significant association was detected between the BR diagnostic and the presence of muscular pain ($p < 0.05$).

4.3. Association between BR, TW and the presence of at least one MSD

Results related to the association between the presence of at least one MSD and the studied parameters (socio-demographic factors, medical history, life habits and stress) are presented in Table 4.

After multivariate analysis, BR and anterior TW were shown to be significantly associated with the presence of at least one MSD ($p < 0.0001$ and $p = 0.0076$, respectively) (Table 5). The presence of sleep BR only was not associated with the presence of at least one MSD, unlike the presence of awake, or awake and sleep BR (Table 5). Age, stress and cervical trauma history were also shown to be independently and significantly associated with the presence of at least one MSD.

		At least one MSD				
	Yes		No			
Variables	Categories	n	Value (%)	n	Value (%)	p-value
Age (years) Median (Q1 – Q3)		380	39.0 (27.0 – 54.0)	36	32.0 (23.0 – 44.5)	0.019*[1]
Sex	 Men Women	384	 160 (41.7) 224 (58.3)	37	 13 (35.1) 24 (64.9)	0.44[2]
BMI (kg/m²) Median (Q1 – Q3)		376	23.7 (21.2 – 26.7)	36	21.8 (19.9 – 25.0)	0.088[1]
Income receipt	 Difficult Easy	380	 81 (21.3) 299 (78.7)	36	 5 (13.9) 31 (86.1)	0.29[2]
Smoking	 Non-smoker Smoker Ex-smoker	386	 263 (68.1) 61 (15.8) 62 (16.1)	37	 30 (81.1) 2 (5.4) 5 (13.5)	0.18[2]
Physical activity	 No Yes	379	 102 (26.9) 277 (73.1)	37	 10 (27.0) 27 (73.0)	0.99[2]
Gastro-esophageal reflux	 372 No Yes		 36 280 (75.3) 92 (24.7)		 0.14[2] 31 (86.1) 5 (13.9)	
Cervical trauma history	 Non Oui	381	 342 (89.8) 39 (10.2)	36	 36 (100.0) 0 (0.0)	0.037*[3]

Physical workload		347		32		0.52(2)
	Light		216 (62.2)		23(71.9)	
	Average		78 (22.5)		6(18.8)	
	Heavy/very heavy		53 (15.3)		3(9.4)	
Motor/neuronal disorders		380		36		1.00(3)
	Non	371 (97.6)		36 (100.0)		
	Oui	9 (2.4)		0 (0.0)		
Stress score Median (Q1 - Q3)		382	22.0 (18.0 - 28.0)	37 (15.0 - 24.0)	20.0	0.040*(1)
Occlusal nightguard wearing		382		37		0.81(3)
	No		319(83.5)		33(89.2)	
	Yes regularly		45(11.8)		3(8.1)	
	Yes rarely		18(4.7)		1(2.7)	
Work schedules		283		25		0.25(2)
	Regular		195(68.9)		20(80.0)	
	Flextime		88(31.1)		5(20.0)	
Sleep apnea		386		37		0.22(3)
	No		356(92.2)		35(94.6)	
	Yes		22(5.7)		1(2.7)	
	Before		7(1.8)		0(0.0)	

(1) Non-parametric Mann-Whitney test
(2) Chi-squared test
(3) Fisher exact test

Tab 4 Results related to the association between the presence of at least one MSD and the confounding factors (socio-demographic factors, medical history, life habits and stress). (1): Non-parametric Mann-Whitney test. (2): Chi-squared test. (3): Fisher exact test. * Indicates that a significant association was detected ($p < 0.05$).

4.4. Association between BR, TW and MSDs per body region

Figure 1 shows the results of the multivariate analyses performed for each of the 9 regions of the body evaluated, indicating the different regions affected by MSDs, which were significantly associated with the presence of BR, anterior TW and/or global TW, with their corresponding OR. All OR were adjusted for significant confounding factors among age, BMI, stress, sex, perception of income receipt, tobacco, physical activity, gastro-esophageal reflux, cervical trauma history, motor neurone disorders, occlusal nightguard wearing, sleep apnea, work schedules and workload. Figure 1 also indicates the confounding factors which were shown to be significantly associated with MSDs in those regions.

Variables	At least one MSD n=386 (91.0%)	No MSD n=37 (9.0%)	p-value(1)	OR (95% CI)(2)	Adjusted p-value(2)
	N = 386	N = 37			
Bruxism n (%)	304 (78.8%)	16 (43.2%)	< 0.0001*	5.88 (2.7 - 12.5)	< 0.0001*
Bruxism n (%)			<0.0001*		0.0001*
Awake	133 (41.5%)	10 (27.0%)		4.27 (1.82 -10.0)	0.0008*
Sleep	18 (5.6%)	0 (0.0%)		8.96 (0.47 -170.9)	0.14
Awake/sleep	153 (47.8%)	6 (16.2%)		7.36 (2.68 -20.2)	0.0001*
	N = 384	N = 36			
Global TW Median (Q1 - Q3)	8.00 (5.00 - 10.00)	6.00 (3.00 - 7.50)	0.003*	1.09 (0.99 - 1.21)	0.087
	N = 384	N = 36			
Anterior TW Median (Q1 - Q3)	4.00 (2.00 - 4.00)	2.00 (2.00 - 4.00)	< 0.0001*	1.53 (1.12 - 2.08)	0.0076*

Tab 5 Results related to the association between the presence of at least one MSD and BR, global TW and anterior TW respectively, with corresponding Odds ratios (OR) and related 95% confidence intervals). P value are presented after adjustment by age, stress and cervical trauma. * Indicates that a significant association was detected ($p < 0.05$). (1): Univariate analysis. (2): Adjusted by age, stress and cervical trauma.

5. Discussion

In the present study, BR was associated with a 5-fold increased risk of prevalent MSD (OR=5.88 (2.7-12.5), p<0,0001) and for one-point increase in anterior TW score, the risk to present an MSD was increased by 53% (OR=1.53 (1.12-2.08), p=0.0076). Additionally, the influence of age, stress and cervical trauma history on MSDs prevalence were also highlighted. This study on the presence of a MSD per body region also demonstrates the influence of global TW and reveals the influence of other parameters, such as BMI and workload, which constitute well-known risk factors of MSDs. More specifically, BR was independently associated with neck, shoulder, upper back, low back, hip and thigh, and knee MSDs, while anterior TW was associated with neck, low back and hip and thigh, and global TW was associated with knee MSDs. Odds ratios were found to be particularly high for BR in some regions, such as neck (OR=3.05 (1.88-4.92)).

In our sample, BR prevalence was very high (75.5%), awake BR being more frequent than sleep BR (71.3% versus 41.9% of the sample, respectively), which is much higher than the general picture obtained from the literature. However, the objective of this study was not to determine BR prevalence among the local population, and the studied sample was not

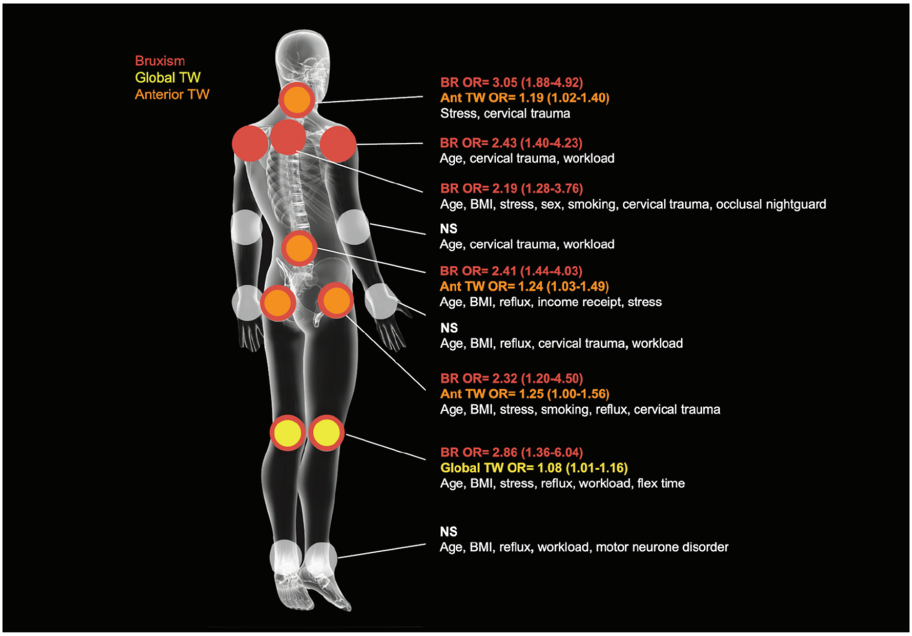

Fig 1 Results of the multivariate analyses performed for each of the 9 regions of the body evaluated, indicating the different regions affected by MSDs, which were significantly associated with the presence of bruxism (BR), anterior tooth wear (TW) and global TW (in red, orange and yellow, respectively, with corresponding Odds ratios (OR) and related 95% confidence intervals). All OR were adjusted for significant confounding factors among age, BMI, stress, sex, perception of income receipt, tobacco, physical activity, gastro-esophageal reflux, cervical trauma history, motor neurone disorders, occlusal nightguard wearing, sleep apnea, work schedules and workload. NS= no significant association detected. The figure also indicates the confounding factors which were shown to be significantly associated with MSDs in those regions.

designed to be representative of this population. It was constituted of patients and personnel frequenting the University Hospital, particularly regular patients of the evaluators, who may treat a significant number of patients for bruxism-related TW. However, it can be suspected that BR prevalence is higher than usually reported. The prevalence of MSDs in the studied sample was also found to be very high (91% of patients reported at least one MSD during the preceding 12 months). The sensitivity of the Nordic questionnaire being reputed to be very good [41], the high MSD prevalence can be explained by the fact that the questionnaire explored symptoms in the past year, which is a long period of time, and included all pain levels, even low-level pain. It should also be noted that in the recent systematic review and meta-analysis on the prevalence of work-related MSDs in secondary industries, back, shoulder and neck MSDs can reach 12-month prevalence values in the range of 70-80% [3]. Neck and low back pain were the more frequently reported MSDs (65% and 60.3% of the sample, respectively), which confirms results of the world global burden of disease report [6]. It must be noticed that the median pain levels were found to be moderate in all regions (median pain levels between 4 and 5 out of 10).

Some MSDs were previously reported to be related to body posture [42, 43] and a few studies have shown a correlation between the stomatognathic system and the body posture, although this topic is highly controversial [43-46]. Some authors highlighted a correlation between jaw position and body posture [47-49], or masticatory dysfunction and neck pain [50], while other authors have reported that there is no link between dental occlusion and the full body [51]. However, a good balance between the masticatory muscles and the head and neck muscles seems to be an important factor for postural stability [52, 53], and some studies have underlined the need to achieve an interdisciplinary approach in complex treatments combining dentists, physiotherapists and posturologists [54, 55]. Posturology studies the relationship between posture and different pathologies, above all the chronic pain, but there is a lack of scientific evidence in that field [56, 57], while postural sway is also analyzed in the field of sport [58]. In particular, the concept of muscular chains was introduced in the seventies by Françoise Mézières [59]. The idea is to stretch at the same time all the muscles contained in a group called muscular chain to correct posture, working with body alignment [42]. Within a muscular chain, muscles are positioned in a longitudinal manner following the same direction and are connected through fascia [49], which are considered by some authors as an important element in musculoskeletal pain, since they can transmit mechanical tension generated by muscular activity through the body. This explanation could support the influence of BR on MSD, and one hypothesis is that reducing BR could, in turn, reduce MSDs. Yet, the effect of physiotherapy and behavioral change strategy in BR treatment has been poorly studied [60], even if there is some evidence to support the use of occlusal splints plus massage or botulinum toxin to reduce related chronic pain [61]. In the present study, the presence of sleep BR alone was not associated with the presence of MSD (Table 5). One hypothesis is that most bruxistic episodes in sleep BR are phasic (grinding) with a few tonic or sustained contractions in contrast to clenching/bracing whereas awake BR is generally characterized by more sustained contractions, and has been reported to cause more orofacial muscular pain than SB [62-64]. However, these findings should be interpreted with caution due to the small sample size (n=18) of patients with sleep BR only. In any case, results of the present study suggest that the body is a whole and that some phenomenon can have long-distance effects.

The main challenge and limitation of the present study is related to BR diagnostic. Indeed, BR diagnostic approaches can be non-instrumental, involving self-report (possible awake/sleep BR, following the bruxism assessment grading system proposed by the international consensus), or clinical inspection (probable awake/sleep BR), or instrumental using polysomnography (PSG) or electromyography (EMG), which are reported to increase diagnostic reliability (definite awake/sleep BR) [8]. However, the use of an instrumental approach in a large sample size, such as the one calculated for this cross-sectional study, was not feasible. The BR diagnostic is complex, which explains that prevalence data are variable and restricted, particularly for awake BR (reported prevalence is 22-30% for awake BR and 1-15% for sleep BR, a prevalence up to 49% being observed in younger patients) and instrumental approaches are poorly used [10]. If attrition (mechanical TW) is an indicator of awake and sleep BR, it does not allow to exclude a past sleep BR without current activity [8], highlighting the importance of self-report and clinical inspection of other symptoms of BR. In the present study, a self-report based on an important questionnaire filled by the patient after its education by the evaluator, was combined with an in-depth clinical inspection of reported BR clinical signs, including examination of masticatory muscles. This inspection was conducted by trained evaluators. Special attention was paid to slight attrition facets, since BR can induce only slight damage to dental hard tissues, particularly in young people or in case of predominance of clenching habits (which do not engender a friction effect) (Figure 2). This fact explains the introduction of an anterior TW score in the present study,

Fig 2 Pictures of a young bruxer patient showing an early stage of TW, with only a few mild facets of enamel attrition in the anterior area. This mechanical TW is combined to a dental fissure on #41 and masseter hypertrophy characteristic of BR, which she reports. This Figure shows that BR activity is not proportional to the amount of hard tissue loss while a mechanical TW limited to the anterior area is typical of BR involving mandibular thrust.

and the TW degree of severity was shown to be higher in the anterior region than globally (median BEWE anterior score of 4 on 6 versus 7 on 18 for the global score) (Table 1). The presence of attrition facets was the most often observed B criteria for defining BR (Table 2).

The analysis of the population defined as bruxers (Table 3) shows that this population had also significantly more BR masticatory muscle-related symptoms than the rest of the sample, which supports the BR assessment method used. It can also be noticed that an important part of bruxers reported clenching during the day, which is a symptom that cannot be disputed. The future perspective of our research is that we may need to involve multidisciplinary research teams in health care in order to analyze the complex relationships observed and to define the role of the dentists in MSD management and prevention, especially with respect to BR diagnostic and treatment.

6. Conclusion

Within the limitations of the present study, BR and TW, particularly mechanical TW, which constitutes a BR symptom, were shown to be associated with MSDs. Further research is needed to confirm those results and more particularly a longitudinal study will be needed to assess if BR or TW are real risk factor for MSDs incidence. Results suggest that the body is a whole, a balanced muscular system, where every part plays its role as a link of the chain.

7. Author contributions: credit author statement

Amélie K. Mainjot: conceptualization, methodology, validation, investigation, data curation, writing-original draft, writing-review & editing, visualization, supervision, project administration; **Julie Oudkerk**: validation, formal analysis, investigation, writing-review & editing; **Sandrine Bekaert**: validation, formal analysis, data curation, writing-review & editing, project administration; **Nadia Dardenne**: statistical analysis, writing-review & editing; **Sylvie Streel**: methodology, writing-review & editing; **Vinciane Koenig**: investigation, writing-review & editing; **Charlotte Grenade**: investigation, writing-review & editing; **Anoushka Davarpanah**: investigation, writing-review & editing; **Anne-Françoise Donneau**: methodology, statistical analysis, writing-review & editing; **Bénédicte Forthomme**: methodology, validation, writing-review & editing, **Olivier Bruyère**: validation, visualization, methodology, writing-review & editing.

8. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationship that could have appeared to influence the work reported in this paper.

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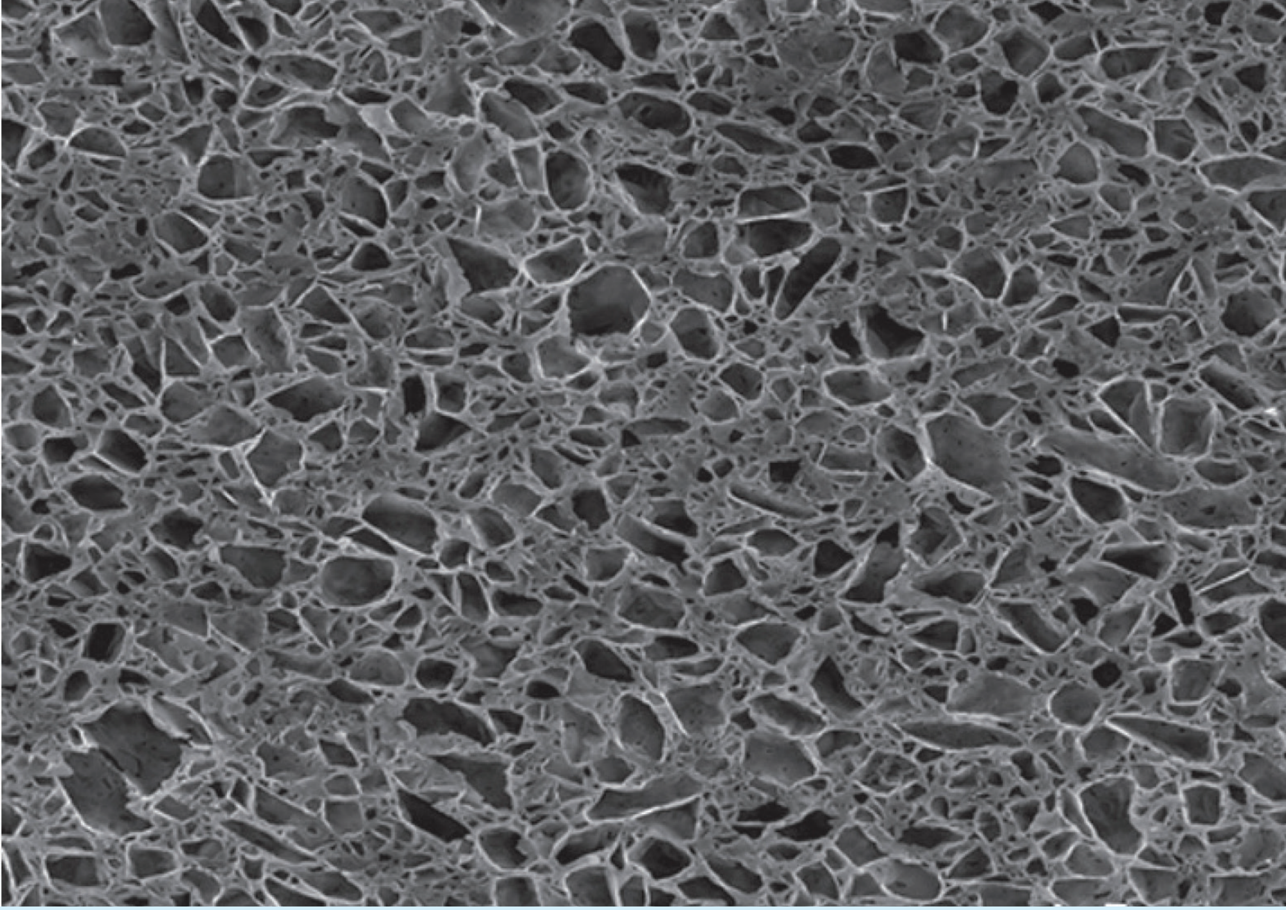

Chapter

5

From Artisanal to CAD-CAM Blocks: State of the Art of Indirect Composites

Journal of Dental Research 1–9

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1. Abstract

Indirect composites have been undergoing an impressive evolution over the last few years. Specifically, recent developments in computeraided design–computer-aided manufacturing (CAD-CAM) blocks have been associated with new polymerization modes, innovative microstructures, and different compositions. All these recent breakthroughs have introduced important gaps among the properties of the different materials. This critical state-of-the-art review analyzes the strengths and weaknesses of the different varieties of CADCAM composite materials, especially as compared with direct and artisanal indirect composites. Indeed, new polymerization modes used for CAD-CAM blocks—especially high temperature (HT) and, most of all, high temperature–high pressure (HT-HP)—are shown to significantly increase the degree of conversion in comparison with light-cured composites. Industrial processes also allow for the augmentation of the filler content and for the realization of more homogeneous structures with fewer flaws. In addition, due to their increased degree of conversion and their different monomer composition, some CAD-CAM blocks are more advantageous in terms of toxicity and monomer release. Finally, materials with a polymer-infiltrated ceramic network (PICN) microstructure exhibit higher flexural strength and a more favorable elasticity modulus than materials with a dispersed filler microstructure. Consequently, some high performance composite CAD-CAM blocks—particularly experimental PICNs—can now rival glass-ceramics, such as lithium-disilicate glass-ceramics, for use as bonded partial restorations and crowns on natural teeth and implants. Being able to be manufactured in very low thicknesses, they offer the possibility of developing innovative minimally invasive treatment strategies, such as "no prep" treatment of worn dentition. Current issues are related to the study of bonding and wear properties of the different varieties of CAD-CAM composites. There is also a crucial need to conduct clinical studies. Last, manufacturers should provide more complete information regarding their product polymerization process, microstructure, and composition, which significantly influence CAD-CAM material properties.

KEYWORDS

polymer-infiltrated ceramic network, high temperature–high pressure polymerization, mechanical properties, toxicity, degree of conversion, minimally invasive dentistry

2. Introduction

Nowadays, dental composites represent a wide and complex variety of materials with an increasing range of properties and indications. The latest developments of computer-aided design–computer-aided manufacturing (CAD-CAM) blocks are especially associated with new polymerization modes, innovative microstructures, and different compositions. All these changes have introduced important gaps among the different classes of indirect composites (ICs) in terms of mechanical properties, chemical stability, biological properties, bonding properties, and long-term performance probability, notably in comparison with ceramic materials (Coldea et al. 2013; Nguyen et al. 2014; Phan et al. 2014; Awada and Nathanson 2015; Swain et al. 2015). These recent and rapid breakthroughs are sometimes associated with confusion about the specific characteristics of emerging materials, which is augmented by incomplete or misleading information delivered by companies. Currently, some materials are listed either as ceramic-like or in composite materials, under a large variety of names, such as resin nanoceramics, hybrid ceramics, resin-matrix ceramics, double-network materials, ceramic-based interpenetrating-phase composites, or polymer-infiltrated ceramic network (PICN; Denry and Kelly 2014; Gracis et al. 2015). Consequently, the aim of this work is to critically review the global evolution of ICs to understand their respective properties and the contribution of new materials to treatment strategies improvement.

3. Classification of Current ICs

The most important characteristics differentiating and influencing the main properties of current ICs are related to 1) the type of manufacturing process (artisanal vs. industrial CADCAM blocks), 2) the microstructure (with dispersed fillers vs. PICN), 3) the mode of polymerization (light, high temperature [HT], or high temperature–high pressure [HT-HP]), 4) the resin matrix composition, and 5) the filler size and volume content. The table intro duces a classification that takes into account those considerations and includes most current ICs. Note that information delivered by companies on their websites is often misleading or incomplete, particularly regarding the mode of polymerization and the composition.

A supplemental appendix to this article is published electronically only at http://jdr.sagepub.com/supplemental.

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3.1. Artisanal

Artisanal ICs are handmade buildups like direct composites. Their composition and structure are also identical, but they are incrementally photopolymerized extraorally, which avoids the negative effect of polymerization shrinkage stress on residual tooth structure or cavity margins (Ferracane and Hilton 2015). Many factors can affect the polymerization efficiency of lightactivated resin composites—such as the light-curing unit, the curing parameters (irradiation time and mode, irradiance, radiant exposure), the temperature, the material composition (photoinitiator, monomers, fillers, shading pigments), its viscosity, and its optical properties (Leprince et al. 2013). Consequently, the degree of conversion is limited and operator dependent, and reported *in vitro* values for light-activated composites, either direct or indirect, vary from approximately 40% to 75%, depending on the different parameters (Ferracane and Condon 1992; Imazato et al. 2001; Ribeiro et al. 2012; Calheiros et al. 2014). Moreover, as the irradiance varies from the surface to the depth, the polymerization is inhomogeneous, which generates internal stress within the material (Nguyen et al. 2012). These disadvantages have a negative impact on mechanical properties and the release of free monomers (Ferracane 1994; Ferracane et al. 1997; Chen et al. 2005; Lin-Gibson et al. 2009; Van Landuyt et al. 2011; Nguyen et al. 2012; Gupta et al. 2012).

The current generation of artisanal ICs is mainly composed of microhybrid materials. For some products, specific curing units were developed that allow the complementary application of temperature (>100 °C). Postcure heating was shown to improve degree of conversion (Ferracane and Condon 1992) and flexural strength (Sedda et al. 2010) and to reduce the unreacted monomers remaining in light-cured composites (Bagis and Rueggeberg 2000). The hypotheses are that temperature can increase 1) volatilization of unreacted monomers and 2) double-bond conversion, mobility of monomers, and polymer chains, promoting cross-linking (Ferracane and Condon 1992; Bagis and Rueggeberg 2000). Yet, the diffusion of free monomers—and, hence, their reactivity after a photopolymerization process—is limited due to the augmentation of the viscosity (Leprince et al. 2013), which could explain that the degree of conversion increase is also limited. Indeed, Ferracane and Condon (1992) showed that a postcure at 120 °C can increase, depending on the composite material, the degree of conversion from 3% to 18%—with the highest value being, in the bulk of the material, 75% for a 10-min treatment and 78% for a 3-h treatment. However, the temperature can promote a chemopolymerization process if the material contains BPO (benzoyl peroxide). Nowadays, the range of available artisanal ICs is decreasing in favor of the development of CAD-CAM blocks.

3.2. CAD-CAM Blocks

CAD-CAM processes have recently revolutionized the world of ICs, introducing high-performance materials that are industrially produced and secondarily milled. Industrial processes used to produce CAD-CAM blocks increase material homogeneity, decrease the presence of flaws and pores, and increase their reliability, in comparison with hand-built materials (Giordano 2006). They also allow for the augmentation of the filler volume content: this is not possible with direct composites, which need to be sufficiently plastic for the restoration buildup. Recent CAD-CAM blocks do not contain any bisphenol A-glycidyl methacrylate (Bis-GMA), and they are no longer photopolymerized—with high-performance industrial polymerization processes involving HT (>100°C) and sometimes HP (>150 MPa) having been developed (Sadoun 2011; Nguyen et al. 2012). The composite class of CAD-CAM blocks should be divided into 2 subclasses, depending on their micro-structure: with dispersed fillers and PICN materials.

With dispersed fillers. Paradigm MZ100 (3M ESPE, St. Paul, MN, USA) was the first marketed CAD-CAM block in the years preceding 2010. It contains 85 wt% of zirconia-silica fillers in a Bis-GMA and triethylene glycol dimethacrylate (TEGDMA) matrix: its composition is similar to Z100 direct composite from the same company. Paradigm MZ100 block is simply photopolymerized and is considered to be like a Z100 block, without any original properties (Nguyen et al. 2013). Then, 3M introduced its "nanoceramic" called Lava Ultimate. Lava Ultimate has a 79 wt% of zirconia-silica nanofillers (in the form of dispersed or aggregated particles) and constitutes a nanofill composite, with the same kind of fillers as direct composites. The real improvements lie in the matrix, which is here composed of urethane dimethacrylate (UDMA) and is totally heat rather than photo polymerized. UDMA has a higher concentration of double bonds than Bis-GMA: it was shown to reach a higher degree of conversion and cross-linking and to exhibit a higher polymerization reactivity with light curing (Sideridou et al. 2002). Light-cured UDMA also exhibits a lower water sorption and solubility than Bis-GMA (Sideridou and Karabela 2011), which can prevent alteration of material properties and water-soluble color pigment absorption. Unlike Bis-GMA, UDMA does not necessarily require the addition of TEGDMA as a diluent to lower the viscosity. In fact, TEGDMA has a higher concentration of double bonds, and when mixed with Bis-GMA, it increases the degree of conversion and cross-linking (Sideridou et al. 2002), but it induces more polymerization shrinkage (Goncalves et al. 2011).

Manufacturing Process	Microstructure	Polymerization Mode	Material	
Artisanal	Dispersed Fillers	Light	Ceramage & Ceramage up	
			Gradia	
			Signum	
			Sinfony	
			Solidex	
			SR Nexco	
			VITAVM LC	
		Light + temperature complement	Estenia C&B	
			SR adoro	
			Twiny	
Industrial	Dispersed Fillers	Light	Paradigm MZ 100 block	
		HT	Cerasmart	
			Lava Ultimate	
			Shofu block HC	
	PICN	HT/HP	VITA Enamic	

The table comprises most of the currently marketed indirect composites. The main composition of the organic matrix, the filler content, and the polymerization mode of each product were obtained from available manufacturers' data, when possible.
Bis-GMA, bisphenol A-glycidyl methacrylate; clusters, aggregated nanoparticles; composite, prepolymerized composite; DMA, dimethacrylates; HP, high pressure; HT, high temperature; PICN, polymer-infiltrated ceramic network—the glass-ceramic network is composed of different oxides

Manufacturer	Main Composition	
	Matrix	Filler
Shofu	UDMA (+ HEMA in opaque paste)	Silica-based glass
GC Corp	UDMA + other DMA	Unknown
Heraeus Kulzer	Unknown DMA	Silica + composite (74 wt%)(64 wt% silica-based glass+ silica in Signum flow)
3M-ESPE	UDMA + other DMA	Silica-based glass +silica
Shofu	UDMA	Unknown
Ivoclar-Vivadent	UDMA + other DMA	Silica (10-50 nm) + composite (for liner and opaque : + zirconia + silica-based glass)
VITA Zahnfabrick	BPA + TEGDMA + other DMA	Unknown
Kuraray	Unknown DMA (+Bis-GMA in opaque paste)	Silica-based glass + alumina (2 µm and 2nm) (92 wt% / 82 Vf%)
Ivoclar-Vivadent	UDMA + other DMA	Silica-based composite
Yamamoto, Precious Metal Co	UDMA + TEGDMA	Silica (20-100nm) + zirconia-, alumina-, silica-particles (200-600nm) + zirconia- aluminasilica-clusters (1-6 µm)
3M ESPE	Bis-GMA + TEGDMA	Silica (0.6 µm) + zirconia (0.6 µm)(85wt%)
GC America	UDMA + other DMA [a]	Silica-based glass + silica (20 and 300 nm (71wt%) [a]
3M ESPE	UDMA	Silica (20 nm) + zirconia (4-11 nm) + zirconia-silica clusters (0.6-10 µm)(79 wt%)
Shofu	UDMA+TEGDMA	Silica-based glass + silica (61 wt%) [a]
VITA Zahnfabrik	UDMA+TEGDMA	Glass-ceramic sintered network (86 wt%/ 75 Vf%)

in amorphous or crystalline form (silica (SiO_2), alumina (Al_2O_3), sodium oxide (Na_2O), potassium oxide (K_2O), boron trioxide (B_2O_3), zirconia (ZrO_2), calcium oxide (CaO); TEGDMA, triethylene glycol dimethacrylate; temperature complement, heating process >100 °C occurring in a specific curing unit after photopolymerization; silica-based glasses, silicates ($[SiO_4]^{4-}$) containing other elements, such as barium, fluorine, bore, aluminum, zirconium, strontium; UDMA, urethane dimethacrylate.
[a]Data were completed following Stawarczyk et al. (2015).

Tab 1 Classification of Indirect Composites Based on Their Manufacturing Process, Microstructure, and Polymerization Mode.

Recently, GC (GC Corporation, Tokyo, Japan) and Shofu (Shofu Inc., Kyoto, Japan,) marketed Cerasmart and Shofu Block HC, respectively, as part of the “hybrid ceramic” group of materials. “Hybrid ceramic” is a confusing commercial name that does not refer to material science notions and does not reflect the real properties of materials. In reality, even if the composition or the filler size is not exactly the same, these new composite blocks are all dispersed filler materials with a UDMA-based matrix, which is HT polymerized (see Table), and can be considered as part of the same family from a mechanical point of view when compared with ceramic and PICN CAD-CAM blocks (Awada and Nathanson 2015).

PICN materials. Inspired by glass-infiltrated ceramics marketed by Vita in the 1980s (In Ceram System; Vita Zahnfabrik, Bad Säckingen, Germany), R. Giordano patented, in 1997, the idea of replacing glass with a polymer to obtain a PICN. Thus, this material is the result of the infiltration of a presintered glass-ceramic scaffold with a monomer, which is secondarily polymerized. PICNs differ significantly from composite materials with dispersed fillers classically incorporated by mixing. Indeed, the ceramic network constitutes a 3-dimensional scaffold of interconnected (in contrast to dispersed) particles: it forms a real skeleton, which is able to distribute stresses more effectively in all directions and to promote resistance to breakdown phenomena (Swain et al. 2015; Fig. 1).

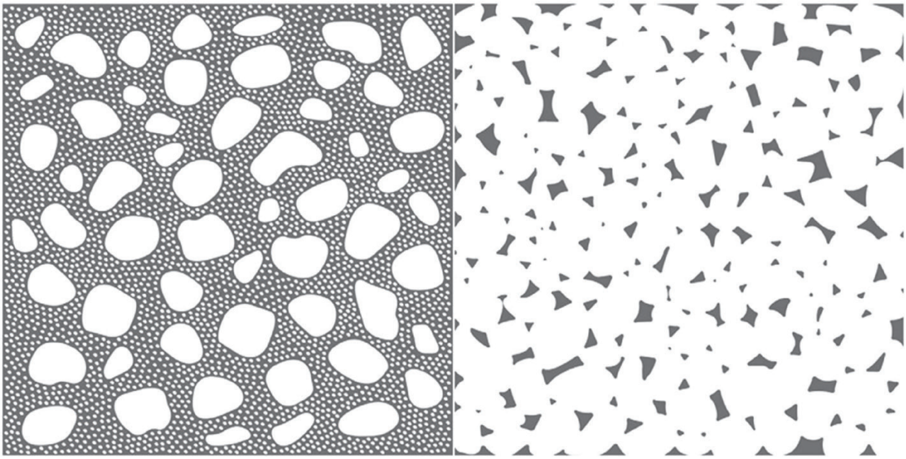

Fig 1 Schematic illustration of the microstructure of a composite with dispersed fillers incorporated by mixing versus a polymer-infiltrated ceramic network (PICN) material. In the latter, the ceramic network (white color) constitutes a 3-dimensional scaffold of sintered ceramic particles, which form a real skeleton.

Time was needed for Vita to put the first PICN, called Enamic, on the market in 2012. This was related to the difficult management of the polymerization shrinkage stress effects on the ceramic network (Swain et al. 2015). This problem was solved through M.J. Sadoun's patent, which introduced a new polymerization process using HT and HP (>150 MPa; Sadoun 2011; Nguyen et al. 2012). Indeed, HT increases the chains' mobility and then polymerization, which decreases with pressure, while HP compensates for shrinkage and reduces the number and size of defects (Nguyen et al. 2012). In the Enamic material, the ceramic network material is infiltrated with a UDMA and TEGDMA mixture. The volume fraction of ceramic is high, which is why Vita was the first to introduce the confusing commercial name "hybrid ceramic" to describe its material. PICNs are also often called double-network materials, ceramicbased interpenetrating phase materials, or interpenetratingphase ceramic-resin composites.

Ongoing research on experimental PICNs shows impressive and promising results in terms of mechanical and biological properties of this class of materials under development (Nguyen et al. 2013; Nguyen et al. 2014)—notably, when the ceramic network is performed by slip casting and uses HT-HP (180 °C, 300 MPa; Nguyen et al. 2014) and when the polymer matrix is composed of only pure UDMA, without TEGDMA and initiator (Nguyen et al. 2013). Those results are described in the next section.

4. Impact of Recent Advances on Material Properties

4.1. Mechanical Properties

Degree of conversion and polymerization mode influence. Many mechanical properties of dental composites are significantly influenced by the degree of conversion and, consequently, the polymerization mode (Ferracane et al. 1997; Chen et al. 2005; Lin-Gibson et al. 2009; Nguyen et al. 2012). Wear resistance (Ferracane et al. 1997), hardness (Chen et al. 2005), and then elasticity modulus (Lin-Gibson et al. 2009) were shown to increase with the degree of conversion. By polymerizing both commercial direct composites and artisanal ICs under HT (180 °C)- HP (250 MPa), Nguyen et al. (2012) showed a significant increase in their mechanical properties in comparison with the photopolymerized samples. They attributed their results to a higher degree of cross-linking, a more homogeneous polymerization, and a reduction in the number and size of defects. Indeed, Phan et al. (2015) recently studied the polymerization of pure UDMA with an initiator (BPO 0.5%) and showed that HT (90 °C, 4 h) generated an 89% degree of conversion, while the combination of HT-HP (200 MPa) was able to increase the degree of conversion to 95%. Note that the monomer nature also influences the degree of cross-linking: UDMA was shown to ensure a higher degree of conversion and cross-linking than Bis-GMA, with light curing (Sideridou et al. 2002).

Filler content influence. But the polymerization mode is not the only parameter improving mechanical behavior. The type, size, and volume fraction (Vf%) of the filler particles as their bond to the resin matrix are often pointed out as important influencing factors on mechanical properties. Increasing the filler content increases tensile and compressive strength, hardness, and elasticity modulus (Li et al. 1985; Chung 1990; Lin-Gibson et al. 2009). Wear resistance, which is a multiparametric property, was also shown to be affected by the filler content (Li et al. 1985; Condon and Ferracane 1997) and by particle size, geometry, and distribution (Turssi et al. 2005), with high filler content and small particles being more advantageous, as confirmed by the results of a recent clinical study (Cetin and Unlu 2012). Nguyen et al. (2013) analyzed HT-HP experimental composites with dispersed fillers and confirmed that mechanical properties increased with filler content. However, above 60 Vf%, the flexural strength tended to decrease, perhaps due to the difficulty encountered with filler incorporation by mixing, which engendered the presence of porosities. Industrial processes used for CAD-CAM blocks allow for the augmentation of the filler content in comparison with artisanal ICs, particularly PICNs, which do not encounter the mixing problem. Yet it is important to note that most manu facturers express the filler content in weight (wt%) instead of volume (Vf%), which does not enable comparisons among the different products (see Table). Indeed, weight is more related to the filler composition—with some fillers, such as zirconia, being significantly heavier than others.

Microstructure influence. Figure 2 gives the flexural strength of commercial and experimental CAD-CAM composite materials, with different microstructures (dispersed fillers and PICNs) and manufacturing processes, in comparison with IPS e.max CAD (Ivoclar Vivadent, Schaan, Liechtenstein), the most resistant glass-ceramic material. Interestingly, experimental HT (180°C)–HP (300 MPa) PICN made by slip casting and infiltration of a sintered glass-ceramic network (73.8 Vf%) with UDMA (without initiator) showed a flexural strength around 288 MPa, while the same HT-HP components manufactured by filler mixing (65 Vf%) showed a flexural strength of only around 122 MPa (Nguyen et al. 2014). The addition of initiator was shown to increase the PICN flexural strength up to 300 MPa, which is a value close to the most resistant glassceramics, such as lithium-disilicate glass-ceramic IPS e.max CAD (Ruse and Sadoun 2014). Enamic, which is the currently marketed PICN, gave results inferior to experimental slip-casted

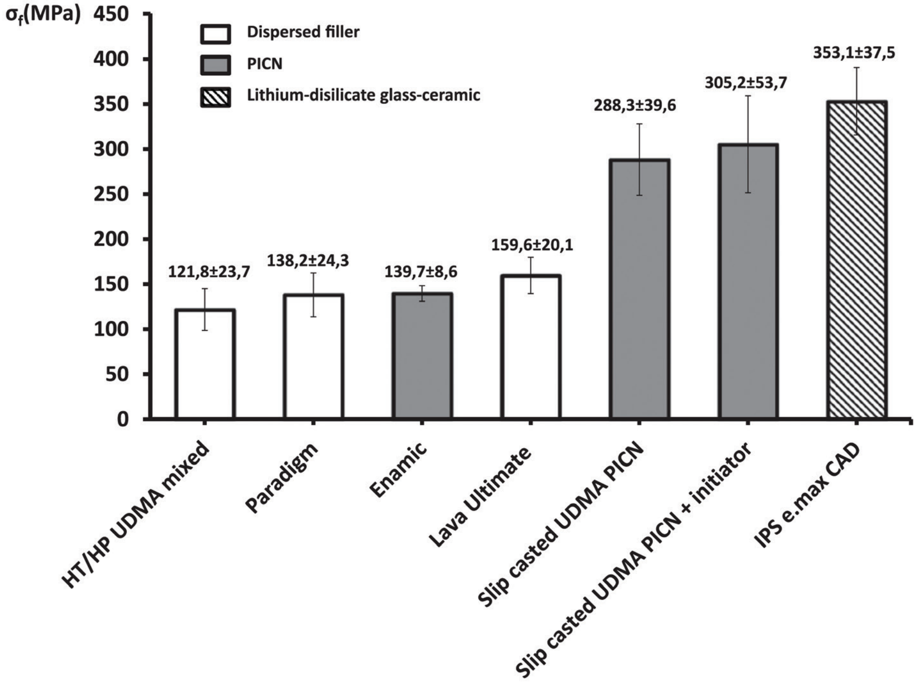

Fig 2 Flexural strength (3-point bending test) of commercial and experimental computer-aided design–computer-aided manufacturing materials different microstructures. Data are from Ruse and Sadoun (2014) for Enamic, Lava Ultimate, and IPS e.max CAD materials and from Nguyen et al. (2014) for Paradigm and experimental materials. CAD, computer-aided design; HP, high pressure; HT, high temperature; PICN, polymer-infiltrated ceramic network; UDMA, urethane dimethacrylate.

PICN (Ruse and Sadoun 2014; Nguyen et al. 2014). Indeed, ifthe ceramic network volume is similar (73.5 Vf% for experimental PICN vs. 75 Vf% for Enamic), there are important differences between the 2 materials: the nature of monomers (UDMA vs. UDMA and TEGDMA), the HT-HP process (180°–300 MPa vs. undetailed HT-HP), and, finally, the ceramic network manufacturing process (slip casted or pressed). Those considerations highlight the complex relationship between manufacturing process parameters and material performance.

Regarding the elasticity modulus, Enamic (elasticity modulus = 30 GPa, hardness = 2.5 GPa) was shown to exhibit intermediate properties between dentin and enamel, while other CAD-CAM blocks with dispersed fillers are under the dentin values (Ruse and Sadoun 2014). In fact, the ideal restorative material should mimic the specific mechanical properties of enamel and dentin as much as possible. Petrini et al. (2013) proposed a concept of a biomimetic composite material, with different layers of alumina lamellae infiltrated with epoxy resin, reproducing the anisotropy of the tooth tissues. New developments should focus on these considerations.

4.2. Toxicity and Monomer Release

The main current issue concerning dental composites from a biological point of view is the release (or elution) of components due to incomplete polymerization and, later, due to degradation (Ferracane 1994; Van Landuyt et al. 2011; Gupta et al. 2012). In 1996, Olea et al. raised the issue of the presence of bisphenol A (BPA), a well-known endocrine disruptor, in dental materials. Indeed, dental composites may release not only BPA but also low weight monomers such as HEMA and TEGDMA, high weight monomers such as Bis-GMA and UDMA, and additives such as free radicals and photoinitiator molecules (Van Landuyt et al. 2011; Kingman et al. 2012; Leprince et al. 2013). All monomers are reported to induce adverse effects, such as bacterial colonization on the composite surface, pulp damage, disturbance of odontoblasts and dental stem cells, dermatologic and allergic reactions, and cytotoxic and genotoxic effects (Bakopoulou et al. 2009; Bakopoulou et al. 2011; Krifka et al. 2013; Leprince et al. 2013). Some photoinitiator molecules may also exhibit significant cytotoxicity (Bakopoulou et al. 2009). Most studies have not proven that BPA was directly released from Bis-GMA-based restorations (Bakopoulou et al. 2009). In fact, BPA was often reported as a degradation product of Bis-DMA, a component of sealants for pits and fissures. Salivary enzymes, such as esterases, are able to degrade the Bis-DMA ester bonds but not the Bis-GMA ether bonds, which encounter the liberation of BPA. However, the evaluation of BPA release from dental composites is highly complicated, since there are many other sources of BPA contamination.

Regarding these biological interactions, recent CAD-CAM blocks are superior to direct and artisanal ICs since they imply 1) a significant increase in the degree of conversion (Lin-Gibson et al. 2009; Gupta et al. 2012), 2) the use of less toxic monomers and the absence of photoinitiators (Gupta et al. 2012; Krifka et al. 2013), and 3) a better resistance to degradation and then to toxic components release (Van Landuyt et al. 2011). Indeed, the degree of conversion was shown to influence cell response (Lin-Gibson et al. 2009), and a recent review highlighted the importance of polymerization of resin materials in regard to their toxicity (Gupta et al. 2012). A short time ago, HT-HP polymerized UDMA was shown to exhibit dramatically reduced monomer release in comparison with light- or thermocured UDMA, which could probably be due to a higher degree of conversion and a higher degree of homogeneity (Phan et al. 2014). Moreover, UDMA—which is used as an alternative to Bis-GMA in modern CAD-CAM blocks—is not synthetized from BPA. In fact, Bis-GMA was shown to exhibit the highest *in vitro* cytotoxicity on human gingival and pulp fibroblasts, greater than UDMA (Gupta et al. 2012). Finally, Nguyen et al. (2013) developed experimental PICNs without TEGDMA and initiator (BPO), while TEGDMA is reputed to have many cytotoxic and genotoxic effects, such as the inhibition of specific odontoblast functions (Krifka et al. 2013). Those effects are promoted by TEGDMA's small molecule size, which increases diffusion processes.

4.3. Bonding Properties

Increasing surface roughness (i.e., micromechanical interlocking) is more important than chemical conditioning with a silane(i.e., an agent coupling inorganic fillers with organic resin cement) to improve bonding properties of ICs (Spitznagel et al. 2014). Currently, for most ICs, there is a consensus in the literature about the use of air abrasion (50-μm alumina particles) or silica-coating systems (Co-Jet and Rocatec systems; 3M ESPE, Seefeld, Germany) to roughen the material surface to increase surface energy and micromechanical interlocking (Spitznagel et al. 2014). The hydrofluoric acid-etching procedure induces lower bond strength values for most composites, while postsandblasting silane pretreatment is generally recommended to further increase bond strength (Spitznagel et al. 2014). Yet in the particular case of Enamic PICN material, the manufacturer recommends a 5% hydrofluoric acid etching for 60 s as an alternative to air abrasion. Indeed, with PICNs, the etching procedure induces the total dissolution of the ceramic phase and the creation of an interesting "honeycomb" structure formed by the remaining resin network, offering a very high potential for micromechanical interlocking (Fig. 3). In fact, Enamic was shown to give higher bond strength to resin cement than Lava Ultimate (Elsaka 2014). Recently, 3M has removed crowns from the indication list of Lava Ultimate material because of the occurrence of debonding failures, which still need to be explained. This phenomenon was notably reported with crowns bonded on zirconia implant abutments and was attributed to the elastic deformation of the restoration during chewing (Schepke et al. 2015). Bonding properties of new CAD-CAM blocks, dispersed fillers, and PICNs need to be investigated, as there is a lack of data in the literature about their behavior, notably in comparison with ceramic materials. Indeed, their specific microstructure and their high degree of conversion—which can decrease the possibility of additional chemical bonding between free monomers and resin cement—can significantly affect their performance and thus constitutes a current issue, particularly in regard to their indications as adhesive restorations.

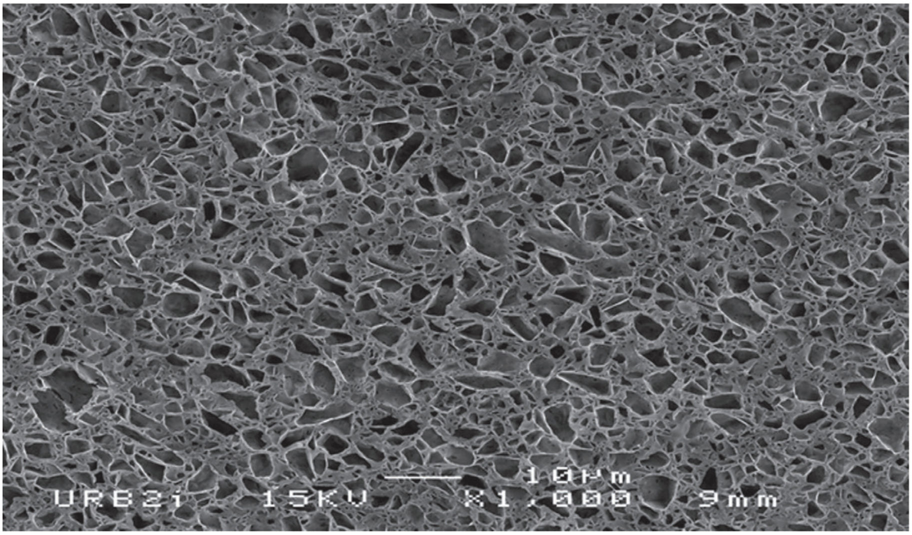

Fig 3 Scanning electron microscope observation (1000× magnification) of experimental slip-casted polymer-infiltrated ceramic network after polishing and etching with hydrofluoric acid for 1 min. Etching leads to glass-ceramic network dissolution and creation of a specific interesting "honeycomb" structure formed by the remaining resin network, which promote bonding.

5. Clinical Considerations

Currently, there is still no universal or ideal material in restorative dentistry, and the material choice varies with the clinical situation. This choice should promote current treatment strategies, which aim to conserve and preserve remaining tooth tissues and structures (Lynch et al. 2014). A critical issue lies in the lack of clinical evidence regarding the comparison of the various existing materials and techniques, particularly for extensive cavities (Fron Chabouis et al. 2013; Grivas et al. 2014). Concerning the objective of minimal intervention approaches and given clinical background, direct composites are reported as the material of choice for the restoration of class I and II cavities in posterior teeth (Lynch et al. 2014), especially when indirect techniques would imply further loss of tooth tissue to adapt the cavity design. Artisanal ICs in general were shown to exhibit good clinical results and similar annual failure rates to direct composites in posterior class I and II cavities (Manhart et al. 2004; Grivas et al. 2014; Opdam et al. 2014) and for the restoration of maxillary premolars with 1 missing cusp (Fennis et al. 2014). A recent systematic review (Fron Chabouis et al. 2013) found limited evidence that ceramics perform better than artisanal ICs for inlays in the short term. In general, indirect techniques are advised for subgingival margins, extensive cavities (including those where multiple cusps require replacement), and altered/abnormal enamel and dentine (Lynch et al. 2014). Those techniques allow 1) the use of a material with better mechanical properties, such as resistance to fracture, which is one of the first causes of failure of direct composites, particularly with larger restorations (Opdam et al. 2014); 2) the reduction of the effect of polymerization shrinkage stresses (Ferracane and Condon 1992); and 3) the achievement of better occlusal anatomy and proximal contact points. The emergence of CAD-CAM composite blocks has generated the apparition of new materials, which possess, *in vitro*, better mechanical properties than artisanal ICs and also significant advantages in comparison with glass-ceramics. In fact, CAD-CAM composites show an elasticity modulus closer to dentin than ceramics and the property of absorbing masticatory forces (Coldea et al. 2013), which can be particularly valuable for crowns on implants (Rohr et al. 2015). Composites are also considered more adapted to CADCAM processes because 1) they are not as brittle; 2) they exhibit a higher damage tolerance, a lower tendency to marginal chipping, and smoother milled margins (Tsitrou et al. 2007; Awada and Nathanson 2015; Coldea et al. 2015); and 3) they are able to be milled to a reduced thickness (0.2 to 0.5 mm; VITA Zahnfabrik). Furthermore, CAD-CAM composites exhibit a better machinability than ceramics in terms of milling time and bur lifetime (Lebon et al. 2015; Fig. 4). The resulting lower cost, added to the absence of

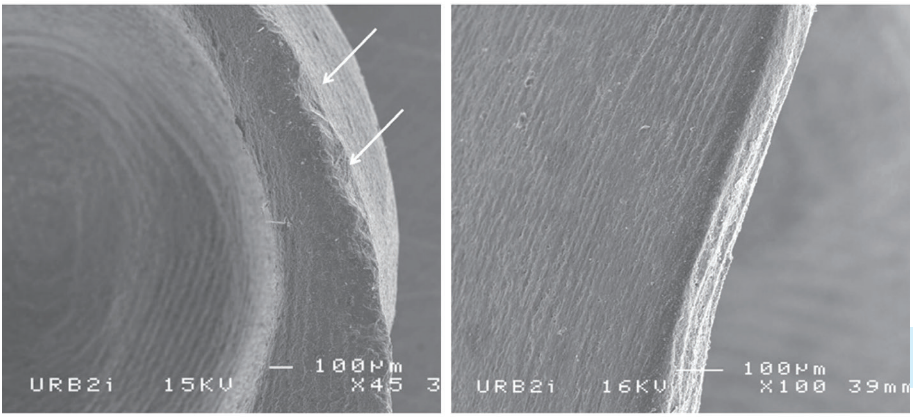

Fig 4 Scanning electron microscope observation of the margins of an IPS eMax CAD (45× magnification) versus an experimental slip-casted polymer-infiltrated ceramic network (PICN) crown (100× magnification), milled with the same CAD-CAM system (Kavo Artica, Biberach, Germany) and on the basis of the same design. The margin edge of the glass-ceramic crown exhibits chipping (arrows), while the margin of the crown is smoother and intact, even at higher magnification.

any firing procedure for ceramic staining or crystallization (required for lithiumdisilicate glass-ceramic restorations), makes those materials very attractive. Additionally, they are easier to mill and to repair in case of failure (no need for hydrofluoric acid use; Zaghloul et al. 2014).

Among CAD-CAM composites, PICN materials—with their specific microstructure and polymerization mode—constitute an innovative and promising class of materials (Albero et al. 2015; Swain et al. 2015). Particularly, as seen previously, experimental PICNs exhibit additional benefits in terms of 1) mechanical properties—namely, comparable flexural strength and toughness to high-performance glassceramics (Coldea et al. 2013; Nguyen et al. 2014), Vickers hardness between enamel and dentin and then reduced antagonistic wear (Swain et al. 2015), elasticity modulus between enamel and dentin (i.e., around 30 GPa, with elasticity modulus of dentin being around 15 to 20 GPa and with enamel around 50 to 100 GPa, while CAD-CAM dispersed filler composites show an elasticity modulus lower than dentin and CAD-CAM ceramics, similar or higher than enamel; Coldea et al. 2013; Awada and Nathanson 2015; Swain et al. 2015)—and 2) low toxicity and monomer release (Phan et al. 2014). Yet the recent advances with CAD-CAM composites described throughout this review through *in vitro* studies cannot be related to any relevant clinical data and consequently cannot support any evidence-based recommendations in clinical practice for the moment.

Future perspectives include the clinical study of CADCAM composites used as crowns on implants and natural teeth and as adhesive restorations, particularly very thin and noninvasive restorations, such as table tops and palatal veneers for "no prep" worn cases (Fig. 5; Schlichting et al. 2011), as illustrated with the pilot clinical case in the Appendix Figure. Current issues are also related to the study of CAD-CAM composites in terms of wear resistance and aging, which still require *in vitro* and clinical studies. Indeed, Swain et al. (2015) recently reported that PICN crowns (Enamic) perform better in chewing simulation than lithium-disilicate glass-ceramic (emaxCAD) crowns in terms of resistance to crack initiation and growth but exhibit more wear. Yet Mormann et al. (2013) showed, also *in vitro*, that PICN self-wear and antagonistic enamel wear did not significantly differ from enamel and lithiumdisilicate glass-ceramics. However, even if their polishing aptitude is similar, the loss of surface gloss with toothbrushing was higher with PICNs than with glass-ceramics. Wear also constitutes an issue for the stability of stains, which are light-cured composites thinly layered on the surface to improve the esthetics. In fact, when a high level of aesthetics is required (e.g., with veneers), ceramics remain the material of choice. Finally, properties concerning soft tissue behavior around implants also need to be evaluated to use them as transgingival implant components and prostheses.

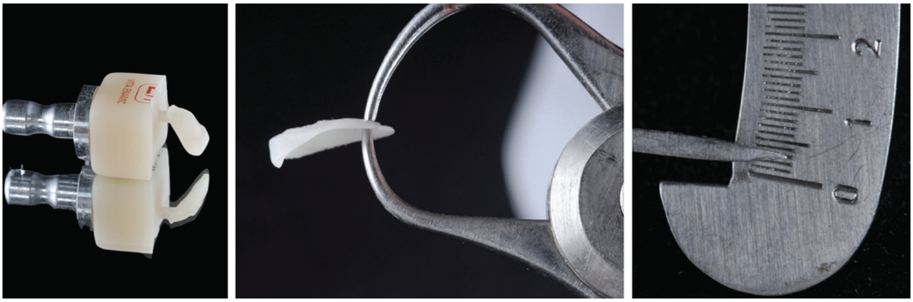

Fig 5 Table top (0.2 mm thick) for a "no prep" clinical case of a worn dentition restored with minimally invasive bonded partial restorations. The restoration was milled in Enamic (polymer-infiltrated ceramic network) with the Cerec MCXL machine (Sirona, Salzburg, Austria).

6. Conclusions and Perspectives

Nowadays, indirect dental composites represent a large-scale class of materials characterized by various manufacturing processes, microstructures, polymerization modes, and compositions, implying important variations in material properties. The apparition of composite CAD-CAM blocks has most particularly generated new generations of materials, which could now rival CAD-CAM ceramics for bonded partial restorations and crowns on natural teeth or implants, while artisanal ICs are tending to disappear. Two subclasses of CAD-CAM blocks must be distinguished: those with dispersed fillers and PICNs. Recent in vitro research outcomes, especially with experimental PICNs, have introduced interesting perspectives in terms of mechanical and toxicity properties as milling ability in comparison with high-performance glass-ceramic materials. These innovative materials could be particularly apt for development of minimally invasive treatment strategies, such as "no prep" treatment of worn dentition with very thin restorations. But there is now a crucial need to conduct clinical studies about the different varieties of CAD-CAM composites to validate in vitro results before establishing clinical recommendations. Current issues are also related to the study of their bonding, wear, and cytocompatibility properties. We are still at the dawn of composite CAD-CAM block evolution and its rapid and competitive market development. Even if complicated due to incomplete information delivered by companies, practitioners should remain aware of each product's specific properties and indications to promote success and new treatment strategies.

7. Author Contributions

A.K. Mainjot, contributed to conception, design, data acquisition, analysis and interpretation, drafted the manuscript; N.M. Dupont, J.C. Oudkerk, T.Y. Dewael, contributed to data acquisition and analysis, drafted the manuscript; M.J. Sadoun, contributed to conception and design, critically revised the manuscript. All authors gave final approval and agree to be accountable for all aspects of the work.

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The remaining authors declare no potential conflicts of interest with respect to the authorship and/or publication of this article.

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Chapter 6

The one-step no-prep approach for full-mouth rehabilitation of worn dentition using PICN CAD-CAM restorations: 2-yr results of a prospective clinical study

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1. Abstract

Objectives: To prospectively evaluate the One-step No-prep treatment of full mouth-worn dentition, a minimally invasive and multidisciplinary approach using PICN CAD-CAM composite restorations without provisional phase.

Methods: Seven patients (n=192 restorations) with severe tooth wear were included. Patient data were recorded, and an occlusal analysis and a tissue-guided wax-up were realized. After replacement of old fillings, noprep Vita Enamic restorations (posterior restorations and palatal veneers) were bonded within 24 h. Direct composites were performed to mask the buccal joint on anterior teeth. Maxillo-facial physiotherapy was performed. Restorations were evaluated following World Dental Federation criteria. Treatment influence on Oral-Health-Impact-Profile-49 (OHIP-49) score was assessed.

Results: Tooth wear etiology was related to soft drink consumption and bruxism. Mean VDO increase was 5.09 ± 0.85mm on the incisal pin. The mean restoration thickness on molars was 0.55 ± 0.21 mm, and the lowest was 0.11 mm. 2-year survival rate of restorations was 100 % and success rate was 93.5 %, with 11 minor chippings and one debonding. A significant improvement of the global OHIP-49 score was observed.

Conclusions: In this clinical study on high risk patients, PICN restorations, applied in a minimally invasive way, showed high survival and success rates after two years, while minor chipping of very thin occlusal borders constituted the most frequent complication. Moreover, the patient acceptance was good according to OHIP-49 in this multidisciplinary approach.

Clinical significance: The use of PICNs allows the development of no prep and simple treatment protocols of worn dentition. The absence of provisionals did not engender any problem, on the basis of the realization of an occlusal analysis, the support of a maxillo-facial physiotherapist, and the use of an easy-to-adjust restorative material.

KEYWORDS

Tooth wear

Minimally invasive treatment

CAD-CAM composite

Fixed prosthodontics

Dental materials

2. Introduction

In recent years, a significant increase in the prevalence of tooth wear has been observed, especially in young patients [1–3]. These problems are promoted by changing lifestyles, particularly chemical erosion favored by acidic food/drink and gastro-esophageal reflux, while mechanical wear is often related to the presence of bruxism, which engenders attrition and abfraction [4,5]. Severe dental tissue wear can engender dental pain due to exposure of dentinal tubules [6,7] and a decrease in the masticatory function. Moreover, severe tooth wear leads to an unsightly appearance in most patients, who report a real social handicap [8,9]. In addition to preventive approaches in the absence of symptoms and patient demand [10], current recommendations emphasize the need to develop minimally invasive treatment strategies that preserve as much as possible remaining tooth tissues [9], with the current tendency being to avoid any tooth tissue preparation ("No prep"). However, restoring functional occlusal relationships and aesthetics requires a full-mouth rehabilitation with an increase in the vertical dimension of occlusion (VDO), constituting a complex treatment. Various techniques have been described: direct techniques with light-cured composites, which constitute the most commonly reported treatment [8], indirect techniques; or a mix of the two techniques. The direct technique can involve the estimation of the new VDO in the articulator before light-cured composites placement using silicone bite-stops in the posterior zone (DSO-technique) [11,12], or the realization of a global wax-up with an arbitrarily determined increase of the VDO, followed by the placement of light-cured composites using a transparent silicon key [13,14]. Additionally, some authors have performed the wax-up on the basis of an analysis of occlusal relationships (e.g., using facial bow and a jig) [13], and others have used provisional restorations to test the new VDO before final direct composite realization [15]. The direct technique is particularly minimally invasive and reversible, restorations being easy to repair, while the treatment cost is reported to be reduced [16,17]. However, the technique can result in the need for maintenance care (for example polishing and repair), especially in the presence of bruxism [9] since the prognosis of restorations is patient dependent [18]. Conversely, with indirect, minimally invasive strategies, composite palatal veneers, eventually associated with ceramic buccal veneers, are usually performed to restore the upper incisors and canines ("sandwich technique"), while ceramic or composite occlusal onlays are realized on the premolars and molars [19–21]. These treatments gave multiple steps and require several appointments, involving the realization of mock ups and provisional restorations, which are intended to test the new VDO, to validate the aesthetic results and to guide tooth tissue preparation for indirect restoration [22]. If indirect techniques allow for the use of materials that are more performant than light-cured composites, the restorations are more expensive [18]. However, there is no evidence regarding the best technique (direct or indirect) or material (composite or ceramic) to be used to restore severely worn dentition [8,9], and to the authors' knowledge, there have been no clinical studies examining the performance of indirect restorations used for full-mouth rehabilitation of worn dentition. Recently, a novel technique (One-step No-prep) for full-mouth rehabilitation of worn dentition using CADCAM composite restorations was introduced [23]. It is characterized by the absence of tooth tissue preparation and a provisional phase, the use of Polymer-Infiltrated Ceramic Network (PICN) materials, the realization of an occlusal analysis and the collaboration with physiotherapists to treat associated symptoms, such as muscular hypertrophy and pain.

In this "one step" treatment, definitive indirect restorations are bonded within two consecutive days, reducing visit numbers in comparison with other indirect techniques and treatment complexity (particularly regarding very thin provisional restorations management). PICN materials (hybrid ceramics, Vita Enamic, Vita Zahnfabrik, Bad Säckingen, Germany) were shown to exhibit several advantages compared to ceramics for this indication, such as the ability to be milled to a very low thickness and ease of in-mouth adjustments [24]. Furthermore, they have also shown good mechanical [25] and bonding properties [26]. The One-step No-prep approach was shown to yield successful short-term clinical results in three pilot cases and to be particularly straightforward and minimally invasive. The absence of provisional restorations to test the VDO increase did not engender any inconvenience and the patients' perceptions were very positive. However, those preliminary results must be confirmed with an in-depth analysis of the different facets of this protocol. Moreover, there is a lack of data about the clinical behavior of PICN partial coverage restorations [27–29]. Consequently, the objective of the present study was to prospectively evaluate the "One Step - No Prep" protocol for full-mouth rehabilitation of worn dentition, studying the clinical behavior of PICN restorations and treatment influence on patients' Oral-Health-Related-Quality of Life (OHRQoL) using the Oral-Health-Impact-Profile-49 questionnaire (OHIP-49).

3. Materials and methods

3.1. Study design

This study was a prospective clinical study evaluating patients treated with the «One-step No-prep» protocol. The patients were treated in the Department of Fixed Prosthodontics of the University Hospital of Liège by four experimented practitioners. They were informed about the objectives of the study, and their consent was obtained before treatment. The study was approved by the Ethics Committee of the University Hospital of Liège (B707201526682).

3.2. Patient record registrations

Specific data were collected regarding the following parameters: sex, age, and occlusal relationships were registered (dental class, function, overjet, overbite, crossbite).

3.3. Patient selection

Seven patients presenting generalized severe tooth wear with an aesthetic or functional demand were included in the study. The patients were required to have a minimum of 28 teeth, palatine veneers of the canine to canine superior teeth and a minimum of 3 teeth per posterior sextant to restore with an indirect restoration (Figs. 1a, 2 a, b). The following patients were excluded from the study: smokers and patients with poor oral hygiene, those with periodontal disease or severe osteoarthritis, and patients with crowns, bridges, or implants. Patients with Parkinson disease or spontaneous temporo-mandibular joint pain associated with a mandibular deflection and an opening limitation (< 25 mm) were also excluded.

3.4. Wear quantification

To quantify dental wear, the Basic Erosive Wear Examination index (BEWE) [30] was calculated for each patient by the same practitioner.

3.5. Chemical erosion assessment

In addition to a thorough clinical examination to detect the presence of dental erosion surfaces (concave, cuneiform or flat lesions), an accurate medical history was recorded including questions about nutrition habits, general diseases, medications, and environmental factors.

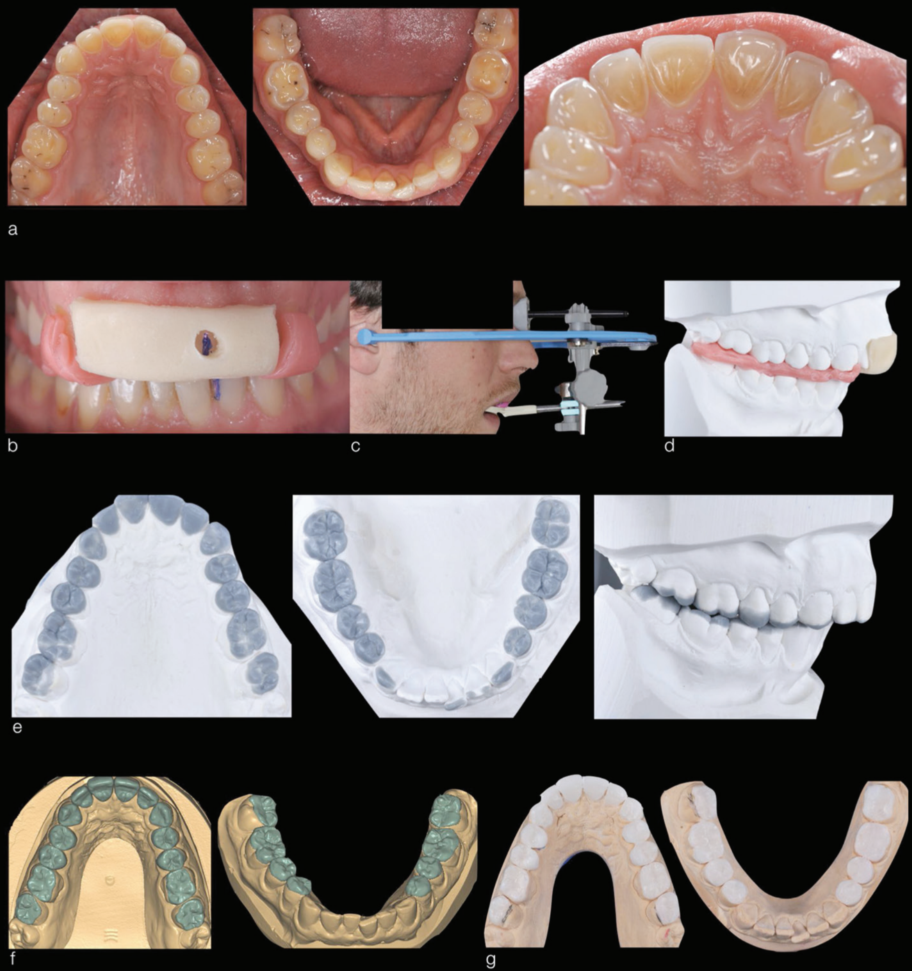
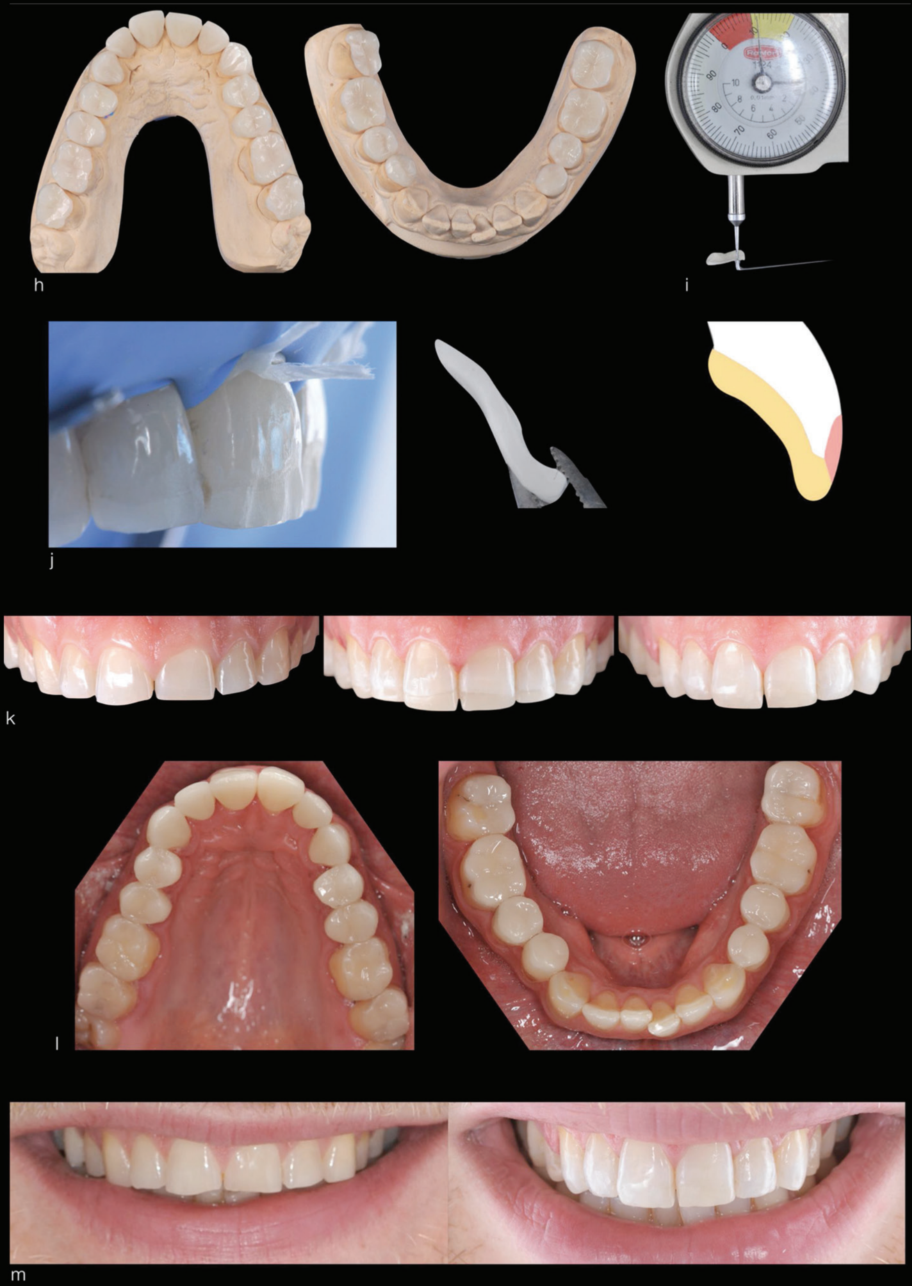


Fig. 1

Case 1 (Photo courtesy of A. Mainjot).
a) Occlusal views before treatment
b) Occlusal relationships registered using a resin jig and a double layer of wax (Moyco Beauty Wax).
c) Facebow (Quick facebow)
d) Plaster models placed in the articulator
e) "Tissue-guided" full-mouth wax-up
f) Superimposition of the scans of the models and the wax-up with th Ceramill system.
g) Wax CAD-CAM mock-up
h) Occlusal views of final PICN restorations on plaster models after polishing (in this case, restorations were not stained)
i) A 0.11 mm-thick PICN (Vita Enamic) posterior occlusal table top immediately after milling
h) Occlusal views of final PICN restorations on plaster models after polishing (in this case, restorations were not stained)
i) A 0.11 mm-thick PICN (Vita Enamic) posterior occlusal table top immediately after milling
j) Direct composite was added on a slight chamfer performed across the junction between the tooth and the palatal veneer to mask the joint between the palatal veneer and the buccal face of the upper anterior teeth. In this case, the chamfer comprised two buccal grooves to fill with incisal direct composite to promote the aesthetic result. Direct composite was also added where needed to optimize tooth shape. This option is a minimally invasive alternative to ceramic buccal veneer, which can be performed a second time if the patient is not satisfied with the result or if the direct restoration is aging too quickly



k) Buccal views of upper anterior teeth before treatment, after palatal veneer bonding and after buccal joint masking with direct composite, respectively. Palatal veneers should be performed a bit longer than needed regarding the position of the incisal edge to be able to perfectly adapt this edge to the horizontal plane after bonding. Direct composite should not be present on the incisal edge for mechanica resistance issues
l) Occlusal views after treatment
m) Smile pictures before and after treatment.

3.6. Non instrumental approach of bruxism assessment

A clinical examination was performed to register the presence of clinical signs of bruxism, such as dental attrition, cracks/fractures, masseteric hypertrophy, linea alba, exostoses or crenated tongue [31,32]. The presence of bruxism was recorded if the patient fulfilled at least two criteria: A) reporting of tooth grinding during the night or day; or B) the presence of at least one clinical sign among the following: abnormal attrition wear facets on the teeth; transitory pain or fatigue on waking felt in the jaw muscles; temporal headaches on waking; and jaw locking on waking related to teeth grinding during sleep [31,33]. A complementary clinical examination was performed by an occlusodontist (i.e. a specialist in occlusion and TMDs) to detect the presence of temporomandibular joint (TMJ) disorder. If patients had symptoms of TMJ disorder, they were sent to a maxillofacial physiotherapist before treatment. Finally, the wearing of an occlusal nightguard before treatment was recorded.

3.7. Clinical protocol

The patients were treated according to the previously described "One-step No-prep" protocol [23]. Before including patients in the study, a complete dental check-up with carious and periodontal examinations, X-rays and photographs was performed. Double mix impressions with polyvinyl siloxane (PVS) material (Imprint 4 Heavy and XLV, 3M ESPE, Seefeld, Germany) were realized, and study models were cast (GC Fujirock EP Super Hard Plaster, GC Europe, Leuven, Belgium). Then, an occlusal analysis was performed using a resin jig [34] (Fig. 1b) and a facebow (Fig. 1c) (Quick facebow, Sintec Inc, New Hampshire, USA). The jig was placed for a few minutes to induce muscular relaxation and lower jaw repositioning, and then occlusal relationships were registered with wax (Moyco Beauty Wax, Philadelphia, PA, USA) in double thickness (Fig. 1d). The dental technician started to deposit the wax on the less damaged teeth and was guided by the residual tissues to restore tooth anatomy, resulting in very low wax thickness on some posterior teeth (Fig. 1e). With this "tissue-guided" approach, the estimation of the new VDO was empirical. The full waxup was shown to the patient for approval. Subsequently, the treatment started with the replacement of amalgam fillings and deficient composite restorations with direct composite restorations (Els composite extra low shrinkage, Saremco Dental, Rebstein, Switzerland). Before impressions, dental tissues were not prepared, but sharp angles were softened and large direct composite fillings, presenting large proximal boxes, were partly removed to be replaced by the indirect restorative material, with cavities filled with provisional composite resin (Telio CS Onlay, Ivoclar Vivadent, Schaan, Lichtenstein). If required, endodontic treatments were performed previously. New double mix impressions and occlusal analysis following the same protocol as previously were performed after a visit to the physiotherapist, which was intended to equilibrate the posture and muscular chains before final occlusal analysis. It should be emphasized that the patients did not wear any occlusal splints to test the new VDO before treatment. A resin posterior key was realized to validate the occlusal relationships in the articulator. The models and the full wax-ups were scanned and superimposed using a CAD-CAM system (Ceramill system, Amann Girrbach AG, Koblach, Austria)(Fig. 1f). A CAD-CAM mock-up was performed in wax and tried to validate the restoration design and aesthetic result (Fig. 1g). Restorations corresponding to the estimated tissue loss (palatal veneer, posterior occlusal tabletops and veneerlays) were milled from PICN blocks (Vita Enamic HT, Vita Zahnfabrik, Germany; Ceramill Motion 2, Amann Girrbach)(Fig. 1h, i). Some restorations were only polished or stained with a light-cured nanofilled composite coating agent (Optiglaze, GC Corporation, Tokyo, Japan). The restorations were tried and then bonded within two consecutive days at two half-day appointments, one for each maxilla (the upper jaw on the first day afternoon, the lower on the second day morning). The restorations were pretreated following the manufacturer's recommendations, i.e., etching the surface with hydrofluoric acid (HF) for 60 s, cleaning it in an ultrasonic bath in ethanol and then applying a layer of silane (Silane Primer, Kerr, Orange, California, United States). A rubber dam was placed for the posterior teeth but not the anterior teeth. Tooth tissues were cleaned with pumice. A diamond burr at low speed was used to open the tubules of sclerotic dentin and enamel was etched with phosphoric acid. Direct composites were sandblasted with the Cojet system (3 M, Saint-Paul, USA) and a silane (Silane Primer, Kerr, Orange, California, United States) was applicated. Then a two-step self-etch adhesive (Optibond XTR, Kerr, Orange, California, United States) was applicated following manufacturer recommendations and the adhesive layer was polymerized before restoration bonding. The restorations were bonded with a composite resin cement with the Nexus XTR system (NX3, Kerr, Orange, California, United States), polymerization was performed after excess removal, and final photopolymerization was performed under a film of glycerin to avoid the persistence of a polymerization inhibition layer. Major occlusal adjustments were realized immediately after bonding of the lower restorations with an Arkansas stone burr, followed by polishing with silicon gums and fine adjustments performed within the subsequent weeks and after a visit to a maxillofacial physiotherapist. A bleaching procedure (home bleaching with a night guard using Illumine 10 % tooth gel Kit, Dentsply Sirona, New York, USA) was also performed (which was not possible when the dentin was still exposed). To mask the junction between the palatal veneer and the buccal face of the upper anterior teeth, direct composite (Inspiro, Edelweiss, Zug, Switzerland) was added on a slight chamfer performed across the junction and where needed to optimize tooth shape (Figs. 1 j–m, 2 c, d). Finally, an acrylic nightguard (for the upper maxilla) (Orthocryl, Dentaurum, Ispringen, Germany) was provided to all of the patients.

Fig. 2 Case 2, severe tooth wear in a patient suffering from anorexia and bruxism (Photo courtesy of A. Mainjot).
a) Occlusal views before treatment
b) Frontal view before treatment
c) Frontal view after treatment. The patient was sent to a specialist to consider soft tissue grafts for gingival recessions
d) Occlusal views after treatment

3.8. Prosthetic parameter analysis

For each restoration, the nature of the antagonist (enamel, dentin, direct composites, PICN restoration) was registered. The lowest thickness of each restoration was measured, and the VDO increase at the incisal guide pin was registered.

3.9. Clinical evaluation of restorations

Two independent and calibrated evaluators assessed restorations following the criteria of the World Dental Federation (FDI) after one month, six months, 1 year and 2 years [35]. Three dimensions, representing 18 items, were described: aesthetic, functional and biological. The functional and aesthetic dimension includes patient-reported satisfaction. Each item is assessed on a 5-point Likert scale (1 corresponding to an excellent restoration and 5 corresponding to a restoration that must be replaced). In case of discrepancies, agreement was found between evaluators to determine the final score.

3.10. Patient reported outcome measures (PROMs)

The Oral-Health-Impact-Profile-49 [36] questionnaire (OHIP-49, OHRQoL for Oral-Health-Related-Quality of Life) was filled out before treatment and at each evaluation time. The OHIP questionnaire includes 49 statements divided into seven areas, namely functional limitations, physical pain, psychological discomfort, physical disability, psychological disability, social disability and disability. For each question, a score between 1 and 5 is given, from never to very often. A high global score identifies poor quality of life related to oral health. In the present study, it was decided to present the global OHIP score [37] and the overall score for each of the seven areas, respectively.

3.11. Statistical analysis

Data analysis was carried out using GraphPad Prism (GraphPad Software, San Diego, CA). The data collected were expressed in terms of the prevalence or the mean ± standard deviation (Mean ± SD). The prevalence was defined as the proportion (%) of people with a given condition relative to the total population studied. The annual failure rate (AFR) of restorations was calculated on the basis of survival and success, respectively [45]. An analysis of the normal distribution of data was systematically performed with the Shapiro-Wilk test. In order to compare the mean scores of OHIP-49 variables, not normally distributed, before and after the intervention (1 month and 2 years), the Mann-Whitney U test and the Wilcoxon signed-rank test were used. In all tests, variations were considered statistically significant when pvalue< 0.05.

4. Results

4.1. Clinical data about the patients

Seven patients (n=192 PICN restorations) were included in this study. Among them, 6 were men. The mean age was 37.7 ± 12.8 years old. Six patients were in class I, and one patient was in class II.2. Of the patients 57.2 % (n=2) showed a group function, 14.3 % (n=1) had a canine function, and 28.5 % (n=2) had both types of function. Regarding the Basic Erosive Wear Examination (BEWE), 6 patients had a high risk level (BEWE score> 14), and one patient had a medium risk level (BEWE score=13). Regarding the etiology of wear, all of the patients showed both chemical (erosion) and mechanical wear (bruxism) signs. Most of the patients (71.4 %, n=5) reported drinking 1-2 liters of soda every day, and 28.6 % (n=2) had gastro-esophageal reflux. All of the patient reported grinding or clenching habits during the night or day, with a minimum score of 4 out of 10. Finally, 85.7 % (n=6) of patients described being stressed and anxious in their daily lives.

4.2. Clinical data about PICN restorations

In total, 192 PICN restorations were evaluated at 2 years. Six patients received PICN restorations on all of their teeth, and one patient received direct restorations for the lower incisors and canines (Inspiro, Edelweiss). Consequently, 96.36 % (n=185) of restorations were in contact with PICN material and 3.64 % (n=7) with direct composite. The mean thickness registered at the thinnest point of restorations was 1.2 ± 0.4mm for upper incisors (n=28), 1.1 ± 0.5mm for lower incisors (n=24), 1.0 ± 0.5mm for canines (n=26), 0.7 ± 0.3mm for premolars (n=56) and 0.5 ± 0.2mm for molars (n=58). The lowest thickness measured was 0,11mm on a molar. The mean VDO increase as measured at the incisal pin was 5.09 ± 0.85 mm, and the greatest VDO increase registered was 6.00mm (n=2).

4.3. Clinical evaluation of restorations

After periods of 1 and 2 years, the survival rates of PICN restorations (n=192) were 100 % and 100 %, respectively, and the success rates were 100 % and 93.75 %. The annual failure rate (AFR) on the basis of survival and success was 0 % and 3.1 %, respectively. FDI rating of restorations at 2 years is presented in Table 1. One hundred percent of restorations were scored as clinically acceptable for all properties at 2 years. The results

	Clinically Excellent % (n)	Clinically Good % (n)
A. Esthetic properties		
1. Surface luster		100 (192)
2. Staining		
a. surface	100 (192)	
b. margin	90.6 (174)	9.4 (18)
3. Color match & translucency	16.7 (32)	67.7 (130)
4. Esthetic anatomical form	97.4 (187)	1.6 (3)
B. Functional properties		
5. Fracture of material/ retention	94.3 (181)	3.6 (7)
6. Marginal adaptation	100 (192)	
7. Occlusal contour &wear		
a. Qualitatively	100 (192)	
b. Quantitatively	100 (192)	
8. Approximal anatomical form		
a. contact point	93.2 (179)	1 (2)
b. contour	99.5 (191)	0.5 (1)
9. Radiographie examination	100 (192)	
10. Patient's view	100 (192)	
C. Biological properties		
11. Postoperative sensitivity / tooth vitality	96.9 (186)	3.1 (6)
12. Recurrence of caries, erosion, abfraction	100 (192)	
13. Tooth integrity	100 (192)	
14. Periodontal response	94.3 (181)	5.7 (11)
15. Adjacent mucosa	100 (192)	
16. Oral and general health	100 (192)	

showed 11 cases of minor chipping and one case of debonding (the weak link was the interface between the resin cement and the sclerotic dentin) (Fig. 3). Restorations presenting minor chipping were polished or repaired following this protocol: rubber dam placement, sandblasting with Cojet, silane application (Silane primer, Kerr), adhesive (Optibond XTR, Kerr) and direct composite placement (Els composite extra low shrinkage, Saremco Dental, Rebstein, Switzerland). The debonded restoration was rebonded

Clinically Sufficient % (n)	Clinically Unsatisfactory %	Acceptable (%)	Unacceptable (%)
		100 (192)	
15.6 (30)			
1.0 (2)			
		100 (192)	
2.1 (4)			
5,8 (11)			
		100 (192)	

Tab. 1 2-year FDI rating of restorations. In bold, failures considered for the success rate calculation.

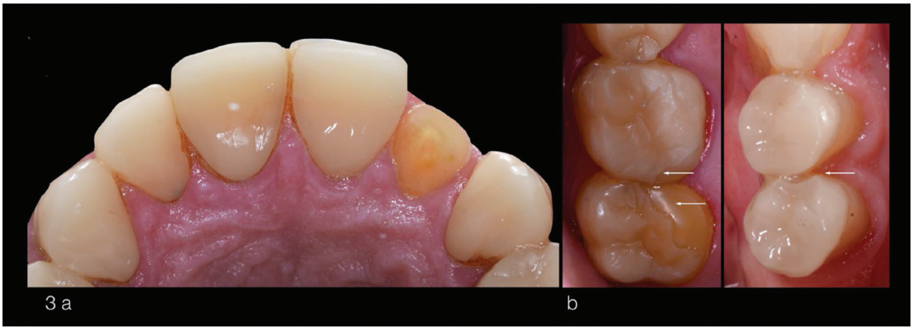


Fig 3 Observed technical complications (Photo courtesy of J. Oudkerk).
a) In case 2, loss of the restoration on tooth #22, which was severely damaged, after a 19-mt follow-up. The weak link was the interface between the resin cement and the sclerotic dentin. The restoration was successfully rebonded after eliminating the sclerotic layer with a diamond burr
b) Typical minor chipping of thin restoration borders in occlusal contact.

following this procedure: elimination of the sclerotic dentin layer and of the surface layer of the composite resin cement in the restoration intaglio with a diamond burr, sandblasting of the resin cement and silane application, application of a three-step etch-and-rinse adhesive on tooth tissues following manufacturer recommendations (Optidbonf FL, Kerr) and bonding of the restoration with Inspiro direct composite (adaptation was not perfect anymore and direct composite was used to increase the mechanical resistance and esthetics of the marginal joint). Those failures affected the success but not the survival rate of the restorations.

4.4. Patient reported outcome measures (PROMs)

The OHIP-49 results before treatment, at 1 month and 2 years, are presented in Table 2.

	Before Treatment (Mean ± SD)	1 month (Mean ± SD)	p value (Before treatment -1 month	2 years (Mean ± SD)	p value (Before treatment -2 years)
Global Score	1.88 ± 1.26	1.54 ± 0.92	0.0010***	1.36 ± 0.92	<0.0001***
Functional limitation	2.02 ± 1.34	1.79 ± 1.03	0.5235 ns	1.56 ± 1.09	0.02*
Physical pain	2.56 ± 1.41	1.84 ± 1.06	0.0035**	1.70 ± 1.21	0.0003***
Psychological discomfort	2.49 ± 1.36	1.71 ± 1.15	0.0006***	1.49 ± 1.7	≤0.0001***
Physical disability	1.66 ± 1.15	1.52 ± 0.89	0.7753 ns	1.17 ± 0.52	0.0055**
Psychological disability	1.79 ± 1.12	1.38 ± 0.73	0.0462*	1.33 ± 0.93	≤0.0002***
Social disability	1.09 ± 0.37	1.09 ± 0.28	1 ns	1.09 ± 0.37	1 ns
Handicap	1.34 ± 0.94	1.14 ± 0.47	0.4345 ns	1.02 ± 0.15	0.0431*

SD : Standard deviation, * Significant (p≤0.05), ** Significant (p≤0.01),
*** Significant (p≤0.001), ns Insignificant.

Tab. 2 Comparison of global OHIP score and sub-scores before treatment and one month after treatment, and before treatment and two years after treatment, respectively (1 being the best score and 5 the worst).

5. Discussion

Tooth wear is a multifactorial phenomenon, and in the present study, all of the patients showed both mechanical and chemical risk factors related to bruxism and soft drink consumption, highlighting the importance of early diagnosis and information in the prevention of this pathology [9]. The BEWE index was used for wear quantitative evaluation because of its common utilization and ease of use [30]. The high scores obtained (> 13) and the presence of patients' aesthetic and functional complaints, particularly tooth pain, constitute indications for treatment, as recommended in recent European guidelines [9].

Despite its high risk regarding the one-step significant VDO increase (mean of 5.08 ± 0.84mm at the incisal pin), i.e., without using provisional restorations or nightguards to test the new VDO as often recommended [22], the results of the One-step No-prep approach confirmed results obtained with the three pilot cases [23]. The global OHIP score was, as shown in a previous study related to severe tooth wear treatment with direct composites [38], significantly improved already one month after treatment and still after two years, while all sub-scores, except the one for social disability, were significantly improved after two years (Table 2). Detailed analysis of the sub-scores showed that, from a function and pain point of view, the patient's quality of life improves with time. In fact, patients quickly adapted to their new occlusal relationships, and only pronunciation troubles were present at one month but not later. The VDO determination is always an inaccurate and empirical process, and with the One-step No-prep approach, the principle is simply to recreate missing tissues on the basis of the remaining tooth anatomy. Although reported to be risky and not recommended for indirect restoration techniques, the one-step approach of VDO increase is already successfully used with direct techniques [16,12], and it was previously reported that a 5 mm increase atthe incisal pin did not engender any undesirable effects on the tempo romandibular joints and associated muscles [39,40]. In this limited clinical study, none of the patients reported any problems with the onestep VDO increase.

PICNs were confirmed to be well-adapted to the technique in terms of the ability to be milled in very low thickness (up to 0.11mm on molars) and ease of in-mouth adjustment, particularly regarding occlusal contact points. Indeed, ceramic restorations cannot be easily adjusted and repolished after placement, with PICNs and other composite materials being more adapted to a one-step approach. PICNs also exhibit an elasticity modulus, which is comprised between the enamel and dentin, while ceramics are too stiff, and other composites are too flexible, and their damping behavior is particularly interesting in cases of bruxism and high occlusal stress [41]. Other advantages of PICNs are the bonding properties: in the present study, despite the presence of bruxism and the non-retentive prosthesis design, only one debonding was registered among 192 restorations. It was related to a severely damaged upper incisor, with sclerotic dentin and a small amount of enamel, and the fracture occurred at the interface with tooth tissues and not in the material (Fig. 2). Regarding mechanical strength, 5.73 % of minor chipping was observed after two years, most often on thin restoration edges, which were in occlusal contacts. Indeed, restorations were very thin and submitted to extreme conditions, particularly due to high occlusal stress. From this point of view, the new generation of PICNs should perform better due to their high flexural strength and flexural load energy [41]. Despite this fact, the survival rate and success rate of restorations were 100 % and 93.75 %, at two years, which were higher than recently reported survival and success rates at three years for partial coverage posterior restorations in PICN (95.6 % and 82.4 %, respectively, for 44 restorations) [27] and in lithium disilicate glassceramic (98.3 % and 85 %, respectively, for 60 restorations) [42]. However, to the authors' knowledge, there have been no clinical studies reporting the performance of partial indirect restorations for full-mouth rehabilitation of severe worn dentition. Several studies were published about treatment of those cases with direct composites showing various results [14,16,43,12]. Loomans et al. reported, for 1256 restorations, an overall success rate of 94.8 % at 3.5 years, and a survival rate of 99.3 % [12], which is similar to the present study, while Sundaram & Bartlett concluded that the use of direct (as artisanal indirect) composite resin for restoring worn posterior teeth is contraindicated [14]. Those contradictory results could be explained by the operator-dependent effect of direct techniques, or the difference between the applied composite resins (microfilled versus highly filled hybrid composite resin) [16]. The inconvenience of direct composites is, from a material point of view and compared to PICNs and other CAD-CAM composites, the degree of conversion of monomers, which is lower due to the polymerization mode (light curing compared to high temperature and high pressure for PICNs) [44]. In fact, this parameter influences all material properties, such as mechanical properties, biological properties (monomer release), chemical stability and aging [24,25]. Moreover, CAD-CAM blocks are more homogeneous with fewer flaws, also promoting mechanical behavior. Finally, with respect to the rapid evolution of digital dentistry and chairside systems, occlusion and tooth anatomy will be easier to design with computer help, promoting the use of CAD-CAM restorations, particularly in composite materials, which are well-adapted to those manufacturing processes.

Regarding the restorations' color matching and translucency, the FDI criteria yielded high scores for evaluators and patients after two years. Furthermore, OHIP results showed significant better psychological comfort after treatment (Table 2).

Future perspectives include the study of new PICN materials, particularly the recently introduced biomimetic PICN, which exhibits a gradient in mechanical and optical properties to mimic tooth tissues. Its hardness is similar to enamel on the surface and dentin in the depths, and its high flexural strength and flexural load energy are promising in terms of wear behavior, chipping resistance and damping effect.

6. Conclusion

The One-step No-prep technique is a minimally invasive and straightforward approach for the treatment of severe and generalized tooth wear. The treatment protocol was shown to yield successful clinical results from the functional and aesthetic points of view, the one-step approach of VDO increase was well tolerated and the global OHIP score, as 6 sub-scores on 7, were significantly improved. The present study provided significant data about the clinical performance of PICN partial restorations with respect to the existing literature, constituting the largest sample of restorations examined until now. The observed survival (100 %) and success (93.75 %) rates of restorations at two years were high, despite the extreme conditions to which the material was submitted. Minor chipping of very thin borders submitted to occlusal stress was the most frequent complication encountered. Finally, with respect to the rapid evolution of digital dentistry and the development of chairside systems, occlusion and tooth anatomy will be easier to design with computer help, which promotes the use of indirect CAD-CAM composite restorations for the treatment of severe worn dentition.

Future perspectives could include the development of clinical research to confirm the present results and the performance of future generations of PICN materials, particularly biomimetic PICN.

7. CRediT authorship contribution statement

J Oudkerk: Methodology, Validation, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization, Project administration.
M Eldafrawy: Investigation, Data curation, Writing - review & editing.
S Bekaert: Validation, Formal analysis, Data curation, Writing - review & editing, Project administration.
C Grenade: Investigation, Writing - review & editing.
A Vanheusden: Investigation, Writing - review & editing.
A Mainjot: Conceptualization, Methodology, Validation, Investigation, Writing - original draft, Writing - review & editing, Visualization, Supervision.

8. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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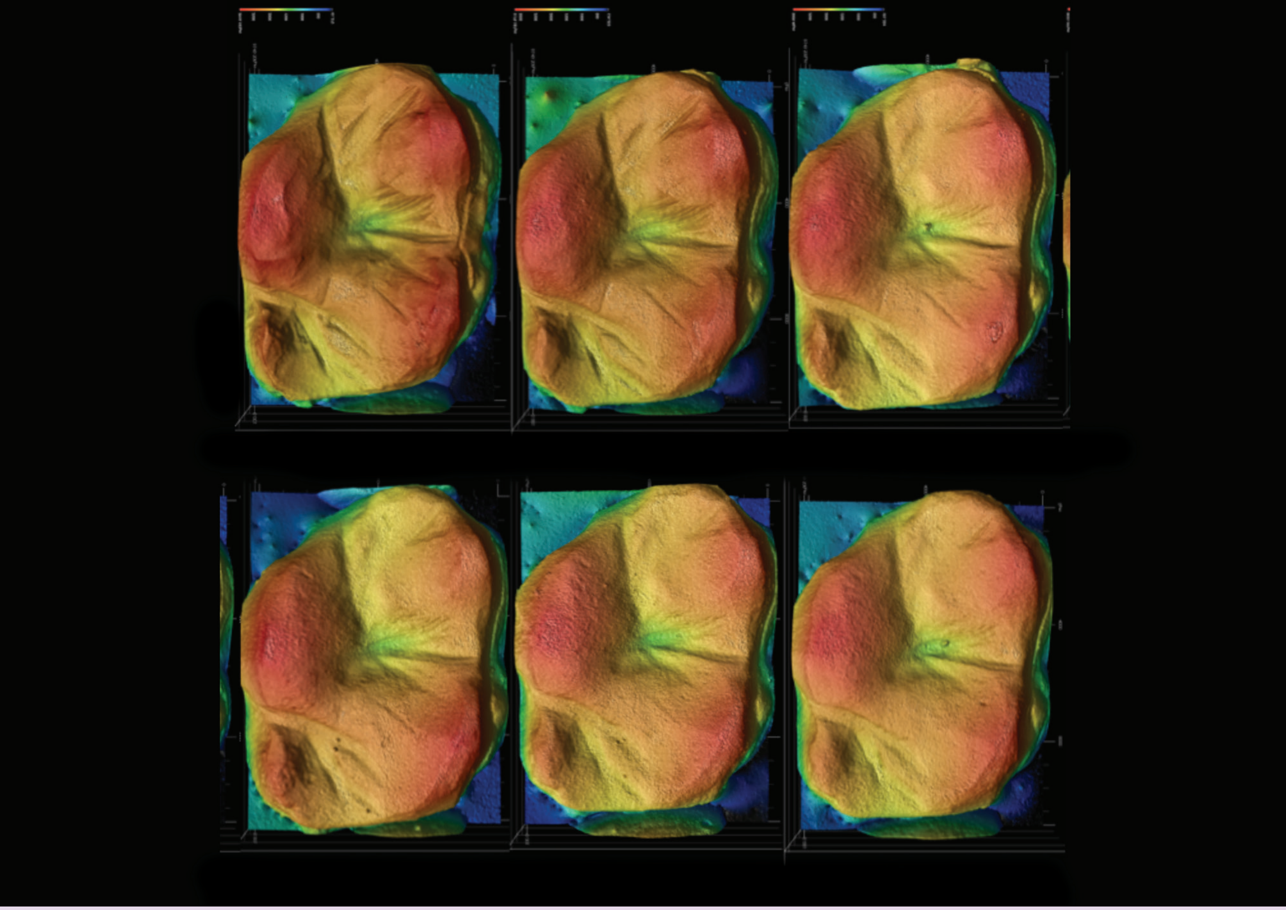

Chapter

7

Intraoral wear of PICN CAD-CAM composite restorations used in severe tooth wear treatment: 5-year results of a prospective clinical study using 3D profilometry

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1. Abstract

Objectives: To evaluate, in a prospective clinical study over 5 years with *ex vivo* 3D profilometry analyses, the intraoral wear of Polymer-Infiltrated Ceramic Network (PICN) CAD-CAM composite restorations used in severe tooth wear treatment with the One-Step No-Prep technique.

Methods: 192 PICN (Vita Enamic) restorations on molars and premolars were included in a prospective clinical study involving patients treated according to the One-step No-prep protocol (n = 7). All patients showed clinical signs of bruxism. Replicas of restorations on molars and premolars were realized at each evaluation time (baseline and then every year up to 5 years) and scanned to perform 3D profilometry. Baseline and recall scans were superimposed with Geomagic Control software. The mean material wear was calculated for the full occlusal area (FOA) and for the occlusal contact area (OCA), respectively. Clinical evaluation of restorations was performed at recall.

Results: At 5 years, the estimated mean material wear for FOA was inferior to the accuracy threshold of the profilometry measurement chain. For OCA, the estimated mean wear of the material was – 27.97 µm. This material wear was shown to be significantly influenced by time ($p < 0.0001$) and patient ($p = 0.026$), while the type of tooth (molar or premolar) had no influence. At 5 years, the survival and the success rates of restorations were 99.48% and 90.62%, respectively.

Significance: The PICN material exhibits a low wear process in the treatment of severe tooth wear despite the presence of clinical signs of bruxism, and it constitutes a suitable material for the One-step No-prep technique.

KEYWORDS

Dental materials, Biomaterials, Prosthetic dentistry, Material wear, CAD-CAM composite Polymer-infiltrated-ceramic-network, Quantitative analysis, Profilometry

2. Introduction

Computer-aided design–computer-aided manufacturing (CADCAM) composite materials appeared on the market more than ten years ago and they constitute the most recent class of CAD-CAM blocks for dental prostheses. Composites are well-adapted to milling processes, particularly chairside, and are gaining popularity thanks to fast manufacturing, related bur lifetime, lack of a firing procedure, ability to be milled in very low thickness, and ease of in-mouth adjustments and repair compared to glass-ceramics [1,2]. Moreover, the industrial manufacturing process of composite blocks produces a significant increase in material homogeneity and a decrease in the presence of flaws [3]. Most importantly, it allows for the use of more performant polymerization modes and innovative material microstructure, resulting in new families of composite materials, with significantly better properties than direct light-cured composites [4,5]. Currently, CAD-CAM composite blocks can be divided into two subclasses depending on their microstructure: dispersed filler materials (DF), where fillers are classically incorporated by mixing into the monomer matrix and polymerized at high temperature, and Polymer-Infiltrated-Ceramic-Network (PICN) materials, which are the result of the infiltration of a pre-sintered glassceramic scaffold with a monomer, which is secondarily polymerized at high temperature but also high pressure (HT-HP) [6,4] . PICN materials are also called "hybrid ceramics" or double network materials, into which the glass-ceramic particles are interconnected constituting a 3D scaffold, and since the polymerization process is patented, the only PICN material on the market is the Vita Enamic (VITA Zahnfabrik, Bad Säckingen, Germany) [7].

The mechanical properties of CAD-CAM composites blocks have often been investigated *in vitro*. In general, they exhibit mechanical values higher than those of artisanal light-cure composites, particularly in terms of flexural strength, while they are lower than those of reinforced-glass ceramic materials, such as lithium-di(silicate) based glassceramics, except for some experimental PICNs. Due to their original microstructure, PICNs show a higher elastic modulus and hardness than DF, these properties being closer to natural tooth tissues than other composite materials [4,8]. They also exhibit comparable fracture toughness and better damage tolerance than glass ceramics [7], and their damping behaviour related to the presence of polymer makes them particularly interesting in the case of bruxism and related high occlusal stress [9]. In general, CAD-CAM composites, especially PICNs, are recommended in severe tooth wear treatment, where highperformance composites exhibit many other advantages compared to glass-ceramics, such as their ability to be milled in low thickness, their easy-to-adjust character, and their repairability. In particular, the One-step No-prep approach, introduced in 2018, constitutes a minimally invasive treatment protocol characterized by the absence of a provisional phase ("One-step") and tooth tissue preparation ("No-prep"), due to the realization of very low thickness restorations [10,11].

However, data about PICN wear resistance are lacking; however, this information is crucial, especially in patients with bruxism [12]. To author's knowledge, the intraoral wear behaviour of CAD-CAM composites is still poorly studied; only two short-term *in vivo* studies related to DF and PICN materials are available in the literature [13,14,15]. In a systematic review of the *in vitro* wear resistance of CAD-CAM composite materials, Laborie et al. reported that PICN (Vita Enamic) show less wear than DF composites and more wear than the lithiumbased glass-ceramics, which are more abrasive [16]. However, if *in vitro* studies are useful, easy to perform, cheaper than clinical studies, and allow accurate analysis of the material surface, they face numerous difficulties in reproducing the oral environment and its variations, which can significantly influence their clinical relevance [17–19]. Therefore, the development of clinical studies, which allow material clinical wear measurement, is recommended [12].

Consequently, the objective of this work was to evaluate, in a prospective clinical study over 5 years with *ex vivo* 3D profilometry analyses, the intraoral wear of PICN CAD-CAM composite restorations used in severe tooth wear treatment with the One-Step No-Prep technique. The 2-year general clinical outcomes of this prospective study were published previously [11].

3. Materials and methods

3.1. Study design

The protocol of this clinical study was approved by the Ethics Committee of the University Hospital Center (CHU) of Liege and was registered in the ClinicalTrials.gov database (B707201526682). Written patient consent was obtained before inclusion. The patients were treated by four experienced practitioners from the Department of Fixed Prosthodontics, Institute of Dentistry, CHU of Liege, Belgium.

3.2. Patient selection

Patients presenting generalized severe tooth wear with an esthetic or functional demand were included in this prospective study. The patients were required to have a minimum of 28 teeth, with a minimum of 3 teeth per posterior sextant to restore with an indirect restoration, and palatal veneers from canine-to-canine superior teeth. The following patients were excluded from the study: smokers and patients with poor oral hygiene, those with periodontal disease or severe osteoarthritis, and patients with crowns, bridges, or implants. Patients with Parkinson's disease or spontaneous temporomandibular joint pain associated with a mandibular deflection and an opening limitation (< 25 mm) were also excluded.

4. Tooth wear diagnostic

4.1. Chemical tooth wear diagnostic

In addition to a thorough clinical examination to detect the presence of dental erosion surfaces (concave, cuneiform, or flat lesions), an accurate medical history was recorded including questions about nutrition habits, general diseases, medications, and environmental factors.

4.2. Mechanical tooth wear diagnostic: non-instrumental approach of bruxism assessment

A clinical examination was performed to register the presence of clinical signs of bruxism, such as dental attrition, cracks/fractures, masseteric hypertrophy, linea alba, exostoses or crenated tongue [20,21]. The presence of bruxism was recorded if the patient fulfilled at least two criteria: A) reporting of tooth grinding during the night or day; or B) the presence of at least one clinical sign among the following: abnormal attrition wear facets on the teeth; transitory pain or fatigue on awakening felt in the jaw muscles; temporal headaches on waking; and jaw locking on awakening related to teeth grinding during sleep [20,22]. The use of an occlusal nightguard was noted. A complementary clinical examination was performed by an occlusodontist (i.e., a specialist in occlusion and TMDs) to detect the presence of temporomandibular joint (TMJ) disorder. Occlusal relationships (class III or class II.2 malocclusion, anterior or posterior crossbite, edge-to-edge or open bite) were recorded before treatment.

5. Clinical protocol

The patients were treated according to the previously described One-step No-prep protocol [10,11] (Fig. 1). Restorations corresponding to the estimated tissue loss (palatal veneer, posterior occlusal tabletops and veneerlays) were milled from PICN blocks (Vita Enamic HT, Vita Zahnfabrik, Germany; Ceramill Motion 2, Amann Girrbach). The lowest thickness of each restoration was measured, and the mean restoration thickness registered was 0.7 ± 0.3 mm for premolars (n = 56) and 0.5 ± 0.2 mm for molars (n = 58).

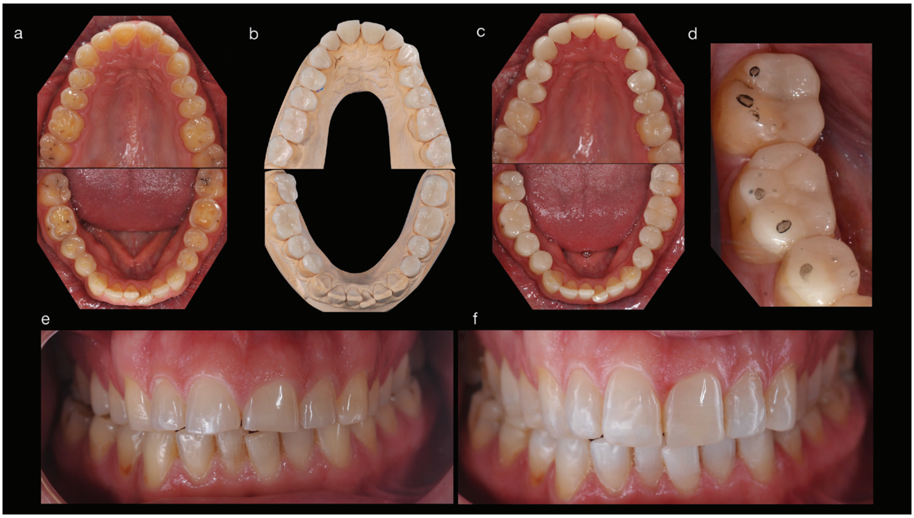

Fig 1 Case of a one-step no-prep treatment in a patient suffering with reflux, bruxism and soft drink excessive consumption.
a) Occlusal views before treatment
b) Occlusal views of final PICN restorations on plaster models after polishing (in this case, restorations were not stained)
c) Occlusal views after treatment
d) Occlusal view of occlusal contact area in maximum intercuspation occlusion in molars
e) Buccal view before treatment
f) Buccal view at the 14-month follow-up. The margin between the buccal surface and the palatal veneer was masked with direct composite (Inspiro, Edelweiss, Zug, Switzerland)

The lowest thickness measured was 0.11 mm on a molar [11]. The restorations were tried and then bonded within two consecutive days at two half-day appointments, one for eachmaxilla (the upper jaw on the first day afternoon, the lower on the second day morning). They were pretreated following the manufacturer's recommendations, i.e., etching the surface with hydrofluoric acid (HF) for 60 s, cleaning it in an ultrasonic bath in ethanol, and then applying a layer of silane (Silane Primer, Kerr, Orange, California, United States). A rubber dam was placed for the posterior teeth but not the anterior teeth. The tooth tissues were cleaned with pumice. A diamond bur at low speed was used to open the tubules of sclerotic dentin and enamel was etched with phosphoric acid. Direct composites were sandblasted with the Cojet system (3 M, Saint-Paul, USA) and a silane (Silane Primer, Kerr, Orange, California, United States) was applied. Then a two-step etch-and-rinse adhesive (Optibond XTR, Kerr, Orange, California, United States) was applied following manufacturer recommendations and the adhesive layer was polymerized before restoration bonding. The restorations were bonded with a composite resin cement withthe Nexus XTR system (NX3, Kerr, Orange, California, United States), polymerization was performed after excess removal, and final photopolymerization was performed under a glycerin film to avoid the persistence of a polymerization inhibition layer. Major occlusal adjustments were made immediately after bonding of the lower restorations with an Arkansas stone bur, followed by polishing with silicon gums and fine adjustments performed within the following month. A bleaching procedure (home bleaching with a night guard using the Illumine 10% tooth gel kit, Dentsply Sirona, New York, USA) was also performed (which was not possible when the dentin was still exposed). To mask the junction between the palatal veneer and the buccal face of the upper anterior teeth, direct composite (Inspiro, Edelweiss, Zug, Switzerland) was added on a slight chamfer performed across the junction and, where needed, to optimize tooth shape. Finally, an acrylic nightguard (for the upper maxilla) (Orthocryl, Dentaurum, Ispringen, Germany) was provided to all of the patients.

6. Recall

Baseline evaluation was performed after final occlusal adjustments (T0). Occlusal contact points in maximum intercuspation occlusion were photographed and recorded at T0 and at each recall appointment, which were scheduled after 1 year (T1) and each year (T2, T3, T4) up to 5 years (T5). Fig. 2

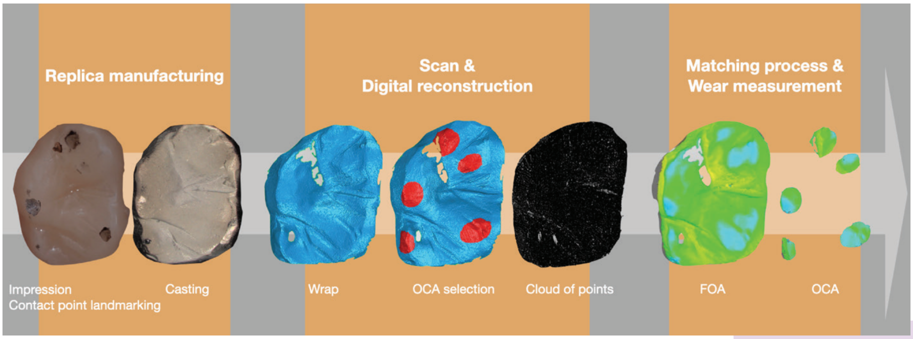

Fig 2 Schematic representation of wear measurement workflow. Images refer to the occlusal surface of a partial PICN restoration on a first molar. The wrap is a detailed superimposition of a patient-specific 3D dental model on a standard reference. OCA (occlusal contact area in maximum intercuspation occlusion) was identified from the clinical pictures and selected in the software. Full Occlusal Areas (FOA) and OCA were digitally delimited on each baseline scan using a mask, which was superimposed to recall scans for wear measurement.

7. Material wear measurement

The sample included all PICN restorations on premolars and molars.

7.1. Replica manufacturing

Restorations were cleaned first with a prophylaxis paste (Detartrine, Septodont, Saint-Maur-des-Fossés, France) and then with alcohol, to reduce the presence of biofilm and contaminants on tooth surface. Double mix impressions with polyvinyl siloxane (PVS) material (Imprint 4 heavy and XLV, 3 M ESPE, Seefeld, Germany) were performed on each posterior sextant with a perforated plastic impression tray. The buccal and lingual/palatal parts of the trays were removed in order to involve only the occlusal surfaces and also to reduce PVS deformation during disinsertion (Fig. 3). All impressions were carried out by the same practitioner (JO) and poured within 24 h using epoxy resin (2:1 wt% base and catalyst, respectively, PVD, Liege, Belgium). An initial layer of epoxy resin was applied using a plastic brush to ensure that the surfaces were properly wet and devoid of air bubbles. Replicas were cleaned ultrasonically in ethanol for 3 min and gold coated.

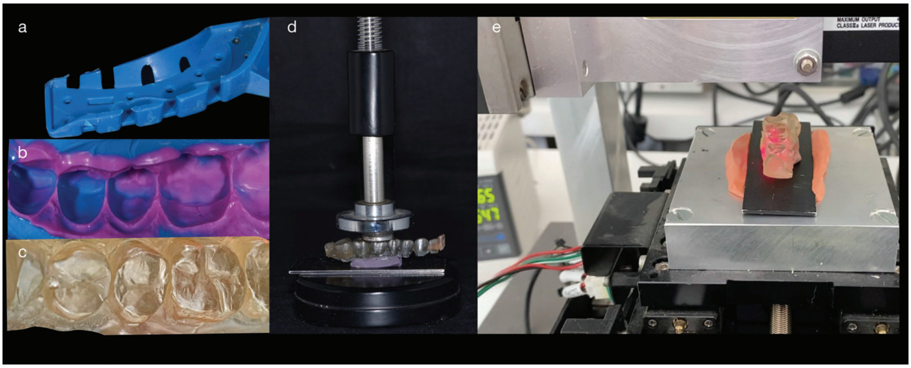

Fig 3 Replica manufacturing.
a) Customized perforated plastic impression tray: buccal and lingual/palatal recovering were eliminated to reduce impression deformation during disinsertion
b) Double mix impressions with polyvinyl siloxane (PVS) material (Imprint 4 heavy and XLV, 33 M ESPE, Seefeld, Germany)
c) Replicas in epoxy resin (2:1 wt% base and catalyst, respectively, PVD, Liege, Belgium) and gold coated
d) Gold-coated replicas scanned with a custom-made device including an XY motorized board stage and a 100 nm resolution laser sensor (Keyence LK G30 with LK GD500 controller, Keyence Corporation, Osaka, Japan)
e) Specific custom-made holder to ensure reproducibility of replica positioning at each evaluation time.

7.2. Profilometry

Gold-coated replicas were scanned with a custom-made device including an XY motorized board stage and a 100 nm resolution laser sensor (Keyence LK G30 with LK GD500 controller, Keyence Corporation, Osaka, Japan) with a step of 25 µm. Models were placed in a specific custom-made holder to ensure reproducibility of positioning at each evaluation time. In fact, the replica was placed on plasticine resting on a rigid metal plate. Using a piston parallel to the plate, pressure was applied to the occlusal surface of the first molar, which determines the 'horizontality'. Raw data acquisition and processing were performed using a custom-developed software with C# language (Microsoft Visual Studio 2013, Microsoft Corporation, Redmond, WA, USA) coupled to a digital data-acquisition PCI board (NI PCI-6534, National Instruments Corporation, Austin, TX, USA). The resulting matrix of Z values was then transferred to the surface-matching software Geomagic Control 2015 (Geomagic Inc, Morrisville, NC, USA). Baseline scans were transformed into a computer-aided design format (STL) and recall scans were superimposed using a best-fit alignment algorithm. First, the software randomly selected and aligned 300 data points. After this rough alignment, a fine alignment was performed using 1000 additional data points by iterative rotations and translations, minimizing the rootmean-squared (RMS) difference between the two images. The deviation eliminator function was used to choose data points with a minimum deviation in the z-axis. Only scans that successfully passed this matching process step were used for the wear analysis [23]. To prevent bias in the wear measurement related to artefacts or surface pollution, a threshold value of 300 µm was defined, leading to the exclusion of points with a measured difference greater than 300 µm from the wear evaluation. Each year, a value of 100 µm was added in relation to the reported wear of direct composites [24]. An additional control for adequate matching was the distribution of the z-values in areas that were not subjected to wear (for example, occlusal grooves). In those areas, data points with a difference in z-values greater than 15 µm were excluded. A 3D comparison analysis (with spectrum) was performed to visualize differences of wear between the scans, where the oldest scan was selected as the 'reference' and the newest scan as the 'test'.

A mean wear value was registered both for the entire occlusal surface (Full Occlusal Area (FOA)) and for each occlusal contact area in maximum intercuspation occlusion (OCA). OCA were identified from the clinical pictures. These areas were digitally delimited on each baseline scan using a mask based, which was superimposed to recall scans for wear measurement.

7.2.1. Accuracy and precision calibration of the measurement

The accuracy and precision of the measurement chain were assessed in a previous study in a series of three experiments using the referencefree superimposition algorithm of Geomagic software according to the protocol proposed by Rosin et al. [25]: (1) precision of the automatic 3D superimposition algorithm, (2) precision of 3D data acquisition, and (3) precision of the reference-free 3D superimposition [17]. Intrinsic errors of the software superimposition program (experiment 1) resulted in an accuracy of 0.01±0.01 μm (the accuracy is reported as the mean of the multiple measures and the precision corresponds to the standard deviation. Assessment of the three-dimensional data acquisition produced height differences of 0.09 ± 0.09 μm (experiment 2). The super-imposition when the position of the restoration within the laser scanner was altered after each scanning procedure (experiment 3) resulted in an accuracy of 0.47±0.17 μm. The vertical resolution of the laser scanner was 15 μm. Therefore, the accuracy threshold of the measurement chain was 15 μm [23].

7.3. Laser confocal microscope

3D images of the replica of a restoration at each evaluation time were obtained using laser confocal microscope (Keyence VK 3050, x and y resolution 5 μm, z resolution 1 nm), at 2.5 fold magnification and four images were stitched together (2 ×2).

8. Statistical analysis

Qualitative variables are described using frequency tables (numbers and percentages) while continuous quantitative variables are described using mean and standard deviation. Simple mixed models are used to investigate different effects on mean distances, considering repeated measurements per tooth within each patient. The results are considered significant at the 5% uncertainty level ($p < 0.05$). Calculations were performed using SAS statistical software version 9.4 and graphs using R statistical software version 4.2.2.

9. Results

9.1. Clinical data on patients and restorations

Seven patients were recruited (6 males and 1 female), with a mean age of 37.7±12.8 years old, and including a total of 192 PICN restorations. Six patients were in class I and one patient was in class II.2 occlusion. Among the treated patients, 57.2% (n = 2) showed a group function, 14.3% (n = 1) had a canine function and 28.5% (n = 2) had both types of function. Regarding the etiology of wear, all patients showed signs of chemical (erosion) and mechanical (bruxism) wear. All patients reported grinding or clenching habits during the night or during the day. At 5 years, the survival and success rates of restorations (n = 192) were 99.48% and 90.62%, respectively including 16 minor chipping, 1 debonding and 1 loss of restoration (tooth fracture). Restorations presenting minor chipping were polished (n = 13) or repaired (n = 3).

9.2. Profilometry

9.2.1. Scan data

A total of 113 premolars and molars restorations were included and evaluated at each recall, except at 3 years (n = 96 at 3 years due to the absence of one patient with 17 restorations), corresponding to a total of 548 scans over 5 years. Thirty-four restorations were excluded from the results because they were not in occlusion with the antagonistic teeth (n= 5), or they were submitted to occlusal adjustments after the baseline assessment (n = 13), or they encountered minor chipping or repair on the occlusal surface (n=16). Additionally, 73 scans (13.32%) were excluded from the analyses because they were unable to be matched. Consequently, the total number of scans included in the results was 393. All surfaces studied had PICN restorations as an antagonist.

9.2.2. Material wear measurement

Table 1 shows the evolution of the mean wear of the material considering the FOA and the OCA, respectively. At 5 years, the estimated mean material wear for FOA was + 5.71 µm, which is lower than the accuracy threshold of the profilometry measurement chain and – 27.97 µm for OCA. There was no significant difference between premolars and molars, while a time and a patient effect were detected. The effect of time was more significant for OCA than for FOA surfaces: this effect is represented graphically in Fig. 5.

9.3. Laser confocal microscope

Fig. 4 shows the 3D images of the replica of the same restoration as in Fig. 3 at each evaluation time. The images show an overall reduction in relief, which is more pronounced in the occlusal contact areas. The measured wear on the FOA at 5 years on this restoration was below the accuracy threshold of the measuring chain (15 µm), while the measured wear on the OCA was – 45.82 µm.

Variable	Categories	FOA Estimated mean (µm)	p-value	OCA Estimated mean (µm)		p-value
Time (year)			0.011 * *			< 0.0001
	1	5.82		-2.99	ad	
	2	2.92		-9.47	b	
	3	2.46		-12.90	c	
	4	5.51		-20.24	d	
	5	5.71		-27.97	abc	
Type of teeth			0.053			0.74
	Premolar	3.40		-6.25		
	Molar	4.97		-7.64		
Patient			0.0035 *			0.026 *
	1	2.97		-9.73		
	2	2.88		-2.79		
	3	1.66	e	-0.77		
	4	5.03		-10.98		
	5	5.40		1.31		
	6	7.43	e	-18.20		
	7	4.65		-21.40		

Tab 1 Description of separated effects on mean distances for FOA or OCA (N = 98 teeth). Significant differences based on Scheffe correction: pa< 0.0001, pb= 0.0029, pc= 0.0089, pd= 0.013 and pe= 0.023. Results of type of teeth categories showed an annual mean of FOA and OCA. * Indicated that significant results were observed (p < 0.05).

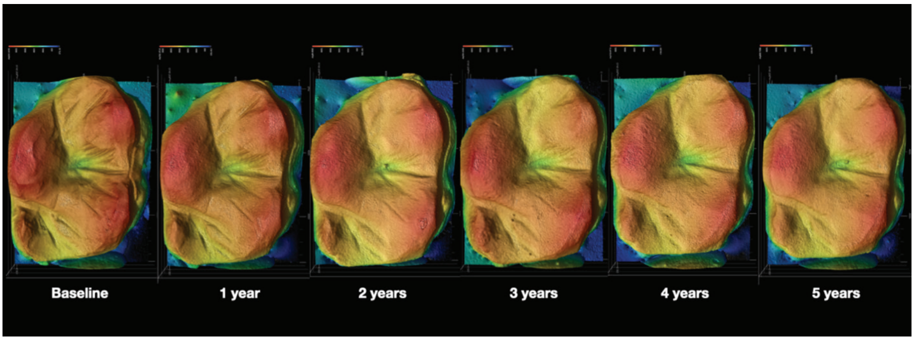

Fig 4 3D images obtained by laser confocal microscopy of the replica of the same restoration as in Fig. 3 at each evaluation time.

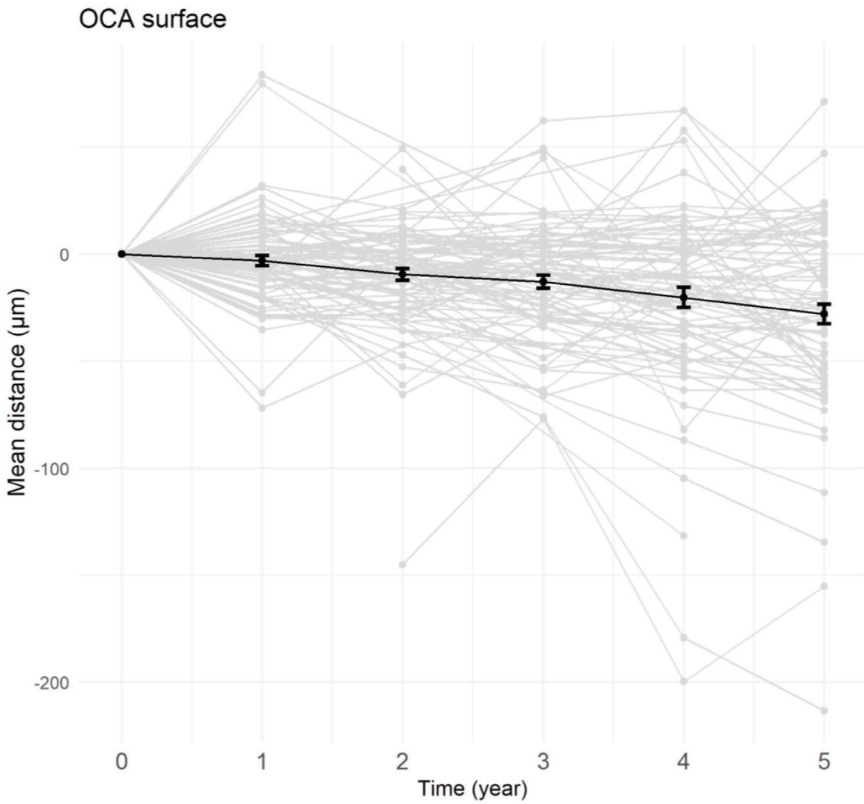

Fig 5 Evolution of the mean distance on the OCA surface as a function of time. The mixed model (mean ±SE – in bold) is added to the individual evolution of each tooth (in grey).

10. Discussion

Studying the wear of prosthetic materials involves asking the question: What should be the ideal material's behaviour in terms of wear? In fact, the ideal material is not a material that does not wear, such as zirconia [23,26]: it should behave as closely as possible to the tissue it replaces, i.e. be biomimetic, being able to follow the evolution of patient occlusion with tooth wear, and also being also able to adapt to occlusal contact point adjustment errors. Following Lambrechts et al., the wear of opposing enamel is 15 µm and 29 µm per year under normal circumstances for premolars and molars, respectively [27]. However, Esquivel-Upshaw et al. [28] reported enamel wear of 40–80 µm per year. In the present study, the mean wear of PICN opposing PICN in patients with severe tooth wear and bruxism is lower than those values (–27.97 µm for 5 years in OCA surfaces, while not detectable for FOA, i.e. inferior to 15 µm), meaning that the patients treated lost less tooth height than a healthy patient. Fig. 4 confirms that the wear process is more pronounced in areas of occlusal contact. Those data confirm results of an *in vitro* study, which showed less wear for Vita Enamic than for enamel [29]. Therefore, within the limitations of this study, PICNs could be considered suitable materials for the treatment of generalized wear, as they resist wear phenomena at least as well as enamel, and do not induce excessive wear of antagonistic restorations when they are made of the same material. In fact, the material may even wear a little more to better mimic enamel. However, it should be noted that the results were patient dependent, and an explanation of this effect may be the wearing of a nightguard. In fact, 3 out of the 7 patients reported not to wear it, and those patients showed higher values of material wear after 5 years (patients 1, 6 and 7). However, there is no proof that the other patients wore their nightguards every night and patient 7 also showed a higher value of material wear despite reporting wearing the nightguard. Other patient-related factors could affect the wear behaviour, such as lifestyle, and most of all severity of bruxism (awake and sleep), which were previously shown to influence the risk level of material wear [30]. In addition to their wear behaviour, PICNs offer numerous advantages in the context of the one-step no-prep protocol, such as their ability to be milled in very low thickness and their damping effect.

Comparison of the present results with the data in the literature is difficult, since intraoral wear of CAD-CAM composites has been poorly studied (to date and to the authors' knowledge, only two *in vivo* studies are available) and measurement methods vary [13,14,15]. In fact, different methods have been reported to assess material wear clinically, and Wulfman et al. have reported an important lack of standardization of wear measurement procedures in clinical studies and an important variation in terms of the performance of the different measurement workflows described [17]. Digital profilometry combined with a matching software is reputed as the best technique for wear measurement in clinical studies [31,32] and is the most often used tool. In the present study, a rate of excluded scans of 13.32% was reported, which is a low and acceptable rate compared to the literature [17] and can be attributed to the precaution implemented within the protocol, aimed at acquiring scans of elevated quality and precision. Replica use should be avoided as much as possible, but this option is only valid for restorations that can be removed and scanned directly [17]. In fact, replicas generate inaccuracies mainly due to the deformation of the impression material, the casting or the presence of positive bubbles on the surface (see Fig. 5). The present protocol aimed to reduce some of these inaccuracies, in particular through the cleaning of the restoration, the injection technique, the use of a hydrophilic silicone and the use of a customized impression tray, which reduces the amount of impression material and allows better control of the silicone layer. In most cases, positive bubbles were unique and smaller than 0.2 mm in diameter (see Fig.5). They were also located at the bottom of the groove, which does not interfere with the analysis of the OCA. On the other hand, the use of intraoral scanners is promising for analyzing the wear of restorative materials and dental tissue [33], but currently they lack accuracy and precision [34].

In the first study related to intraoral wear of CAD-CAM composites [13], 24 single crowns were performed in different materials (two lithium-based glass-ceramic (IPS e-max CAD and Vita Suprinity), one DF CAD-CAM composite (Cerasmart (GC) and PICN (Vita Enamic)). The measurement and recording of the crown surfaces using an intra-oral scanner were carried out in the short term. At 6 months, no significant differences were detected between li-based glass-ceramic materials and CAD-CAM composites (DF and PICN) in terms of material and wearinduced antagonist [13]. However, there was a significant difference between DF and PICN, in which DF were shown to be subjected to higher material wear, in addition to being less abrasive for the antagonist. In the second study [14,15], 12 patients underwent complete rehabilitation with full occlusal coverage restorations (experimental DF CAD-CAM composite or lithium-based glass-ceramic). Impressions were made and the models were scanned with a laboratory scanner (D810, 3Shape, Copenhagen, Denmark), which is less accurate than the scanner used in the present study [17]. At 1 year, the mean material wear for pressed lithium disilicate ceramic restorations was 90.0 ± 40.8 μm (mean±SD) for the premolar and 93.6±24.0 μm for the molar, while the mean material wear of the experimental DF CAD-CAM composite was 186 ± 107 μm (mean ± SD) for the premolar and 342 ± 242 μm for the molar, respectively [15]. These values are much higher than the present results and can be explained by the method used.

Results can also be compared with data related to direct composites. Recently, Ning et al. reported results after 5 years of patients with severe tooth wear treated with direct composite restorations made of two different composite materials. Quantitative wear analysis was performed using intra-oral 3D scans (LAVA COS/True Def, 3 M) superimposed with Geomagic software (3D Systems, Morrisville, North Carolina, USA). The results showed a mean wear on bearing cusps of molars of – 464 ± 185 μm (mean ± SD) and – 318 ± 281 μm (mean ± SD) for the two different composite materials, respectively. These values are much higher than those of natural tooth tissue, which highlights one of the disadvantages of direct composites. In the same way, Söderholm et al. reported, using replica and 3D-profilometry, a mean vertical height loss of direct composite of 102 µm after 1 year [24] while two other studies reported, with the same method, values between 20 and 40 µm [35,36]. Glass-ceramic 1-year mean material wear in the frame of full-mouth treatment was mentioned to vary between 12 µm (feldspathic ceramic) [37] and 90 µm (lithium-based glass-ceramic) (replicas and 3D-laser profilometry) [15]. Surprisingly, these values are also superior to the results of the present study.

Future prospects include the study of material wear resistance at longer term and the evolution of intra-oral scanner resolution, which should make it possible to avoid the use of replicas and improve final accuracy and precision.

11. Conclusion

In the context of the treatment of severe tooth wear, PICN (Vita Enamic), with the same material as antagonist, shows lower material wear values than reported for natural enamel. It does not induce a significant abrasive effect, thus promoting the stability of the recreated vertical dimension of the occlusion while allowing the adaptation of occlusal contacts to function over time. On the basis of the concept that the ideal restorative material for a single-unit restoration should behave like natural tooth tissue in a biomimetic approach, PICNs are appropriate and in-between materials, since zirconia are reported to be wear-resistant, and direct composites wear too much. PICN material wear was limited to occlusal contacts and, at 5 years, the restorations showed excellent clinical results with a survival and a success rates of 99.48% and 90.62%, respectively.
In conclusion, PICNs appear to be adapted to severe tooth wear treatment in high-risk patients with bruxism, considering that they combine the advantages, without the disadvantages, of direct composites and reinforced glass-ceramics in terms of material wear, and the ability to be milled in very low thickness (promoting no-prep treatment), as well as the ability to deform thanks to the presence of polymer (promoting occlusal stress adaptation).

12. Declaration of Competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Amélie Mainjot is married with the founder of the company Majeb, which participates in the development of PICN biomaterials.

13. Acknowledgments

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The One-Step No-Prep Technique for Minimally Invasive Full-mouth Rehabilitation of Worn Dentition using PICN (Hybrid Ceramic) CAD-CAM Restorations: Up to 9-Year Results from a Prospective and Retrospective Clinical Study

Chapter

8

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1. Abstract

Objectives: To report up to 9-year results of non-invasive full-mouth rehabilitation of worn dentition with PICN CAD-CAM restorations using the One-Step No-Prep technique. The secondary objective is to evaluate the influence of restoration thickness on fracture of restorations.

Methods: A total of 580 Vita Enamic restorations (218 anterior and 362 posteriors; 260 monoblock (MO) and 320 multiColor (MC)) in 24 patients were clinically evaluated once a year (from 11 months to 9 years) according to FDI criteria. The minimum thickness of restorations was measured in 15 patients.

Results: The Kaplan-Meier survival rate of restorations at 9 years was 98.4% (100% for anterior and 96.7% for posterior) and the success rate was 79.7%, while the success rate excluding minor chipping requiring only polishing was 86.7%. Actually, minor chipping was the leading cause of failure and significantly more fractures were observed in the posterior region (9.2 times higher risk), particularly in the first and second molars or when the restoration thickness was less than 0.56 mm. Except for fracture, FDI evaluation showed clinically acceptable results for all restorations, mostly rated as excellent. Results remained consistent over time, including material luster and color, with no staining. MC showed superior esthetics compared to MO. Patient satisfaction was high.

Significance: The One-Step No-Prep technique exhibits successful long-term outcomes, and PICN (hybrid ceramic) is an appropriate material for this non-invasive treatment of tooth wear. Nevertheless, the minimum thickness of posterior restorations should be 0.6 mm, particularly at occlusal contact points. MultiColor blocks are recommended for esthetics.

KEYWORDS

Tooth wear, CAD-CAM composite, fixed prosthodontics, dental materials, fracture

2. Introduction

Tooth wear (TW) is known to have a high and increasing prevalence, especially among young patients. TW is a multifactorial condition influenced by changing lifestyles [1]. Chemical erosion, driven by acidic foods and drinks as well as gastroesophageal reflux (GER), is a major contributing factor [2, 3]. Additionally, mechanical wear is frequently linked to bruxism, which results in attrition (the loss of tooth tissue on the occlusal surface due to friction) and abfraction (the loss of tooth tissue near the gum line due to mechanical stress) [4] [5]. Various methods have been described to rehabilitate patients suffering from severe TW [6]: direct techniques with light-cured composites [7] [8], indirect techniques using different materials such as, CADCAM composite or ceramics [9][10][11][12]; or a mix of the two techniques.

In 2018 and 2020, Mainjot introduced the One-Step No-Prep technique for the treatment of generalized [13] and localized [14] severe TW, respectively. This technique uses Polymer- Infiltrated Ceramic Network CAD-CAM bonded partial restorations (PICN or "hybrid ceramics", Vita Enamic, Vita Zahnfabrik, Germany) [15] Its main feature is that it does not require any preparation of the tooth tissue ("no-prep" technique) and is performed in a single step, i.e. there is no phase with temporary restorations ("one-step"). This is made possible by the fact that PICN are composite materials that can be milled to a very thin thickness, bonded in a high-performance manner [16] and easily retouched to adjust proximal and occlusal contact points. The material is also easy to repair in the event of failure. In this way, the technique combines the advantages of direct techniques (minimally invasive, one-step procedure, easy to repair) and indirect techniques (access to materials that perform better than direct restoration materials, restoration anatomy realization with greater ease and speed). This approach also includes bruxism management by maxillofacial physiotherapist and occlusal analysis for full mouth cases [13]. For localized TW, the technique is associated with simple orthodontic extrusion (orthodontic-assisted One-Step No-Prep technique) [14].

The first three pilot cases of generalized severe TW were realized in 2014 and 2015 [13]. The 2-year results of a prospective study including material wear analysis of 7 additional clinical cases were published in 2020 [12]. All the results were very promising, and our team developed the technique routinely. More recently, 5-year results of the evaluation of intraoral PICN wear in the 7 cases using *ex vivo* 3D profilometry have been published [17].

The purpose of the present work is to report the up to 9-year results of a prospective and retrospective study of minimally invasive full-mouth rehabilitation of worn dentition with PICN (hybrid ceramic) CAD-CAM restorations using the One-Step

No-Prep technique, from the first pilot study conducted at the Department of Fixed Prosthodontics of the University Hospital Center of Liège. The secondary objective is to evaluate the influence of PICN restoration thickness on fracture of restorations.

3. Materials and methods

3.1. Study design

This study is a prospective and retrospective clinical study evaluating patients treated with the « One-Step No-Prep « protocol. The patients were treated in the Department of Fixed Prosthodontics of the University Hospital of Liège by four experimented practitioners (AM, JO, CG, AV). The study was approved by the Ethics Committee of the University Hospital of Liège (B707201526682, B707201835507). A total of 24 patients (n=580 PICN restorations) was included in this study and evaluated from 11 months to 9 years: three pilot cases realized in 2014 and 2015 [13] and 21 cases realized since 2016. These three pilot cases were studied retrospectively but were routinely followed by the practitioner once a year. The mean age was 44.0 years old (range 26 to 72 years) and 13 patients were men. Table 1 lists the patients and restorations characteristics. Two groups of patients were observed, characterized by the two types of PICN used: Vita Enamic Monoblock Translucent or High Translucent (n=260) and Vita Enamic MultiColor (n=320) (Vita Zahnfabrik, Germany).

3.2. Patient selection

Patients presenting generalized severe tooth wear with an esthetic or functional demand were included in the study. Patients were required to have palatine veneers from canine to superior canine, and a minimum of 3 teeth per posterior sextant to be restored with an indirect restoration. The following patients were excluded from the study: patients with untreated periodontal disease and patients with removable prosthesis. Patients with Parkinson disease, or severe arthropathy or spontaneous temporomandibular joint pain associated with mandibular deflection and limited opening (<25 mm) were also excluded.

3.3. Wear quantification

The Basic Erosive Wear Examination index (BEWE) [18] was calculated for each patient by the same practitioner (JO).

3.4. Chemical erosion assessment

In addition to a thorough clinical examination to detect the presence of dental erosion surfaces (concave, cuneiform or flat lesions), a questionnaire on dietary habits, general diseases, medications and environmental factors was completed to identify risk factors.

Patients (n tot=24)	% (n)	
Sex		
Female	45.8% (11)	
Male	54.2% (13)	
Impression - Occlusal analysis		
Analog	95.8% (23)	
Digital	4.2% (1)	
Adhesive		
Excite	8.3% (2)	
Adhese Universal	62.5% (15)	
Optibond XTR	29.2 % (7)	
Composite resin cement		
Variolink Esthetic DC	70.8% (17)	
Nexus XTR	29.2% (7)	
Restorations (n tot=580)	**% (n)**	**Follow-up (years) Mean +/- SD (range)**
Type of restorations		
Anterior	37.6% (218)	
Palatal veneers	21.6% (125)	
Chips	11.4% (66)	
Envelope	3.1% (18)	
Buccal veneers	0.5% (9)	
Posterior	62.4% (362)	
Occlusal tabletop	51.9 % (301)	
Onlays	6.0% (35)	
Veneerlays	4.5 % (26)	
Type of Vita Enamic block		
Monoblock	44.8% (260)	7.0 +/- 0.7 (6.0 - 9.1)
MultiColor	55.2% (320)	2.4 +/- 1.0 (0.9 - 4.1)

Tab 1 Sample description in terms of patients and materials used.

3.5. Non instrumental approach of bruxism assessment

A clinical examination was performed to register the presence of clinical signs of bruxism, such as dental attrition, cracks/fractures, masseteric hypertrophy, linea alba, exostoses or crenated tongue [19] [20]. The presence of bruxism was recorded if the patient fulfilled at least two criteria: A) reporting of tooth grinding/clenching during the night or day; and B) the presence of at least one clinical sign among the following: abnormal attrition wear facets on the teeth; transitory pain or fatigue on waking felt in the jaw muscles; temporal headaches on waking; and jaw locking on waking related to teeth grinding during sleep [19] [21] [22]. A complementary clinical examination was performed by an occlusodontist (i.e. a specialist in occlusion and TMDs) to detect the presence of temporomandibular joint (TMJ) disorder. If patients showed symptoms of temporomandibular joint disorders, they were not treated and they were referred to the specialist. Finally, the wearing of an occlusal nightguard before treatment was recorded.

3.6. Clinical protocol

The patients (n=21) were treated according to the previously described "One-Step No-Prep" protocol [13] (Figure 1). Before treatment, a complete dental examination with carious and periodontal examinations, X-rays and photographs was performed. Double mix impressions with polyvinyl siloxane (PVS) material (Imprint 4 Heavy and XLV, 3M ESPE, Seefeld, Germany) were made, and study models were cast (GC Fujirock EP Super Hard Plaster, GC Europe, Leuven, Belgium). Then an occlusal analysis was performed using a resin jig [23] and a facebow (Quick facebow, Sintec Inc, New Hampshire, USA). The jig was placed for a few minutes to induce muscular relaxation and lower jaw repositioning, and then occlusal relationships were registered with wax (Moyco Beauty Wax, Philadelphia, PA, USA) in double thickness. The dental technician proceeded to a a diagnostic wax-up and started to deposit the wax on the less damaged teeth. He was guided by the residual tissues to restore tooth anatomy, resulting in a very low wax thickness on some posterior teeth. With this "tissue-guided" approach, the estimation of the new VDO was empirical. The wax-up was shown to the patient for approval. Subsequently, the treatment began with the replacement of amalgam fillings and deficient composite restorations with direct composite restorations by the operator (Els composite extra low shrinkage, Saremco Dental, Rebstein, Switzerland or Inspiro, Edelweiss, Zug, Switzerland) or the general dental practitioner (various products were used). Before final impressions, dental tissues were not prepared, but sharp angles were softened. Large direct composite fillings were partially removed to be replaced by indirect restorative material, but the cavity floor

Fig 1 *Case of the first patient treated with the One Step - No Prep technique using PICN restorations. On the buccal surface from 13 to 23, lithium (di)silicate reinforced veneers (IPS e.max Press, Ivoclar Vivadent) were fabricated secondarily. Minor chipping of thin restoration margins in occlusal contact was observed in tooth 15 and in tooth 17. Prosthodontics: Prof. A. Mainjot. Dental laboratory for PICN restorations made with the Cerec system (Dentsply Sirona, Charlotte, CN, USA): Renaud Maka, University of Liège. Glass-ceramic veneers: Dental technician: Pieter Ghysens, Brussels, Belgium*
a) Frontal view before treatment
b) Occlusal view of the upper maxilla before treatment
c) Occlusal view of the lower maxilla before treatment
d) Frontal view after treatment
e) Occlusal view of the upper maxilla after treatment
f) Occlusal view of the lower maxilla after treatment
g) Frontal view at 9 years after treatment
h) Occlusal view of the upper maxilla at 9 years after treatment
i) Occlusal view of the lower maxilla at 9 years after treatment

was left intact to avoid any sensitivity (in some cases cavities were filled with provisional composite resin, Telio CS Onlay, Ivoclar Vivadent, Schaan, Lichtenstein)). If required, endodontic treatments were performed previously. New double mix impressions (n=23) and occlusal analysis were performed following the same protocol as previously. One case was digitally realized using an optical impression with an intraoral scanner (Primescan, Dentsply Sirona, Charlotte, North-Carolina, USA) and a jaw tracking system for occlusal analysis (Modjaw, Villeurbanne, France). It should be emphasized that the patients did not wear any occlusal splints to test the new VDO before treatment. In some cases, models and full waxups were scanned and superimposed using a CAD-CAM system (Ceramill system, Amann Girrbach AG, Koblach, Austria); in more recent cases, digital set-up was performed directly. A CAD-CAM mock-up was realized in wax and tried to validate the restoration design and esthetic result (Ceramill Wax, Amann Girrbach AG, Koblach, Austria). Restorations corresponding to the estimated tissue loss were milled from PICN blocks (Vita Enamic, Vita Zahnfabrik, Germany; Ceramill Motion 2, Amann Girrbach). Depending on the situation, different restoration designs were used. In the anterior region, palatal veneers, buccal veneers, chips or envelope restorations were performed, and in the posterior region, occlusal tabletops, onlays and veneerlays were employed (Table 1). Two types of PICN were used: Vita Enamic Monoblock Translucent or High Translucent (n=10) and Vita Enamic multiColor (n=14) (Vita Zahnfabrik, Germany). Some restorations were only polished, and some were stained with a light-cured nanofilled composite coating agent (Optiglaze, GC Corporation, Tokyo, Japan or VITA Akzent Plus, Vita Zahnfabrik, Germany). Restorations were tried and then bonded within two consecutive days at two half-day appointments, one for each maxilla (the upper jaw on the first day afternoon, the lower on the second day morning). Restorations were pretreated according to the manufacturer's recommendations, i.e., etching the surface with hydrofluoric acid (HF) for 60 seconds, cleaning it in an ultrasonic bath in ethanol, and then applying a layer of silane (Silane Primer, Kerr, Orange, California, United States or Monobond Plus, SG Ivoclar Vivadent, Schaan, Lichtenstein). A rubber dam was placed for the posterior teeth but not the anterior teeth. Tooth tissues were cleaned with pumice. A diamond burr at low speed was used to open the tubules of sclerotic dentin and enamel was etched with phosphoric acid. Direct composites were sandblasted with the Cojet system (3M, Saint-Paul, USA) and a layer of silane was applied. Then a two-step etch-and-rinse adhesive (Optibond XTR, Kerr, Orange, California, United States) or an universal adhesive (Adhese Universal, Ivoclar Vivadent, Schaan, Lichtenstein) was applicated following manufacturer recommendations and the adhesive layer was polymerized before restoration bonding. The restorations were bonded with a composite resin cement, either Nexus XTR (NX3, Kerr, Orange, California, United States) or Variolink Esthetic DC (Ivoclar Vivadent, Schaan, Lichtenstein). Polymerization was performed after excess removal and final photopolymerization was carried out under a film of glycerin to avoid the persistence of a polymerization inhibition layer. Major occlusal adjustments were made immediately after bonding of the lower restorations with an Arkansas stone burr, followed by polishing with silicon gums and fine adjustments performed within the subsequent weeks. Silicon gums include the Easycomp polishing set (EVE Ernst Vetter GmbH, Germany) and since its introduction, the Vita Enamic polishing set (Vita Enamic, Vita Zahnfabrik, Germany).

A bleaching procedure (home bleaching with a night guard using Illumine 10% tooth gel Kit (Dentsply Sirona, New York, USA) or Opalescence 10% tooth gel (Ultradent Products, South Jordan, UT USA) was also performed (which was not possible when the dentin was still exposed). To mask the junction between the palatal veneer and the buccal face of the upper anterior teeth, direct composite (Inspiro, Edelweiss, Zug, Switzerland) was added on a slight chamfer performed across the junction and where needed to optimize tooth. In some cases (n=3) where TW was more severe on the buccal surface, lithium (di)silicate-reinforced glass-ceramic veneers were used in addition to the palatal veneers ("sandwich technique"). Finally, a nightguard (for the upper maxilla) was provided to all of the patients (Orthocryl, Dentaurum, Ispringen, Germany, n=22). Two patients received a CAD-CAM nightguard using a PMMA blank (Splint Transparent, Zirlux, NY, USA).

3.7. Registration of patient data

Gender, age, and occlusal relationships were registered (dental class, function, overjet, overbite, crossbite). In 15 of 24 patients, the VDO increase was recorded at the incisal guide pin.

3.8. Registration of prosthetic parameters

The minimum thickness of each restoration was measured in 384 restorations (15 in 24 patients). The type of antagonist (enamel, dentin, direct composites, PICN restoration) was also noted for each restoration.

3.9. Clinical evaluation of restorations

Two independent and calibrated evaluators assessed restorations following the criteria of the World Dental Federation (FDI) [24]. Three dimensions, representing 18 items, were described: esthetic, functional and biological. The functional and esthetic dimension includes patientreported satisfaction. Each item is assessed on a 5-point Likert scale (1 corresponding to an excellent restoration and 5 corresponding to a restoration that must be replaced). In case of discrepancies, agreement was found between evaluators to determine the final score. Different types of restoration failure were defined: fracture, debonding, caries at restoration margin, as well as endodontic failure and fracture of the tooth supporting the restoration. Restoration fracture was further graded from 0 to 5 according to FDI criteria with (0): no crack, chipping/delamination or material bulk fracture; (1): one hairline crack; (2): two or more or larger hairline cracks and/or material chip. fracture not affecting the marginal integrity or approximal contact (material loss can mainly be corrected by repair if needed); (3): material chip fractures which damage marginal quality or proximal contact; (4): bulk fracture with partial loss (less than half of the restoration, repair is possible); (5): generalized severe deficiencies, e.g., extensive delamination, multiple bulk fractures, or (nearly) completely loose/lost restoration (repair not possible/reasonable) [24].

3.10. Statistical analysis

Data analysis was carried out in R (version 4.3) using the statistical software jamovi Project 2024 version 2.5.6 (https://www.jamovi.org/). In calculating the success rate, we defined a restoration as «success 1» if it did not require any intervention during the follow-up period, as well as exhibiting no signs of failure. As proposed by other authors, we also calculated a second success rate, «success 2,» which included minor chipping that required only polishing as success. This approach aligns with the definition of success proposed by [25] and [26]. Finally, we defined a restoration that did not require replacement as «survival». Kaplan–Meier curves were applied to illustrate the no-fracture success or survival probability over time and to generate life tables. The log-rank test was used to compare differences between groups (anterior vs posterior, type of PICN, type of restoration, BEWE score). In addition, Bonferroni corrections Cox proportional hazards model was computed to assess the potential influence of several factors on restoration success or survival and find cut-off (age, gender, thickness of the restoration, tooth position 4-5-6-7-8, DVO, anterior vs posterior). Annual failure rates (AFRs) were calculated from life tables according to the formula: (1 − y) z = (1 − x), in which "y" expresses the mean AFR and "x" the total failure rate at "z" years [27].

4. Results

4.1. Clinical data on patients

Sample descriptions in terms of patients, restorations and protocol used are presented in Table 1. Eighteen patients were in class I, 2 in class II.1, 3 in class II.2 and 1 in class III. Regarding the Basic Erosive Wear Examination (BEWE) score, 19 patients had a high-risk level (BEWE score >14), and 5 patients had a moderate risk level (BEWE score =12 or 13). Regarding the etiology of tooth wear, all patients showed clinical signs of both chemical (erosion) and mechanical (bruxism) wear. The mean VDO increase at the incisal guide pin was 5.2 mm ± 0.5 mm (n=15 of 24 patients).

4.2. Clinical data on restorations

In total, 580 PICN restorations were evaluated up to 9 years (Table 1). Ten patients received PICN restorations on all teeth, and thirteen patients received direct composite restorations for the lower incisors and canines (Inspiro, Edelweiss, Zug, Switzerland (23 patients) or Miris, Coltene, Altstätten, Switzerland (in one patient)). Consequently, 88.04% (n=486) of the restorations were in contact with PICN material and 11.96% (n=66) were in contact with direct composite (in the anterior teeth).

Patients (n tot=24)	% (n)
Sex	
Female	45.8% (11)
Male	54.2% (13)
Impression - Occlusal analysis	
Analog	95.8% (23)
Digital	4.2% (1)
Adhesive	
Excite	8.3% (2)
Adhese Universal	62.5% (15)
Optibond XTR	29.2 % (7)
Composite resin cement	
Variolink Esthetic DC	70.8% (17)
Nexus XTR	29.2% (7)

Restorations (n tot=580)	% (n)	Follow-up (years) Mean +/- SD (range)
Type of restorations		
Anterior	37.6% (218)	
Palatal veneers	21.6% (125)	
Chips	11.4% (66)	
Envelope	3.1% (18)	
Buccal veneers	0.5% (9)	
Posterior	62.4% (362)	
Occlusal tabletop	51.9 % (301)	
Onlays	6.0% (35)	
Veneerlays	4.5 %(26)	
Type of Vita Enamic block		
Monoblock	44.8% (260)	7.0 +/- 0.7 (6.0 - 9.1)
MultiColor	55.2% (320)	2.4 +/- 1.0 (0.9 - 4.1)

Tab 1 Sample description in terms of patients and materials used.

Year	n	Survival % (95% CI)	Success 1 % (95% CI)	Success 2 % (95% CI)	Success 1 Anterior % (95% CI)
1	580	100.0 (100.0-100.0)	99.5 (98.9-100.0)	99.6 (99.1-100.0)	99.5 (98.6-100.0)
2	486	100.0 (100.0-100.0)	96.5 (94.9-98.1)	98.6 (97.7-99.6)	98.5 (96.9-100.0)
3	360	99.8 (99.3-100.0)	92.5 (90.1-94.9)	97.2 (95.7-98.7)	98.5 (96.9-100.0)
4	319	99.4 (98.6-100.0)	91.0 (88.3-93.7)	96.3 (94.4-98.1)	97.8 (95.8-100.0)
5	319	99.4 (98.6-100.0)	88.0 (84.8-91.4)	95.1 (92.9-97.4)	97.8 (95.8-100.0)
6	263	99.4 (98.6-100.0)	87.3 (83.9-90.8)	94.0 (91.4-96.6)	96.9 (94.2-99.7)
7	211	99.4 (98.6-100.0)	83.0 (78.9-87.4)	90.1 (86.6-93.8)	96.9 (94.2-99.7)
8	17	98.4 (96.4-100.0)	79.7 (74.6-85.1)	86.7 (82.0-91.6)	93.7 (88.8-99.0)
9	17	98.4 (96.4-100.0)	79.7 (74.6-85.1)	86.7 (82.0-91.6)	93.7 (88.8-99.0)

The median thickness of the restorations was 0.86 mm (IQR 0.51-1.22) in the anterior region and 0.53 mm (IQR 0.35-0.70) in the posterior region.

4.3. Clinical outcomes

4.3.1. Restoration evaluation

The 9-yr Kaplan-Meier estimated survival rate of restorations was of 98.4 % (95% CI 96.4-100.0). The success rate ("Success 1") was 79.7% (95% CI 74.6-85.1), while the success rate excluding minor chipping requiring only polishing ("Success 2") was 86.70% (95% CI 82.0- 91.6) (Table 2). The Annual Failure Rate (AFR) based on survival and success is also shown in Table 3 [27]. Fracture was the first cause of restoration failure (most often marginal chipping (Figure 2)) and results have shown a probability

Success 1 Posterior % (95% CI)	Success 1 Premolars % (95% CI)	Success 1 Molars % (95% CI)	No-fracture Restoration thickness <=0.56mm % (95% CI)	No-fracture Restoration thickness >0.56mm % (95% CI)
99.4 (98.7-100.0)	98.8 (97.3-100.0)	100.0 (100.0-100.0)	99.5 (98.4-100.0)	100.0 (100.0-100.0)
95.2 (92.9-97.6)	96.8 (94.1-99.6)	93.8 (90.1-97.6)	94.2 (90.5-98.0)	98.4 (96.7-100.0)
88.6 (84.9-92.4)	95.9 (92.6-99.2)	81.6 (75.3-88.3)	86.9 (81.5-92.6)	97.9 (95.9-100.0)
86.5 (82.4-90.8)	94.8 (91.0-98.7)	78.4 (71.5-85.9)	84.5 (78.3-91.1)	97.3 (95.0-99.7)
81.6 (76.8-86.9)	91.1 (85.8-96.8)	72.3 (64.4-81.2)	78.0 (70.0-87.0)	96.6 (94.0-99.3)
80.9 (75.8-86.4)	91.1 (85.8-96.8)	71.1 (63.0-80.2)	78.0 (70.0-87.0)	95.1 (91.8-98.5)
73.6 (67.2-80.5)	84.5 (76.8-93.0)	63.0 (53.7-74.0)	73.7 (64.4-84.3)	94.0 (90.2-98.0)
70.0 (62.5-78.4)	81.0 (71.4-91.9)	59.3 (48.6-72.4)		
70.0 (62.5-78.4)	81.0 (71.4-91.9)	59.3 (48.6-72.4)		

Tab 2 Results of survival, success and no-fracture probability results up to 9 years (Kaplan-Meier analysis).
Success 1: success rate including minor chipping (requiring polishing or repair), caries or debonding
Success 2: success 1 rate excluding minor chipping requiring only polishing
No-fracture: probability of no-fracture, including minor chipping requiring only polishing
Anterior : Tooth position 1-2-3
Posterior: Tooth position 4-5-6-7-8. When several failures occurred at the same restoration, the first one was taken for the time of success (1 restoration concerned on the 580).

of fracture of 16.4% at 9 years based on the total sample. Complications included 51 minor and 3 major chippings, 6 debonding, and 4 caries (Table 4, Figure 3). There was no significant difference in failure rates between the two types of PICN. Patient age, gender or BEWE risk-score didn't significantly influence the survival or the success rates. However, patients with Class II.2 occlusion were 5.63 times more likely to have a

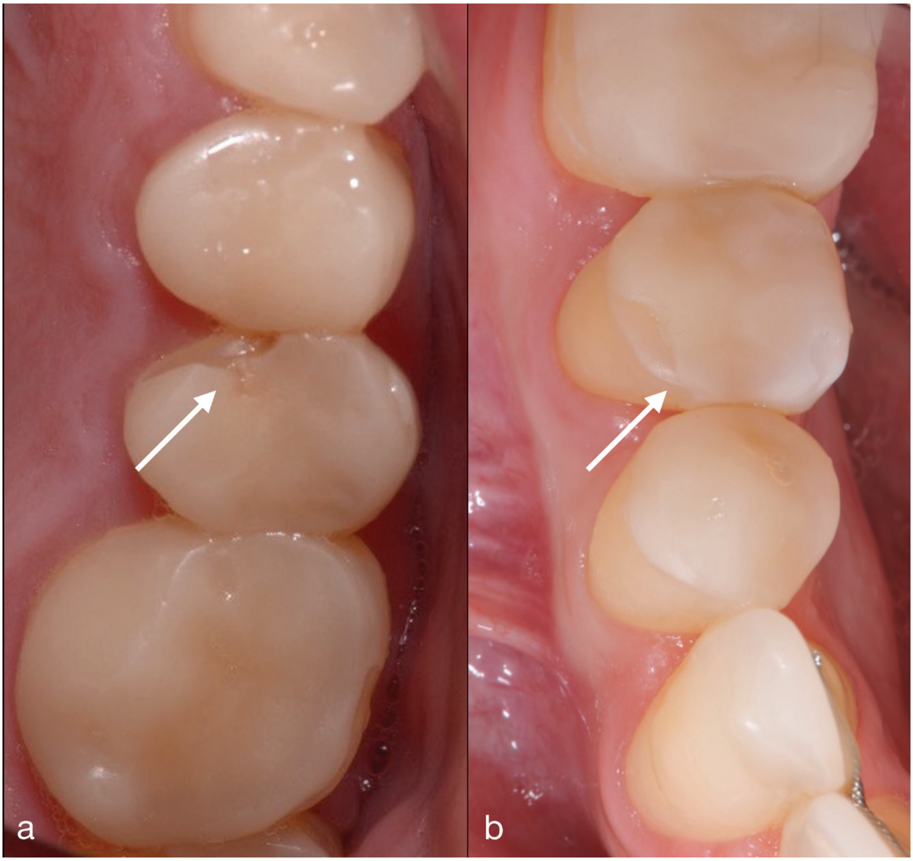

Fig 2 Observed technical complications (Photo courtesy of J. Oudkerk an A. Mainjot)
a) Typical minor chipping of thin restoration borders in occlusal affecting the approximal contact
b) Typical minor chipping of thin restoration borders in occlusal contact affecting the marginal integrity (marginal chipping).

major fracture of their restoration than Class I but this trend is not significant (p=0.226). The results did not show an effect of the antagonist, as most contacts were PICN-PICN (88.04%) and we observed very few failures in the anterior region, where contacts with direct composite as the antagonist were involved (Table 5). Figures 4 show the Kaplan-Meier estimated success and survival rates for anterior and posterior restorations, respectively. Significantly more failures were observed in first and second molars than in other teeth (Table 5), but no difference was observed between maxillary and mandibular restorations. The results show that the risk of fracture is 9.16 (3.31-25.39, p<0.001) times higher for posterior restorations than for anterior restorations, particularly it was 4.06 times higher for position 6 (1.50-11.02, p=0.006) and 5.01 times higher for position 7 (1.88-13.35, p=0.001) than position 4 (Table 5, Figure 3).

Year	n	AFR Survival %	AFR Success 1 %	AFR Success 2 %	AFR Success 1 Anterior %	AFR Success 1 Posterior %	AFR Success 1 Premolars %	AFR Success 1 Molars %	AFR Fracture Restoration thickness <=0.56mm %	AFR Fracture Restoration thickness >0.56mm %
1	580	0.0	0.5	0.4	0.5	0.6	1.2	0.0	0.5	0.0
2	486	0.0	1.8	0.7	0.8	2.4	1.6	3.1	2.9	0.8
3	360	0.1	2.6	0.9	0.5	4.0	1.4	6.6	4.6	0.7
4	319	0.1	2.3	0.9	0.6	3.6	1.3	5.9	4.1	0.7
5	319	0.1	2.5	1.0	0.4	4.0	1.8	6.3	4.8	0.7
6	263	0.1	2.2	1.0	0.5	3.5	1.5	5.5	4.1	0.8
7	211	0.1	2.6	1.5	0.4	4.3	2.4	6.4	4.3	0.9
8	17	0.3	2.8	1.8	0.8	4.4	2.6	6.3		
9	17	0.2	2.5	1.8	0.7	3.9	2.3	5.6		

Tab 3 Annual failure rate (AFR) derived from survival, success and no-fracture probability results up to 9 years (Kaplan-Meier analysis).
Success 1: success rate including minor chipping (requiring polishing or repair), caries or debonding.
Success 2: success 1 rate excluding minor chipping requiring only polishing.
Fracture: annual fracture rate, including minor chipping requiring only polishing.
Anterior: tooth position 1-2-3.
Posterior: tooth position 4-5-6-7-8.
When several failures occurred at the same restoration, the first one was taken for the time of success (1 restoration concerned on the 580).

Restorations presenting minor fracture were polished or repaired (Table 4). The following protocol was used: rubber dam placement, sandblasting with the Cojet system, silane application, adhesive and direct composite placement. The debonded restorations were rebonded according to the same procedure as the initial bonding (if resin cement was present in the intaglio, the surface was sandblasted), using the same resin composite cement. Direct composite was used in some cases where the fit was no longer correct.

The FDI evaluation of the restorations 1 month after intervention is shown in Table 6. It shows clinically acceptable results for all restorations from an esthetic, functional and biological perspective, with the majority of restorations rated as excellent, except for some esthetic properties where the majority were rated as good (score 2). However, a difference was observed in the esthetic properties between the two types of PICN: Vita Enamic MultiColor showed overall better results in terms of surface gloss, color match and translucency, as well as esthetic anatomical form (Table 7). The FDI results demonstrated remarkable stability over the followup period, with 427 restorations

Failure type		1Y	2Y	3Y	4Y	5Y	6Y	7Y	8Y	9Y	Total
No failure	n	571	463	354	312	259	255	204	17	17	517
	%	98.5 %	95.3 %	98.3 %	97.8 %	98.5 %	97.0 %	96.7 %	100.0%	100.0 %	89.1%
Fracture, polished	n	5	16	3	5	0	1	0	0	0	30
	%	0.9 %	3.3 %	0.8 %	1.6 %	0.0 %	0.4 %	0.0 %	0.0%	0.0 %	5.2%
Fracture, repaired	n	1	6	2	1	4	3	4	0	0	21
	%	0.1%	1.2%	0.6%	0.3%	1.5%	1.1%	1.9%	0.0%	0.0%	3.6%
Fracture, restoration lost	n	0	1	0	1	0	0	1	0	0	3
	%	0.0 %	0.2 %	0.0 %	0.3 %	0.0 %	0.0 %	0.5 %	0.0%	0.0 %	0.5%
Tooth fracture	n	0	0	0	0	0	0	0	0	0	0
	%	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0%	0.0 %	0.0%
Restoration debonding	n	3	0	1	0	0	1	1	0	0	6
	%	0.5 %	0.0 %	0.3 %	0.0 %	0.0 %	0.4 %	0.5 %	0.0%	0.0 %	1.0%
Carie	n	0	0	0	0	0	3	1	0	0	4
	%	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	1.1 %	0.5 %	0.0%	0.0 %	0.7%
Endodontic failure	n	0	0	0	0	0	0	0	0	0	0
	%	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0%	0.0 %	0.0%
Total	n	580	486	360	319	263	263	211	17	17	580
	%	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0%	100.0 %	100%

Tab 4 Failures observed in the study with relative frequency by year of follow-up.

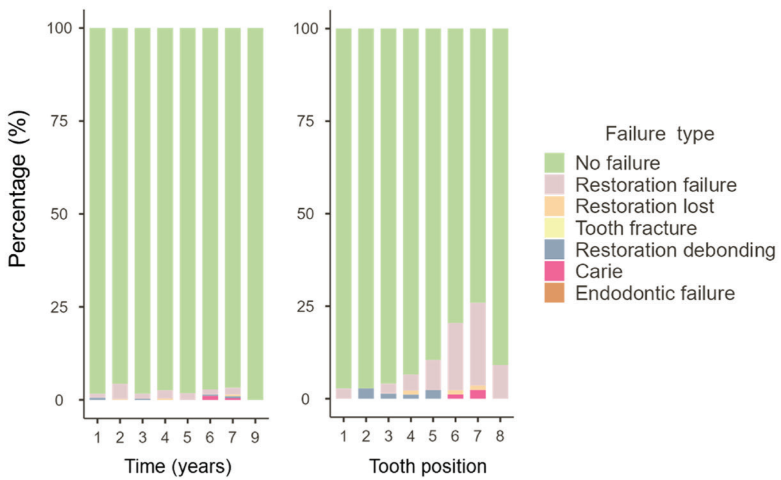

Fig 3 Failures observed in the study with relative frequency by year of follow-up and by influence of tooth position.

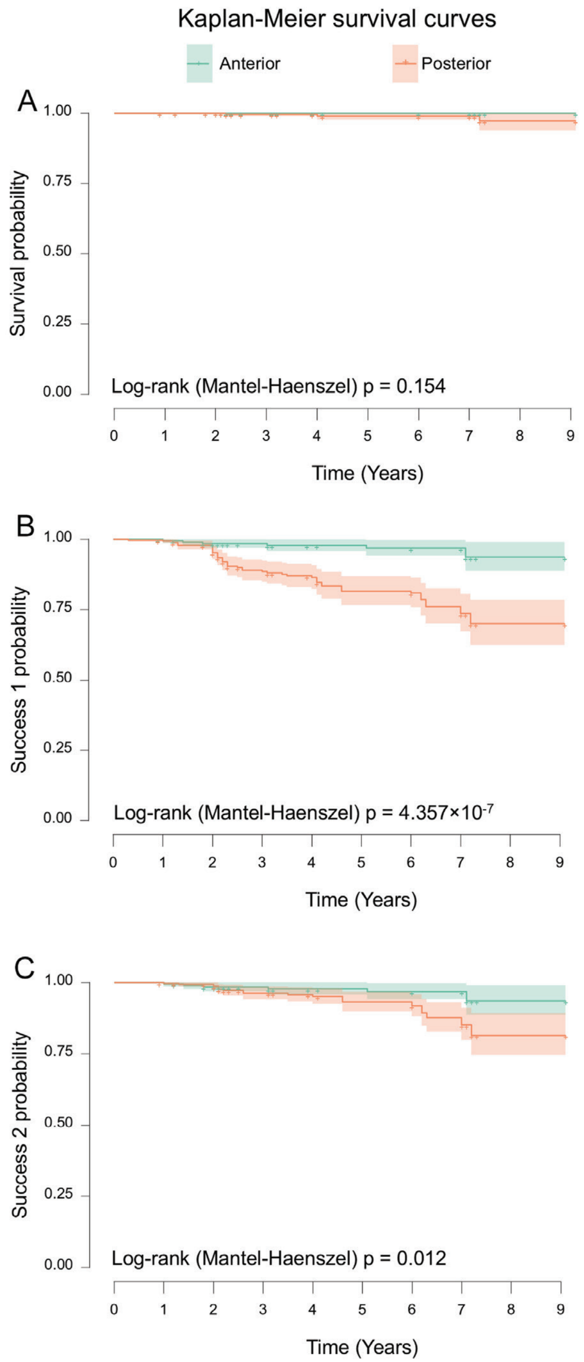

Fig 4 Kaplan-Meier survival and success rate for anterior (in blue) and posterior (in red) restorations. In addition, the success rate excluding minor chips requiring polishing was shown.

Failure type		Tooth position								Total
		1	2	3	4	5	6	7	8	
No failure	n	70	70	71	86	77	70	63	10	517
	%	97.2 %	97.2 %	95.9 %	93.5 %	88.5 %	79.6 %*	74.1 %**/#	90.9 %	89.1 %
Polished	n	0	0	0	2	3	10	14	1	30
	%	0.0%	0.0%	0.0%	2.1%	3.5%	11.4%	16.5%	9.1%	5.2%
Repaired	n	2	0	2	2	4	6	5	0	21
	%	2.8 %	0.0 %	2.7 %	2.1 %	3.6 %	6.8 %	5.9 %	0.0 %	3.6 %
Restoration lost	n	0	0	0	1	0	1	1	0	3
	%	0.0 %	0.0 %	0.0 %	1.1 %	0.0 %	1.1 %	1.1 %	0.0 %	0.5 %
Tooth fracture	n	0	0	0	0	0	0	0	0	0
	%	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
Restoration debonding	n	0	2	1	1	2	0	0	0	6
	%	0.0 %	2.8 %	1.4 %	1.1 %	2.3 %	0.0 %	0.0 %	0.0 %	1.0 %
Carie	n	0	0	0	0	1	1	2	0	4
	%	0.0 %	0.0 %	0.0 %	0.0 %	1.1 %	1.1 %	2.3 %	0.0 %	0.7 %
Endodontic failure	n	0	0	0	0	0	0	0	0	0
	%	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
Total	n	72	72	74	92	87	88	85	11	580
	%	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %

Tab 5 Failure types observed in this study according to the tooth position. Pairwise Comparisons with holm adjustment p-value:
* = $p<0.05$ compared to position 4,
** = $p<0.01$ compared to position 4 and
# = $p<0.05$ compared to position 5.
Note: One tooth in position 5 had one carie at 6 years of follow-up after having a polished fracture at 2 years of follow-up.

evaluated at two years, 264 at four years, and 140 at seven years. Notably, none of the restorations exhibited deterioration in any of the FDI criteria, with the exception of fracture. Patients were shown to be highly satisfied.

4.3.2. Influence of restoration thickness on fracture failure

The Cox regression analysis indicated the existence of a fracture risk threshold at a thickness of 0.56 mm. An increase in thickness by 0.1 mm has been demonstrated to reduce the risk of failure by 23% (95% CI 12-33%, p-value <0.001). Figure 5 illustrates the fracture survival curves for restorations with a minimum thickness of 0.56 mm and a

	Clinically Excellent %(n)	Clinically Good %(n)	Clinically Sufficient %(n)	Clinically Unsatisfactory %(n)	Clinically Acceptable %(n)	Clinically Unacceptable %(n)
A. Esthetic properties					100(515)	
1. Surface luster 38.4(198)61.6(317)						
2. Staining						
a. surface	99.8(514)	0.2(1)				
b. margin	99.8(514)	0.2(1)				
3. Color match & translucency	36.7(189)	57.5(296)	5.8(30)			
4. Esthetic anatomical form	96.5(497)	3.5(18)				
B. Functional properties					100(515)	
5. Fracture of material/ retention	99.4(512)		0.6(3)			
6. Marginal adaptation	62.9(324)	37.1(191)				
7. Occlusal contour & wear						
a. Qualitatively	99.4(512)	0.2(1)	0.4(2)			
8. Approximal anatomical form						
a. contact point	89.1(459)	4.3(22)	6.6(34)			
b. contour	98.3(505)	0.2(1)	1.6(8)			
9. Radiographic examination	100(317)					
10. Patient's view	68.2(351)	31.8(164)				
C. Biological properties					100(515)	
11. Postoperative sensitivity / tooth vitality	98.6(508)	1.4(7)				
12. Recurrence of caries, erosion, abfraction	100(515)					
13. Tooth integrity	100(515)					
14. Periodontal response	98.8(509)	1.2(6)				
15. Adjacent mucosa	100(515)					
16. Oral and general health	100(515)					

Tab 6 Baseline FDI rating of restorations (1 month after treatment).

thickness below this value. At seven years, the estimated Kaplan-Meier fracture survival rates were 94.0% for restorations with a minimum thickness of 0.56 mm and 73.7% for the rest. The corresponding AFRs are presented in Table 2.

A. Esthetic properties	Vita Enamic monoblock			Vita Enamic multiColor			X^2 p-value
	Clinically Excellent %(n)	Clinically Good %(n)	Clinically Sufficient %(n)	Clinically Excellent %(n)	Clinically Good %(n)	Clinically Sufficient %(n)	
1. Surface luster		100(192)		46.8(198)	53.2(125)		1.73e-43
2. Staining							
a. surface	99.5(191)	0.5(1)		100(323)			ns
b. margin	99.5(191)	0.5(1)		100(323)			ns
3. Color match & translucency	14.6(28)	69.8(134)	15.6(30)	40.4(161)	59.6(162)		2.67e-22
4. Esthetic anatomical form	100(192)			92.3(305)	7.7(18)		8.69e-4

Tab 7 Baseline esthetic FDI rating of restorations with influence of PICN type (1 month after treatment).

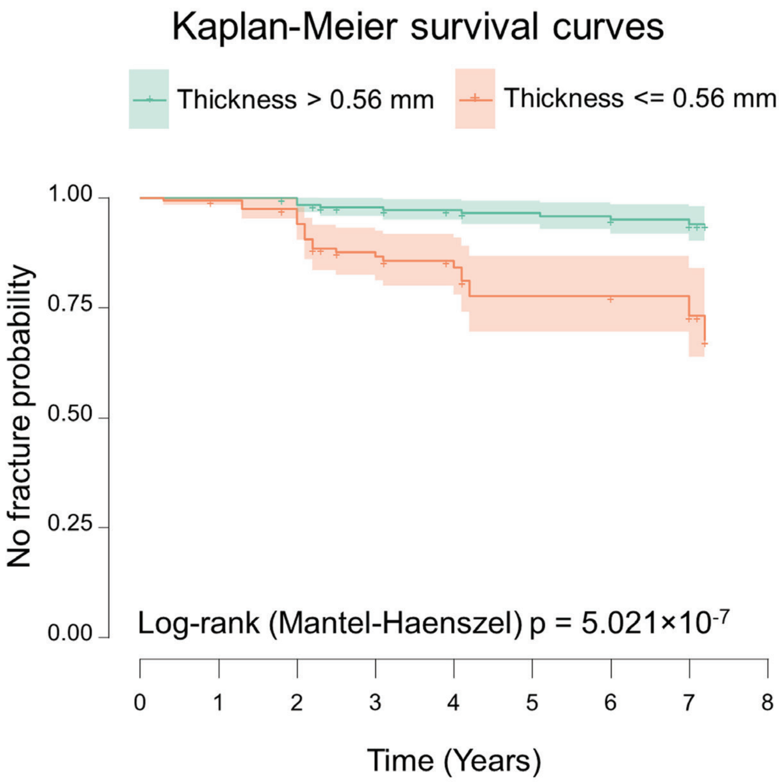

Fig 5 Kaplan-Meier fracture rate for anterior (in blue) and posterior (in red) restorations according to thickness of restorations.

5. Discussion

The present study provides important and original data on the long-term behavior of restorations in the field of full-mouth rehabilitation of severe tooth wear and generally represents the largest sample of PICN restorations studied to date. It shows excellent long-term estimated survival (98% at 9 years) and success rates (79.7% at 9 years while the success rate excluding minor chipping requiring only polishing was 86.70%) of those restorations under extreme conditions. Indeed, patients suffering from tooth wear have a very high risk of restoration failure due to the very high mechanical and chemical stresses to which biomaterials are subjected. The FDI scores demonstrated excellent results for all properties, with over 90% of restorations receiving a score of excellent or good for all criteria. These results remained stable over time, with the exception of the appearance of fractures. Some observed scores that were clinically sufficient were attributed to the absence of proximal contact points (which is not related to the material), color match and translucency. However, this latter point is not a concern with Vita Enamic multiColor block. Indeed, they are distinguished by a color gradient that imitates the appearance of dentin and enamel and one hypothesis suggests that the manufacturing process of these multilayered blocks may contribute to the observed surface gloss. It is noteworthy that PICN does not demonstrate any loss of luster, color changes, or staining over time. This is in contrast to direct light-cured composites, which have been observed to degrade as rapidly as 36 months in cases of tooth wear, with a percentage of deterioration of 44% for surface staining, 31% for loss of surface luster, 25% regarding contour and wear and 24% for marginal adaptation [28].

Indeed, both direct and indirect restorations using composite or pure ceramic materials can be considered for severe tooth wear treatment. However, the current lack of scientific studies in the literature means there is no definitive evidence to favor one type of restoration or material over another for tooth wear treatment [6]. Notwithstanding, international guidelines endorse the utilization of minimally invasive or even non-invasive restorations (no-prep) [29], which is facilitated by the use of materials from the composite family due to their capacity for lowthickness manufacturing. PICN, or 'hybrid ceramic', consists of a block of glass-ceramic infiltrated with resin polymerized at high temperature and pressure, unlike other CAD-CAM composites which are all conventional glass fillers mixed with resin. This manufacturing process is patented and Vita Enamic (Vita Zahnfabrik, Germany) is the only PICN material on the market [30]. CAD-CAM composites have the lowest flexural strength of all prosthetic materials and are therefore only indicated for single-unit restorations. However, they offer other very important benefits. Indeed, compared to direct composites, PICN offers a high degree of polymerization and high homogeneity with fewer defects [30]. As a result, mechanical properties, wear resistance and chemical stability (water absorption and discoloration resistance) are significantly improved, while toxicity (monomer release) is reduced [31]. In addition, the use of the indirect technique can reduce in-mouth working time and facilitate the realization of proper anatomy as occlusal and proximal contact points [15]. Compared to pure ceramics, PICN offers the ability to be milled to a very thin thickness (allowing no-prep treatment), the ability to deform and absorb occlusal stress in bruxers (its stiffness is similar to tooth tissue, whereas ceramics are too stiff and other composites are too soft), the ease of adjustment of occlusal and proximal contact points (allowing one step treatment), and the ease of repair [12]. PICN is also less expensive, less abrasive than lithium-based glass-ceramics and is more translucent due to the presence of resin (with a «chameleon» effect similar to composites). The present study's FDI results demonstrated that the esthetic properties of PICN restorations, particularly those made with Vita Enamic multiColor blocks, were clinically excellent or good in terms of luster, color match, and translucency (monocolor blocks exhibiting poorer results). No staining was observed over time. Although the material may not be as glossy nas a pure ceramic, the esthetic properties are adequate for patients (particularly when recovered with saliva), as evidenced by the high patient satisfaction scores for esthetics and function.

Finally, PICN has been shown to develop high bond strength with resin composite cement (better than other CAD-CAM composites) [15, 28], and despite the poor macromechanical retention of the restoration and the high occlusal stress, the results of the present study highlight a low debonding rate. Indeed, a recent meta-analysis evaluated the clinical performance of different types of composite and ceramic inlays, onlays and overlays and found a pooled incidence of debonding of 0.9% (95% CI=0.2%-2.1%) according to the 6 studies included [32], which is similar to our study with a probability of debonding of 0.9 % at 5 years and 2% at 9 years. No caries occurred before the 6-year assessment, and this type of failure was observed in the same patient, who drinks soda and suffers from an eating disorder.

While anterior restorations were found to perform extremely well, the most common complication observed in this study was minor chipping of posterior restorations (47 in posterior (8.1%) and 4 (0.7%) in anterior in the total sample during the follow-up), mainly at the thin margins that were in occlusal contact with another PICN restoration. This complication can be explained by the relatively low flexural strength of the material. It was easily managed by polishing or repair. In this regard, the present study highlights an important risk factor, which is the thickness of the restoration, with a cut-off of

0.56 mm, and for every 0.1 mm increase in restoration thickness, the risk of failure was shown to be reduced by 23%. This value is markedly inferior to the manufacturer's recommendations (1 mm in the occlusal area), thereby facilitating the potential for minimally invasive treatment. It is therefore incumbent upon the dental technician to exercise particular vigilance with regard to the thickness value at the occlusal contact points on molars, with particular attention being paid to the first and second molars, which are more susceptible to failure.

The results of this study can be compared with other data relating to direct and indirect treatment of tooth wear. A recent study of 110 dispersed filler CAD-CAM composite (Lava Ultimate, 3M, Saint-Paul, USA) and feldspathic CAD-CAM glass-ceramic (Vitadur, Vita Zahnfabrik, Germany) onlays for full-mouth rehabilitation using the "3-step technique" revealed a 98.2% survival rate and no significant differences between materials and locations of restorations at 6 years [33]. In our study, a similar estimated survival rate of 98.4% was observed at 6 years. Additionally, a study conducted in 2024 evaluated 568 dispersed filler CAD-CAM composite restorations (Lava Ultimate) utilized for full-mouth rehabilitation of patients with severe tooth wear at a 5.5-year follow-up [26]. The posterior survival rate for premolars was 96.8%, while the rate for molars was 100%. In comparison, our study yielded a posterior survival rate of 100% for premolars and 98.1% for molars. The success rate was 87.4% for premolars and 70.7% for molars at 5.5 years [26], while in our study, the success rate was 91.1% for premolars and 71.11% for molars at 6 years. In conclusion, the results of the present study are comparable to those obtained with other indirect materials at medium-term. However, it is noteworthy that the two aforementioned studies did not specify the thickness of the restoration. In contrast, the present study allows for a restoration thickness that may be considerably reduced in order to solely restore the missing tooth tissue without preparation. Furthermore, it would be beneficial to conduct a longer-term evaluation of other materials to facilitate a comprehensive comparison.

The 5-year clinical performance of PICN restorations in the treatment of tooth wear (99.4% estimated survival rate) is shown to be superior to the gold standard in fixed prosthodontics. Indeed, in a meta-analysis, Sailer et al. showed an estimated 5-year survival rate of metalceramic of 95.7%. This was similar to the estimated 5-year survival rate of single crowns of leucite or lithium disilicate reinforced glass ceramic (96.6%), glass-infiltrated ceramic, alumina (94.6%) and densely sintered alumina (96%) and zirconia (91.2%) [34]. In this meta-analysis, ceramic chipping was also reported to be a common problem and occurred similarly in metalceramic and all-ceramic crowns. Of the studies included in this meta-analysis, one study reported 5.3 % of minor chipping (smoothened by polishing) at 9 years for lithium disilicate posterior crowns (versus 8.8% in our study), and 2.1% of crown fracture (versus 0.5% in our study) [35]. The recent meta-analysis on the clinical performance of composite and ceramic partial coverage restorations (inlays, onlays, and overlays) demonstrated estimated 10-year survival rates of 75% for composite, 91% for feldspathic glass-ceramic, and 89% for reinforced glass-ceramic [32]. In a retrospective study about all-ceramic inlays and onlays (leucitereinforced glass-ceramic (IPS Empress)) in posterior teeth, the Kaplan-Meier estimated survival rate of restorations was 92.3% at 10 years (versus 98.4% at 9 years in the present study). The most common clinically unacceptable technical complication was ceramic fracture, with an incidence of 10.6% (versus 0.5% in the present study), and minor chipping, with an incidence of 2.3% (versus 8.8% in the present study). Minor chipping seems to be more common in our study probably due to the very thin thickness of the restorations and, more importantly, the presence of bruxism, which was not the case in the studies cited above. However, PICN appears to be less prone to larger fracture which could be explained by its damping behaviour and its lower brittleness than ceramics [36]. Data about PICN restorations are still sparse in the literature. In the study of Spitznagel et al., posterior teeth of 47 patients without tooth wear or bruxism were restored with 103 VITA Enamic restorations (45 inlays and 58 partial coverage restoration (PCR)) and their evaluation at 3 years highlighted high survival rates (97.4% for inlays and 95.6% for PCR) [37].

In regard to direct techniques used in the treatment of tooth wear, Mehta et al. demonstrated an annual failure rate of 2.9% for direct composite posterior restorations (5.5-year follow-up study), which is comparable to our findings at the 6-year evaluation (annual failure rate of 2.2%) [8]. The survival rates at 5.5 years was 97.7% (versus 99.4% in our study) while the success rate 1 was 88.6% (refurbishment by polishing included, versus 87.3% in our study) and the success rate 2 was 90.4% (refurbishment by polishing excluded, versus 94% in our study).

This study showed that direct composite may be an acceptable medium-term option for the treatment of generalized tooth wear, whereas molar restorations may require more maintenance. In fact, the need for regular intervention (refurbishment and repair) with direct resin composite restorations to treat tooth wear was frequently reported [38, 39]. Moreover, longer-term clinical data are required given that direct composite restorations are known to be susceptible to aging processes, particularly due to the limited effectiveness of light-curing and the resulting low degree of polymerization in comparison to CAD-CAM blocks [15]. Consequently, the primary concerns reported with direct composites are related to significant material wear and discoloration/staining [40] [41], which is not observed at long-term with PICN in the present study. Ultimately, if the cost of PICN restorations exceeds that of direct restorations, the restorative procedure is completed with greater ease and speed.

In conclusion, PICN is a promising material among those available on the market for treating worn dentition in high-risk patients, such as those with bruxism. It effectively combines the advantages of both direct and other indirect composites and pure ceramics, potentially minimizing their associated drawbacks, as previously discussed.

With regard to the specific aspects of the One-Step No-Prep technique, in particular the absence of provisional restorations to test the new VDO, as is always the case with indirect restorations, the present results confirm previous findings [12, 13]. Indeed, despite the one-step significant VDO increase (mean 5.2 mm ± 0.5 mm at the incisal pin), none of the patients reported any problems and they quickly adapted to their new occlusal relationships. This has been confirmed by other authors using Lava Ultimate restorations [26]. This approach is simpler than classical solutions and allows a reduction in costs. In order to further reduce costs, the digital setup is now only performed at the time of realization of the CAD-CAM mockup. Only the intra-oral pictures, a digital smile analysis, and examples of cases are shown to the patient for the purpose of treatment planning acceptance. It should be noted that One-Step No-Prep technique would be very difficult to implement with pure ceramics, which are not easily adaptable to proximal and especially occlusal contact points, and which require a very precise restoration design, facilitated by multi-step procedures. Finally, from the patient's point of view, the results were very satisfactory, both esthetically and functionally.

Future perspectives include, the developpment of fully digital workflow using optical impression and the Modjaw jaw tracking system for occlusal analysis, and the influence of this workflow on occlusal adjustments and related restoration failures. It is also necessary to comply with the minimum thickness of restorations at occlusal contact points on molars, as currently defined.

6. Conclusion

The One-Step No-Prep technique offers a minimally invasive and straightforward approach for treating severe and generalized tooth wear. This study provides valuable data on the clinical performance of PICN partial bonded restorations, with a 9-year estimated survival rate of 98.4% and a success rate of 79.7%, increasing to 86.7% when excluding minor chipping requiring only polishing, despite the extreme conditions to which the material was subjected. The findings indicate that PICN restorations can be manufactured in very low thickness; however, minor chipping at thin borders exposed to occlusal stress was the most frequent complication. To reduce chipping, the thickness of posterior restorations should not be less than 0.6 mm, especially at occlusal contact points. Additionally, FDI evaluations showed clinically acceptable results for all restorations, with most being rated as excellent, except in cases of fracture. Results remained consistent over time, including material luster and color, with no staining, while Vita Enamic MultiColor blocks provided better esthetic outcomes than monoblock options. Future directions include the further development of digital workflows within the One-Step No-Prep technique.

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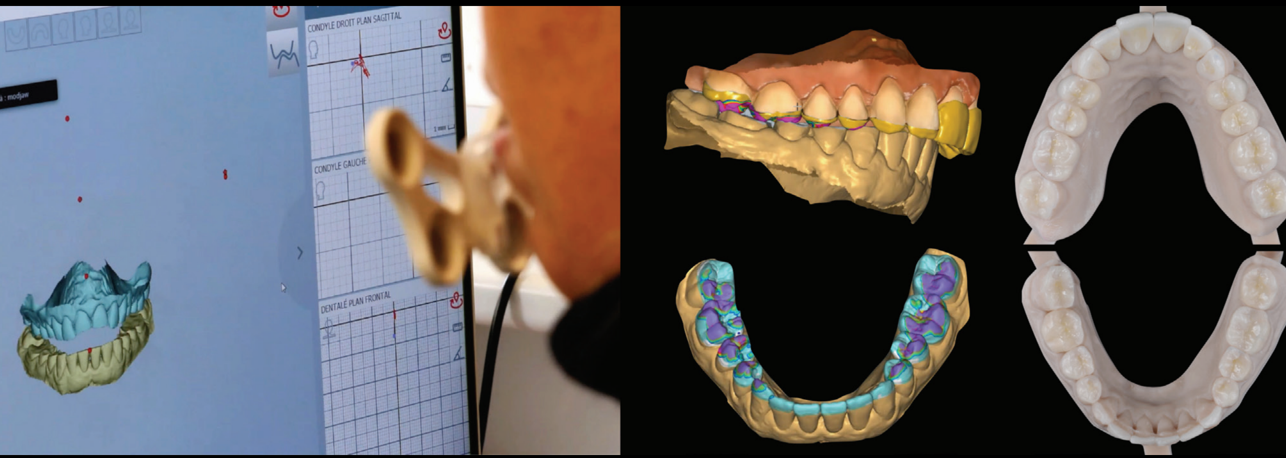

Chapter

9

Discussion & Conclusions

1. Discussion & Conclusions

Tooth wear (TW) is a multifactorial phenomenon that represents a significant public health concern, both in terms of its local consequences and its association with important chronic diseases, including sleep apnea, gastroesophageal disorders, and even musculoskeletal disorders (MSDs), as demonstrated in this thesis. It is imperative that dental practitioners recognize the interconnectivity of the human body and the necessity of a **holistic approach to TW**. This approach should be integrated into the curriculum for dental students and promoted among the wider dental community. Dental practitioners have a pivotal role in diagnosing and managing a range of medical conditions associated with TW. Additionally, there is a need to develop targeted information campaigns and interventions for patients, with a focus on promoting healthier lifestyles and preventive strategies for TW and its associated pathologies. The proposed **ToWeR checklist** has the potential to significantly enhance practitioners' knowledge of TW risk factors, as well as their clinical diagnosis and management [1]. Furthermore, this tool can facilitate the dissemination of guidelines. The checklist may be utilized to monitor TW at each visit. Further studies should concentrate on the use and validation of the tool, as well as the investigation of poorly studied factors, such as bruxism, which is believed to be a significant TW risk factor. Indeed, the results of the scoping review showed a large number of heterogeneous studies analyzing a wide range of factors that may be associated with TW. In addition, the diagnosis and quantification of wear is difficult, and the results of the review show a lack of standardization in the indices used to measure TW. It would be ideal to agree on a standard index that is easy for practitioners to use and that allows studies to be compared.

Furthermore, this thesis identifies a significant challenge in the **clinical diagnosis of bruxism**. Indeed, the recommended instrumental approach, namely polysomnography (PSG), is not readily attainable in research on large sample sizes, nor in clinical practice. It would be beneficial to investigate the efficacy of the Bruxoff device (Bruxoff®, Spes Medica, Battipaglia, Italy), a portable screening tool for individuals presenting with symptoms indicative of nocturnal bruxism. Nevertheless, future research should concentrate on enhancing **non-instrumental methodologies**, which could be incorporated into routine practice.

In light of the aforementioned considerations, the cohort of patients that our team follows (association between bruxism and MSDs, chapter 4) may prove to be a fruitful source of insight. This cohort constitutes a component of a comprehensive research initiative, designated as the **CHAIN project**, which is dedicated to investigating the interrelationships between TW, bruxism, and body posture using electromyography and a posture platform in collaboration with the Movement Analysis Laboratory (LAM-Motion Lab of University of Liège). In this context, a **specific application dedicated to patient therapeutic education**, with the objective of improving bruxism treatment by maxillo-facial physiotherapists, has been developed and is currently under study. The integration of this tool into the One-Step No-Prep treatment and the impact of the restorative procedure on **body posture** are currently under investigation.

Furthermore, the CHAIN project examines the relationship between TW, bruxism, and various medical conditions. In addition, the data collected from this cohort of patients could be analyzed with respect to clinical signs associated with bruxism and tooth wear risk factors. If the diagnosis and prevention of TW is arguably the most crucial aspect of TW management, the selection of an **appropriate restorative treatment**, when necessary, is also of paramount importance. The objective of this thesis was to **contribute to the development of evidencebased recommendations** regarding the most appropriate technique for this procedure, with a particular focus on minimally invasive techniques, as recommended by international guidelines.

The findings of this thesis substantiate the efficacy of the **One-Step No-Prep technique** as a **completely non-invasive and straightforward method** for treating generalized TW [2] [3]. The treatment protocol has been demonstrated to yield successful clinical outcomes from both functional and aesthetic perspectives. The one-step approach to VDO augmentation was well tolerated, and the global OHIP score exhibited a statistically significant improvement [3]. The feasibility of this protocol is contingent upon the material utilized, as **PICN** possesses specific properties that render them conducive to this technique. In this way, the protocol combines the advantages of direct techniques (minimally invasive, one-step procedure, easy to repair) and indirect techniques (access to materials that perform better than direct composite materials, restoration anatomy realization with greater ease and speed than direct techniques).

Subsequent research endeavors will concentrate on the integration of **digital work flow**, incorporating intraoral scans and the Modjaw jaw tracking system for the registration of occlusal relationships, and its impact on restoration performance. In **localized TW cases**, our team focuses on the study of the innovative **"Orthodontic-assisted One-Step No-Prep" technique** proposed by Mainjot & Charavet in 2020 [4]. This approach is an advantageous, straightforward and more predictable evolution of the Dahl concept [5] with an ortho-pros collaboration associated to PICN material. No-prep anterior (and sometimes posterior) partial-coverage CAD-CAM PICN restorations are bonded in supraocclusion, creating a posterior open bite. Then, brief

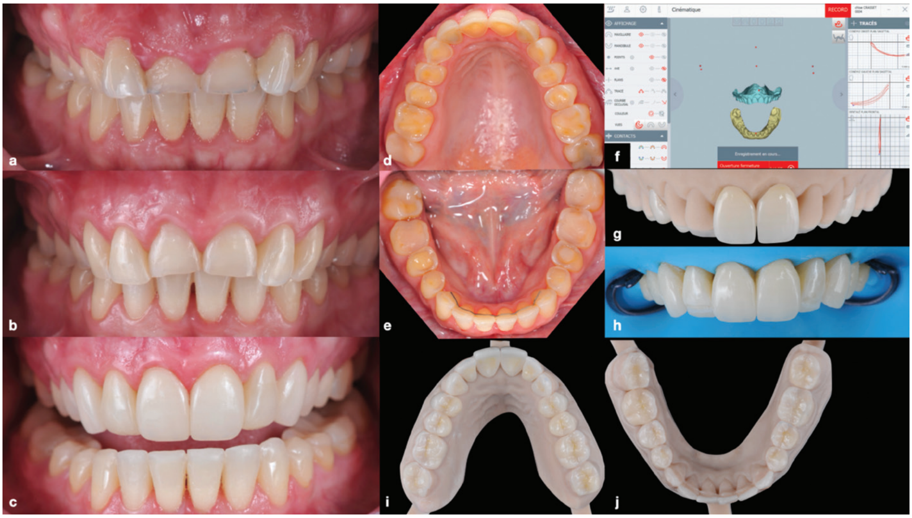

Fig 1

Case of a 32-year-old female patient treated with the One Step - No Prep technique using a full digital workflow
a) Baseline frontal view
b) Baseline frontal view after orthodontic treatment with aligners to align the upper front teeth
c) Frontal view after treatment
d) and e) Occlusal view of the upper and lower maxilla before restoration bonding
f) Screen capture of the occlusal relationships registering with the Modjaw jaw tracking system (Modjaw, Villeurbanne, France)
g) PICN (Vita Enamic multiColor blocks) "envelope" (no-prep partialcoverage restoration, restoring palatal and buccal surfaces, without recovering proximal surfaces, on centrals), palatal veneers (on laterals and canines) and veneerlays (on premolars) restorations on printed model after staining with the Vita Akzent Plus (Vita Zahnfabrik, Germany)
h) After restoration bonding and subsequent teeth bleaching, the junction between palatal veneers the buccal surface of the laterals is masked with direct composite (Inspiro, Edelweiss), creating a groove across the junction. Moreover, PICN buccal veneers were bonded on 13 and 23
i) PICN restorations of the upper maxilla on printed model j) PICN restorations of the lower maxilla on printed model. After being diagnosed with TW, the patient changed her lifestyle with regard to soda consumption. She also received an occlusal splint and is being treated for bruxism by the maxilla-facial physio-therapist. The diagnosis of bruxism led to the diagnosis of sleep apnea. Prostho dontics: Prof. A. Mainjot. Orthodontics: Prof. A. Bruwier. Dental lab: Jean-Michel Paulus, Liège. Photo courtesy of Prof. A. Mainjot.

partial orthodontic treatment is performed to extrude the posterior teeth and re-establish posterior occlusal contacts an additive way. This technique was shown to give successful short-term clinical results and there is now a need to develop clinical research with this protocol.

The selection of appropriate **material** and the application of sound knowledge are critical determinants of the efficacy of any given treatment. This work aimed to shed

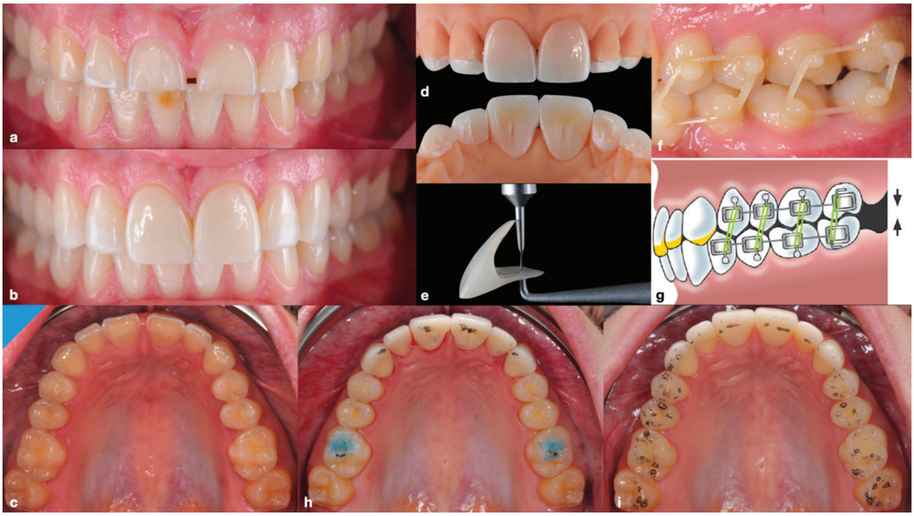

Fig 2

Case of a 21-year-old female patient showing localized tooth wear of the maxillary anterior teeth due to bruxism and gastro-esophageal reflux
a) Frontal view before treatment
b) Frontal view after treatment
c) Occlusal view before treatment
d) and e) PICN (Vita Enamic multiColor blocks) palatal veneers (on lateral incisors and canines) and "envelope" (on centrals incisors) on printed model after staining with Optiglaze (GC Corporation, Tokyo, Japan)
f) Lateral view showing the orthodontic extrusion system, which is very simple (direct composite buttons and intermaxillary elastics). After 13 days, the open bite was already closed
g) Schematic illustration of the orthodontic-assisted One-Step No-Prep approach, in which definitive PICN palatal veneers are placed in supraocclusion to restore the anterior teeth and the extrusion of the posterior teeth, is accelerated and controlled by partial orthodontic treatment h) Occlusal view after bonding of the restorations: occlusal contact is only present on the restorations. Consequently, posterior orthodontic bites are placed on the first molars to improve patient comfort
i) Occlusal view after treatment, showing occlusal contacts in all teeth
The patient received an occlusal splint and is treated for bruxism by the maxilla-facial physiotherapist. She is also treated for a gastro-esophageal reflux. Prosthodontics: Prof. A. Mainjot. Orthodontics: Prof. C. Charavet. Dental lab: Jean-Michel Paulus, Liège. Photo courtesy of Prof. A. Mainjot [4][6].

light on the distinctive characteristics of **CAD-CAM composites** in comparison to other materials. It introduced a classification system based on fundamental concepts in material science, delineating between dispersed filler and **PICN (hybrid ceramic)** materials. Furthermore, this thesis sought to present substantial data regarding the clinical behavior of PICN restorations. PICN was found to be well suited to the One-Step No-Prep protocol in terms of its ability to be milled in very thin thicknesses, its ease of repair in the event of failure, and its ease of in-mouth adjustment, particularly with respect to occlusal contact points. This work shows that, contrary to what is claimed by manufacturers, flexural strength is not an end in itself. Other properties must be considered, especially for bruxers, such as the way the material distributes occlusal stress, which is partly related to its modulus of elasticity. In this context, composites are the material of choice, and although these materials currently have weaknesses, they have the potential to improve with the development of new manufacturing process.

PICN with the same material as the antagonist shows slightly lower **material wear** values than reported for natural enamel, while not inducing a significant abrasive effect. Thus, it promotes the stability of the restored vertical dimension of the occlusion while allowing the occlusal contacts to adapt to the function over time. In consideration of the notion that the optimal restorative material should exhibit characteristics analogous to those of natural tooth tissue in a **biomimetic manner**, PICN represents a suitable intermediate between reinforced glassceramics, which are excessively abrasive and do not undergo wear, and direct composites, which exhibit excessive wear.

The most prevalent cause of failure was **minor chipping**, a phenomenon that has been documented in numerous studies of other materials and is promoted by the presence of bruxism.

However, PICN appears to be less prone to larger fracture, which can be attributed to its damping behavior and lower brittleness compared to ceramics.

The occurrence of minor chippings can be mitigated by paying attention to restoration thickness, as demonstrated by this thesis, which highlighted a cut-off of 0.56 mm. Fortunately, most of the small chips observed only required polishing, but they can also be easily repaired as direct composites, if necessary, which is an advantage over pure ceramics. It is likely that the chipping rate could be reduced by the development by the company of the next generation of experimental PICN, which displays a gradient of mechanical properties similar to those of enamel and dentin, respectively, and flexural strength similar to that of lithium-based glassceramics [7].

Results of this work demonstrated that the **esthetic properties of PICN** restorations, particularly those made with Vita Enamic multiColor blocks, were clinically excellent or good in terms of luster, color match, and translucency. **No staining, discoloration or loss of luste**r was observed over time, in contrast to direct composite. Although the material may not be as lustrous as pure ceramics, the esthetic properties are fully acceptable to patients, especially when recovered with saliva.

Finally, throughout this work, we have highlighted a significant **lack of long-term studies** concerning the clinical aging and wear of the various materials used in TW treatment.

Additionally, there is considerable heterogeneity among the studies reviewed, with frequent **omissions in the analysis of the types and respective properties of the materials** used. In this context, this thesis presents the **most extended evaluation of restorations in the field of TW treatment**. It also provides the **longest evaluation of PICN restorations**. For future studies, it is essential to **standardize clinical evaluations** to enable more accurate comparisons between studies.

In conclusion, as healthcare professionals, our foremost goal is to serve our patients. Prevention remains the gold standard, with the understanding that the oral cavity is an integral part of the broader systemic health. When proposing treatments, it is essential to prioritize three fundamental principles: non-invasiveness, efficacy, and cost-effectiveness. Ongoing research supports our clinical decision-making, and it is our hope that this thesis offers a modest contribution to the growing body of knowledge in this field.

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Scientific conferences (University or Research institution)

Diagnosis, prevention and management of tooth wear in multidisciplinary team, CHU of Liège, Master class Expert Usure, Liège, September 2022 and 2023

Curriculum Vitae

Julie Oudkerk
Born: March 20, 1990, in Liège, Belgium

Julie Oudkerk is a dedicated dental professional with a background in restorative dentistry and fixed prosthodontics. She earned her DDS degree from the University of Liège in 2014. Following her degree, she pursued a full-time postgraduate program in Oral Rehabilitation at the same institution from 2014 to 2017. During this time, she also played a key role in organizing the Study Club of Liège (Société de Médecine Dentaire) for six years.

Currently, Julie serves as the Head of Clinic in the Department of Fixed Prosthodontics at the University Hospital of Liège, under the leadership of Professor A. Vanheusden. She manages her clinical practice three days a week, specializing in restorative dentistry and fixed prosthodontics with a particular focus on minimally invasive treatments and the multidisciplinary management of complex rehabilitation cases on teeth and implants. In addition to her clinical duties, Julie is actively involved in pre-doctorate education, supervising the clinical internships of dental students, fostering the next generation of dental professionals.

In 2017, Julie embarked on a PhD journey within the dental-Biomaterials Research Unit (d-BRU) at the University of Liège, under the guidance of Professor A. Mainjot. Her research focuses on tooth wear, with a particular interest on the minimally invasive treatment of worn dentition using PICN CAD-CAM composites. Julie is also a mother of two daughters, Emma (born in 2020) and Victoria (born in 2023), whom she raises with her partner, Laurent.

Aucun grand projet ne se réalise seul, et cette thèse ne fait pas exception. Ce travail, fruit de plusieurs années d'efforts, n'aurait pu aboutir sans le soutien précieux, les conseils avisés et la collaboration généreuse de nombreuses personnes. Je souhaite donc exprimer ma gratitude à toutes celles et ceux qui, de près ou de loin, ont contribué à la réalisation de ce projet.

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Alors que je touche bientôt au terme de ces remerciements, il m'est difficile d'imaginer ce parcours sans le soutien de mes collègues et amis de l'Institut de Dentisterie. Merci pour tous ces moments de partage, de convivialité, et pour votre présence précieuse au quotidien. Je tiens à exprimer une gratitude toute particulière à Charlotte, Vinciane et Nathalie pour leur relecture attentive et leur amitié chère à mes yeux. Merci aux secrétaires et aux assistantes, notamment Gioia, Sylvie, Sandrine et Bénédicte, toujours présentes à mes côtés. Votre aide m'a été d'une grande valeur tout au long de ce chemin.

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Cette thèse marque la fin d'un beau chapitre de ma vie, riche en rencontres, en événements marquants et en amitiés précieuses. Ce chemin n'aurait pas été le même sans le soutien et l'accompagnement de toutes les personnes que j'ai eu la chance de croiser. À toutes et à tous, un immense merci d'avoir contribué à rendre cette aventure aussi inoubliable.

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Tooth wear (TW) *is a multifactorial issue, making the understanding of its risk factors essential for effective management. Despite its importance, a comprehensive review to guide clinical decisions is lacking. Bruxism and TW may be linked to various chronic diseases, but curarent data are limited, highlighting the need for further research. Diagnosis and prevention of TW are crucial, but selecting appropriate restorative treatments is equally important. Currently, there is no consensus on the optimal technique or material for restoring severely worn dentition, particularly due to the lack of long-term studies. The* ***One Step No-Prep technique*** *is a non-invasive restorative approach for generalized TW, using Polymer-Infiltrated Ceramic Network (PICN or hybrid ceramic, Vita Enamic) CAD-CAM restorations. Introduced in 2018, the technique has shown successful preliminary results, but its long-term effectiveness needs to be validated. PICN materials seem well-suited for this technique, but their clinical performance, especially long-term, is not well-studied, particularly regarding wear resistance—an important factor for bruxism patients.*

The primary aim of this thesis was to contribute to the assessment of the One-Step No-Prep technique. Additionally, this study sought to advance TW diagnosis and to investigate the intraoral wear of PICN materials. The first work package (WP) introduced the ***ToWeR checklist****, a tool to enhance the understanding of TW risk factors in clinical practice. The second WP explored the association between bruxism, TW, and MSDs, emphasizing a holistic approach. The third part of this work presents a critical review of the* ***evolution of indirect composites*** *to better understand their properties and the contributions of new materials to improved treatment strategies. Subsequent WPs focused on evaluating the One-Step No-Prep technique in* ***a prospective clinical context****.*

The fourth WP investigated PICN restorations' clinical performance and their impact on patients' oral health-related quality of life over two-year in seven patients. The fifth WP evaluated the ***intraoral wear of PICN*** *CAD-CAM composite restorations over five years using ex vivo 3D profilometry analyses. The sixth WP reported up to nine years of follow-up in 24 patients, assessing restoration thickness's influence on fracture rates.* ***PICN*** *was confirmed as well-suited to the One-Step No-Prep protocol due to its thin milling capability, adaptability during in-mouth adjustments, and ease of repair, especially in bruxers. The material's polymer component aids in occlusal stress absorption. At nine years, the survival rate was 98.4%, with a success rate of 79.7%, rising to 86.7% when excluding minor chipping. The thesis demonstrated that maintaining a restoration thickness of 0.56 mm could reduce minor chipping. After five years, PICN restorations exhibited wear values slightly lower than natural enamel, without significant abrasive effects, maintaining occlusal stability. The esthetic properties of PICN, particularly with Vita Enamic multiColor blocks, were rated as excellent or good over time, outperforming direct composites in resistance to staining and discoloration. The One-Step No-Prep protocol was shown to combine the benefits of direct techniques—minimally invasive, easy repair—with those of indirect techniques, such as access to superior materials and efficient restoration anatomy creation. This work highlights the successful long-term outcomes of the One-Step No-Prep technique and exhibits the clinical performance of PICN material, an appropriate material for this non-invasive treatment of TW.*

Keyword*:*
Tooth wear, Risk factors, Bruxism, Musculoskeletal disorders, CAD-CAM composite, PICN, Minimally-invasive treatment, Fixed prosthodontics, Clinical study, Dental materials, Material wear, Profilometry

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