Published in : Monographs in Oral Science (2025), vol.33, pp. 261-274
DOI: 10.1159/000543631

Status : Postprint (Author's version)

RESTORATIVE THERAPY OF EROSIVE TOOTH WEAR LESIONS : INDIRECT STRATEGIES

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ABSTRACT

For the first-line restorative management of worn dentition, direct composite restorations offer several advantages. However, the selection of this material and its method of application may not consistently provide a satisfactory longer-term treatment solution, particularly at molar teeth. This clinical approach is neither mutually exclusive, as there are various alternative dental materials available for similar clinical purposes, often applied using indirect fabrication techniques. These alternatives may offer benefits such as enhanced aesthetics and superior mechanical properties. It is essential for clinicians to have a comprehensive understanding of the various dental materials and techniques that may be suitable for a given clinical presentation. This involves evaluating the risks, benefits, costs and likely prognosis of each option. A thorough grasp of application protocols, along with an evidence-based approach, is crucial with the attainment of informed consent. In this chapter, the role of indirect restorations – ranging from resin-based composites to ceramic materials – will be discussed, along with the supporting evidence. The use of both partial and full-coverage indirect restorations will be

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reviewed, as well as the performance of more novel dental materials. An overview of the key stages in planning the rehabilitation of worn dentition will also be provided, including occlusal considerations, occlusal treatment concepts and smile design – critical factors for achieving optimal treatment outcomes. Additionally, this chapter will cover the steps involved in preparing diagnostic mock-ups used for the treatment of worn dentition.

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Introduction

In Chapter 16, an overview of the concepts relating to the management of tooth wear is provided. This includes the importance of establishing a prompt and accurate diagnosis, counselling, monitoring, indications for restorative intervention and the prescription of direct resin composite restorations for the treatment of pathological tooth wear. The use of direct resin composite restorations for the additive, adhesive rehabilitation of worn teeth, as supported by the European Consensus Statement on the Management Guidelines (for Severe Wear) [1], has been advocated as the initial treatment of choice, offering several benefits [2]. The latter approach also enables verification of the patient's acceptance of the planned aesthetic and functional changes in a minimally invasive manner [1, 3], allowing the flexibility to change the occlusal and aesthetic scheme when complex changes accompany the final treatment outcome.

A large prospective investigation [4], reporting the performance of 1,269 direct resin composite restorations provided to 34 patients with severe (generalised) tooth wear involving full-mouth rehabilitation with a mean observation time of 62 months, alluded to a favourable performance (annual failure rates [AFRs] of less than 3%). However, when prescribing direct resin composites for tooth wear, patients must be properly advised about the higher maintenance needs, especially at molar teeth, as well as the well-known risks of staining, chipping, fracture, adhesive failure, loss of lustre, wear and the potential failure to meet aesthetic expectations [1, 3, 4].

Indirect (extra-orally fabricated) restorations for the treatment of tooth wear versus the use of direct resin composite may offer the benefits. These include superior occlusal and inter-proximal form, superior aesthetics, a more favourable resistance to fracture and chipping and reduced chair-side time, especially when multiple restorations are indicated. However, the additional costs, the lack of opportunity to consistently readily undertake adjustment in the oral environment (which may vary according to the chosen material), the possible need for subtractive tooth preparation (with well-known accompanying biological risks when more aggressive tooth reduction may be required [5, 6]), risk of the display of the cementation line and wear/ breakdown of the cementation material are associated risk factors. However, indirect restorations may have a place where consent is not attained for the definitive rehabilitation of tooth wear using direct resin composite and/or where direct resin composite restorations might fail to meet the patient's (longer-term) aesthetic and functional requirements. These factors must be carefully discussed with the patient whilst seeking informed consent.

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The indirect restorations/techniques that will be covered in this chapter include:

- *Indirect (laboratory fabricated) composite resin restorations*
- *Polymer-infiltrated ceramic network (PICN), computer-aided design and manufacturing (CAD-CAM) restorations*
- *Partial-coverage restorations*
- *Full-coverage tooth-coloured crowns*

This chapter will also discuss some specific aspects of planning the restorative rehabilitation of worn dentition.

Planning of Restorative Rehabilitation

PLANNING THE NEW FUNCTIONAL–OCCLUSAL PRESCRIPTION FOR THE RESTORATION OF THE WORN DENTITION

To help maintain the functional merits of the masticatory system, dento-alveolar compensation commonly follows the loss of coronal tissue from tooth wear. Restorative rehabilitation of the worn dentition will, therefore, usually either involve a planned increase in the vertical dimension of the occlusion (VDO) and/or the adoption of a re-organised approach, utilising any inter-occlusal space that may be available between the first point of tooth contact in centric relation (centric relation contact point) and the inter-cuspal position [7]. The treatment aim is to reconstruct the original size and length of the teeth, provide an adequate volume/bulk of restorative material to help ensure the mechanical integrity and its durability of the restorations, improve aesthetics and provide adequate vertical occlusal support in the anterior and posterior areas.

Pragmatically, the concepts stipulated by the mutually protected occlusal scheme are often applied as the desired occlusal endpoint (circumstances permitting) for the restored worn dentition [8]. The latter would apply whether full-mouth rehabilitation is undertaken for cases of generalised tooth wear, or for partial-mouth wear cases (or where localised treatment is provided), often involving the initial placement of restorative materials in a supra-occlusal location using the concept of relative axial movement/the Dahl principle [9, 10], followed by an

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appropriate period of occlusal adaptation (if required). A canine-guided/ canine-protected occlusion is also considered to be generally desirable (pending the good health of the canine teeth) [8], in which canine guidance must be seen as a restorative treatment concept but has not been shown to have a beneficial effect in the protection of tooth wear progression. A possible benefit of applying a canine guidance compared to a group-guided occlusal scheme is that canine guidance is easier to accomplish [8].

For cases of generalized tooth wear, an increase in the VDO is often necessary. Where indirect restorations are planned at the outset to test the new VDO, transparent polymethylmethacrylate removable (occlusal splint) appliances have been historically prescribed, representing the desired VDO. Such appliances are associated with aesthetic and functional disadvantages and may challenge the patients' compliance. Eventhough "testing of the new VDO" is often viewed as a mandatory step as part of the clinical protocol, a recent randomised clinical trial [11] reported the absence of any beneficial effect on the short-term intervention rate of the restorations provided. To some extent, these observations are in line with those of Abduo and Lyons [12], where the application of a removable appliance to test the increase in the VDO needed for direct or indirect rehabilitation for severe tooth wear (up to 5 mm) with minimally invasive techniques offered no added value. Therefore, we conclude that "testing the VDO" is not usually necessary. However, it may still be advised to test out these changes during specific indications, such as testing the new situation in cases involving extensive and expensive indirect restorations. In this way, verifying and accepting the proposed changes using anatomically contoured forms permits a more realistic and comfortable clinical evaluation of the proposed VDO increment [13]. This can be done using, for example, three-dimensional (3D)-printed or milled polymethyl methacrylate restorations, which are placed temporally to test drive the proposed VDO. Patients are expected to be more compliant with wearing these devices instead of the more traditional forms of removable appliances.

PLANNING THE NEW AESTHETIC PRESCRIPTION FOR THE RESTORATION OF THE WORN DENTITION: THE USE OF AWAX-UP

To help establish the definitive aesthetic prescription, there is a need for a technique that allows all parties to reversibly visualise the planned aesthetic changes, gain informed consent and avoid unrealistic expectations. This can be accomplished by performing an initial 'intra-oral mock-up', involving the direct placement and sculpting of unbonded resin composite to verify

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the impact of alterations to tooth size and shape, or by using, for example, two-dimensional computer-generated or virtual simulations of the digital smile evaluation [14] or lip-generated smile design [15]. The intra-oral or virtual prescription can be used by a dental technician to guide a 3D digital CAD design or conventional wax-up of the aesthetic and functional requirements of the case.

On the receipt of the completed diagnostic (analogue or digital) wax-up, it should be verified intra-orally to demonstrate the proposed changes. To accomplish this, an impression of the wax-up is attained, typically using a polyvinyl siloxane-based material. The impression carrying the chosen shade of provisional crown and bridge resin is then transferred to the patient's oral cavity [16]. An alternative technique may include the fabrication of 3D-printed resin shells or overlays, replicated by the laboratory from the diagnostic wax-up, also referred to as the 'clip-on smile', undertaken indirectly. The dentist and patient must critically appraise the intra-oral mock-up derived using the wax-up (sometimes called the 'trial smile'), including the aesthetic, occlusal and phonetic features. Photographs or intra-oral 3D scan of the mock-up can help facilitate communication with the laboratory and provide patient information that they can view remotely to help them make an informed decision.

The use of indirect composite resin restorations for the treatment of tooth wear

OVERVIEW OF INDIRECT COMPOSITES FOR THE TREATMENT OF TOOTH WEAR

While the application of indirect composite resin restorations was first described 50 years ago, material preparations have been introduced more recently to offer a viable alternative to dental ceramics with the desired mechanical and aesthetic properties. Most current indirect composite resin materials are based on hybrid resins, which offer superior fracture resistance and better wear resistance compared to micro-filled composites.

Indirect composite resin restorations may be 'traditionally' fabricated, using a die stone. Initial light curing can be followed by a post-curing phase, aiming to increase the level of polymerisation. Post-curing techniques have included light, heat, pressure nitrogen or a vacuum. Post-curing has been suggested to enhance the fracture toughness, tensile strength,

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wear resistance and the colour stability of the restorations. As a more contemporary alternative, using CAD-CAM, indirect composite resin restorations may also be made from pre-polymerised blocks of resin materials. Blocks may be formed by compressing and polymerising a filler and monomer. Compared to traditionally fabricated indirect composite resin restorations, CAD-CAM generated restorations may offer better adaptation/fit and superior mechanical properties, such as improved flexural strength, especially given that the blocks are likely to be more homogenous, with reduced risks of flaws.

CLINICAL TECHNIQUES FOR THE APPLICATION OF INDIRECT RESIN COMPOSITE RESTORATIONS FOR THE TREATMENT OF TOOTH WEAR

Clinical techniques for the provision of indirect composite resin restorations for tooth wear patients are often minimally invasive, ranging from no preparation, the simple removal of undercuts, to the placement of small resistance grooves or pits when necessary to facilitate the seating of the restoration into the correct location and/or the removal of sharp external line angles (to help reduce stress concentration) and the provision of a chamfered finishing line using a diamond bur to define the preparation outline. Margins should ideally finish on enamel tissue to help ensure predictable bonding and be maintained away from the gingival tissues and, where possible, without involving the proximal contact areas [17].

Levels of occlusal clearance with indirect composite resin restorations may vary; Schlichting et al. [17] in their study involving the placement of ultra-thin CAD-CAM indirect composite resin posterior occlusal veneers (LAVA Ultimate HT; 3M) prescribed an average occlusal clearance of 0.4–0.6 mm at the central groove area and 1.0–1.3 mm at the cusp tips. Intra-oral 3D scans or traditional impression techniques may be used. As part of the cementation protocol, preparations would usually be cleaned using pumice and a water spray under rubber dam isolation. Adhesive surfaces of restorations and any existing direct restorations should be air abraded, and the restorations receive silane treatment, followed by an appropriate adhesive.

THE PERFORMANCE OF INDIRECT RESIN COMPOSITE RESTORATIONS FOR THE TREATMENT OF TOOTH WEAR: THE EVIDENCE BASE

Fewer studies have reported on the survival and success of indirect restorations, including indirect composite resin restorations, compared to the performance of direct resin composite

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for the treatment of tooth wear. The outcomes of several available studies reporting on the clinical performance of indirect resin composite restorations for the treatment of tooth wear have been summarised in Table 1 [17–25].

Vailati et al. [18] documented the outcomes of a prospective clinical study involving the use of a "sandwich approach", for the restoration of severely worn anterior maxillary teeth. The technique involved the placement of two separate veneers fabricated in differing materials and fitted with dissimilar paths of insertion, alleviating the need to provide invasive crown restorations. Despite relatively small sample sizes, promising functional and aesthetic outcomes were documented for the indirect palatal surface composite veneers (51 restorations) and for the labial surface porcelain veneers (64 feldspathic ceramic veneers); no complete or major failures were seen over a mean observation time of 50.3 months and 49.6 months, respectively.

In 2024, Maier et al. [19] reported the 5.5-year survival of 568 CAD-CAM-manufactured indirect composite resin restorations (LAVA Ultimate, 3M) to treat severe, generalised tooth wear. In total, 96 failures were reported; however, only 6 were catastrophic, with the rest mainly involving either adhesive failure or small (chipping) fractures and overall survival and success rates of 99% and 83%, respectively. Most of the observed failures were amenable to repair or refurbishment without needing a remake. Whilst the molar tooth restorations showed significantly higher risks of failure compared to other tooth types ($p < 0.006$), the authors concluded that the minimally invasive CAD-CAM restorations displayed acceptable mid-term survival for the treatment of severely worn dentitions. Fractures were the main cause of failure, and it was postulated that the CAD-CAM process might result in micro-crack formation at the surface, which may represent areas where future defects may be encountered. However, overall, the performance data were comparable to the use of direct resin composite by Mehta et al. [4], also reporting an observation period of 5.5 years.

Crins et al. [20] published the outcomes of a randomised controlled trial evaluating the performance of direct and artisanal indirect hybrid composite restorations placed at the palatal surfaces of maxillary anterior teeth and on the occlusal surfaces of first molars – 'tabletop restorations'. In contrast to the study by Maier et al. [19], the indirect restorations in this study were fabricated traditionally using a micro-hybrid indirect resin composite material (Clearfil Estenia C&B, Kuraray). After light curing, the restorations were heat treated in an oven for 15–20 min at 110–120°C. Restorations which were replaced and restorations that displayed material

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chipping were recorded as failed. Direct and indirect restorations on maxillary anterior teeth showed good performance and AFRs of 0.7% and 1.8% were respectively reported. Direct composite restorations on first molars had an AFR of 5.4%, whilst the indirect composite restorations had an AFR of 15.5%, indicating that artisanal indirect hybrid composite restorations in the posterior area had a 3.2 times higher risk of failure compared to the direct composite restorations. Variations in layer thickness may have been a possible reason for the difference in the performance of the direct and indirect molar restorations, where space would also need to be allowed for the cementation material. The importance of layer thickness for the successful performance of composite resin restorations cannot be overemphasised.

As seen in Table 1, a randomised control trial by Bartlett and Sundaram [21] documented an unfavourable overall failure rate with an evaluation period of 3 years with the use of indirect cusp coverage (micro-filled) composite resin restorations for the treatment of localised posterior tooth wear; fracture and complete loss were the most common modes of failure observed. Whilst the sample size was small (n = 16), the use of micro-filled materials is unlikely to be suitable for this application, especially amongst higher risk patients, such as those with severe bruxism tendencies.

Overall, based on the available evidence, indirect composite resin restorations for the treatment of tooth wear may offer very acceptable survival rates and high success rates when appropriate types of materials and fabrication techniques are used. Molar tooth restorations may be at a higher risk of failure; however, ensuring adequate material thickness may help improve treatment outcomes. The use of indirect composite may offer a suitable alternative to the use of direct composite for the treatment of tooth wear.

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Table 1. *Summary of some of the available performance data for indirect composite resin restorations, for the treatment of erosive tooth wear*

Authors	Study design	Number of restorations	Number of patients	Location (anterior, posterior or both)	Follow-up time, years	Survival rate, %	Success rate, %
Bartlett and Sundaram, 2006 [21]	Randomised controlled trial (RCT)	16	16	Posterior	3	69	44
Crins et al., 2021 [20]	RCT	188	20	Anterior and posterior	3	100	78
Edelhoff et al., 2023 [22]	Prospective study (non-RCT)	162	21	Posterior	7	100	75
Burian et al., 2021 [23]	Prospective study (non-RCT)	96	6	Anterior and posterior	3	97	97
Gow and Hemmings, 2002 [24]	Prospective study (non-RCT)	75	12	Anterior maxillary and mandibular	2	100	87
Vailati et al., 2013 [18]	Prospective study (non-RCT)	51	12	Anterior maxillary	4	100	100
Torosyan et al., 2022 [25]	Retrospective study (non-RCT)	257	28	Anterior and posterior	6	100	98
Maier et al., 2024 [19]	Prospective study (non-RCT)	568	22	Anterior and posterior	5.5	99	83
Schlichting et al., 2022 [17]	RCT	36	11	Anterior and posterior	3	100	85

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PICN materials

OVERVIEW OF PICN RESTORATIONS FOR TREATMENT OF TOOTH WEAR

PICN is a hybrid material that integrates the characteristics of ceramics and polymers, positioning itself as an innovative option for addressing tooth wear. With a patented process, the sole commercially available PICN material is VITA ENAMIC® (Vita Zahnfabrik, Germany), introduced in 2013. The latter benefits from a decade of clinical use, research and development.

The manufacturing process of PICN involves several key steps. Initially, a glass-ceramic block (Vita Mark II) is partially sintered. This block is then infiltrated with monomers, which are subsequently polymerised under high temperature and pressure [26]. PICN material is also referred to as hybrid ceramic or double network material, where the glass-ceramic particles are interconnected, giving rise to a 3D configuration. PICN material was developed to offer mechanical properties that closely mimic human enamel, such as the modulus of elasticity or wear behaviour, enabling mechanical biocompatibility.

PICN exhibits notable advantages over traditional light-cured direct composites. Its high degree of polymerisation contributes to increased mechanical strength and durability. Additionally, the material demonstrates high homogeneity, resulting in fewer internal flaws which enhances its reliability. These properties lead to improved wear resistance, chemical stability and reduced toxicity (due to the absence of monomer release), making PICN a viable alternative in restorative dentistry [26–29].

When compared to pure ceramics, PICN offers several benefits [26]. Its lower stiffness (between dentin and enamel) promotes better occlusal stress distribution, which may be of importance for reducing failures in patients with bruxism. The material can be manufactured in very low thicknesses (up to 0.2 mm), allowing for 'no-prep' treatments that preserve tooth structure. Moreover, PICN is easily adjustable and repairable and is less abrasive than lithium-based glass-ceramics. Additionally, PICN possesses a chameleon effect that allows it to blend with natural tooth structures, contributing to favourable aesthetic outcomes.

Finally, PICN exhibits excellent bonding properties to resin composite cement. These properties have been shown to be similar to those of glass-ceramics and higher than those of other CAD-

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CAM composites, which are composed of glass filler mixed with monomers, similar to light-cured composites.

Table 2. *Summary of some of the available performance data for all-ceramic, partial-coverage restorations, for the treatment of erosive tooth wear*

Authors	Study design	Number of restorations	Number of patients	Location (anterior, posterior or both)	Follow-up time, years	Survival rate, %	Success rate, %
Edelhoff et al., 2019 [33]	Prospective study (non-randomised controlled trial [RCT])	103	7	Posterior	8	100	99
Edelhoff et al., 2023 [22]	Prospective study (non-RCT)	274	21	Anterior and posterior	13	100	95
Schlichting et al., 2022 [17]	RCT	3	11	Posterior	3	100	100
Burian et al., 2021 [23]	Prospective study (non-RCT)	96	6	Anterior and posterior	3	100	100
Walls, 1995 [40]	Prospective study (non-RCT)	43	12	Anterior maxillary and mandibular	5	95	86

CLINICAL TECHNIQUE AND THE PERFORMANCE DATA OF PICN RESTORATIONS FOR THE TREATMENT OF TOOTH WEAR

PICN was introduced in 2018 and 2020 for the treatment of generalised and localised tooth wear using the one-step no-prep technique [30]. This technique is characterised by the absence of tooth tissue preparation and a provisional phase, making it non-invasive and cost-effective. Figure 1 shows an example of a patient with tooth wear treated via this approach.A 2-year prospective evaluation of 192 PICN CAD-CAM restorations showed very good patient acceptance, where a mean increase in the VDO of 5 mm was prescribed. The observed survival (100%) and success (93.75%) rates of restorations at 2 years were high [31]. Minor chipping of

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the very thin occlusal borders was the most frequently observed complication in the latter study. In occlusal areas, the authors recommend a minimum thickness of 0.6 mm, based on their recent research findings. At 5 years, using 3D profilometry, the estimated mean wear of the material at the occluding surfaces was reported to be 28 µm, which was close to the levels of physiological wear that have been reported [32].

Fig. 1.

Clinical views before, after treatment and at 9-year follow-up. After endodontic retreatment, amalgams were replaced with direct composites, and impressions were taken for the analysis of occlusal relationships. A wax-up simulating the tooth tissue restoration was made on the duplicate of the models. Restorations were designed in the Cerec system by superimposing scans of the models and the wax-up. The design of the restoration corresponds to the loss of tissue, and there is no preparation of the teeth. No-prep partial bonded restorations (tabletops and palatal veneers) were milled in Vita Enamic (PICN or hybrid ceramic, Vita Zahnfabrik, Bad Säckingen, Germany) using the Cerec MCXL machine (Sirona, Salzburg, Austria). Minimal preparation of upper incisors and canines was performed for the fabrication of buccal veneers in pressed lithium disilicate glass-ceramic (IPS e.max Press, Ivoclar Vivadent, Shaan, Liechtenstein). The incisal edges of the lower incisors and canines were restored with direct composite. Vita ceramic crowns for implants 16, 24, 36 and 46 (Ceramill Motion 2 system, Amann Girrbach, Koblach, Austria). After 9 years, some chipping of the thin margins of the restorations can be observed at some teeth, particularly at the occlusal contact points.

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Partial-coverage all-ceramic restorations

PARTIAL-COVERAGE ALL-CERAMIC RESTORATIONS FOR TREATMENT OF TOOTH WEAR

Adhesively retained all-ceramic, partial-coverage restorations for the treatment of tooth wear usually include minimally invasive, additive occlusal veneers. Restorations fabricated in adhesive ceramic such as leucite-reinforced glass-ceramic (IPS Empress, Ivoclar) and, more recently, lithium disilicate-reinforced glass-ceramics (IPS e.max, Ivoclar) compared to the use of resin composite restorations offer the merits of superior aesthetics, favourable resistance to the wearing away of the material, reduced susceptibility for staining (due to a lower relative surface free energy compared with resin composite) and good gingival tissue tolerance.

Whilst non-etchable ceramic materials, such as those based on alumina or zirconia, offer higher strength and fracture resistance, they could have inferior optical properties and may make the adhesive procedure more challenging. The cost, the risk of wear at antagonistic surfaces, the brittle nature of some ceramic materials and the limited scope for intra-oral adjustment may favour the use of resin-based materials, at least while attempting to verify the patient's acceptance of planned changes to their aesthetic zone and occlusal scheme.

CLINICAL TECHNIQUES FOR THE APPLICATION OF ADHESIVELY RETAINED ALL-CERAMIC RESTORATIONS FOR THE TREATMENT OF TOOTH WEAR

For ceramic onlay restorations, the manufacturer's instructions must be carefully followed to help avert the risks of premature failure. With the plan to provide a lithium disilicate onlay, IPS e.max, Ivoclar, preparation guides stipulate the need for a minimum 1.0-mm inter-occlusal clearance, concomitantly ensuring all internal line angles are rounded, with the absence of any grooves or sharp angles. The marginal finish should include the placement of a circular shoulder with rounded inner edges or a chamfer at an angle of approximately 10°–30° with a width of at least 1.0 mm. Inter-occlusal clearance for onlay restorations can be attained by undertaking subtractive tooth preparation and/or by placing the restoration in a supra-occlusal location to that of the existing occlusal plane. In the latter, preparation may be limited to a marginal finish line.

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THE PERFORMANCE OF PARTIAL-COVERAGE, ADHESIVELY RETAINED ALL-CERAMIC RESTORATIONS IN THE TREATMENT OF TOOTH WEAR: THE EVIDENCE BASE

Table 2 summarises some of the longevity data for the use of partial-coverage adhesive ceramic restorations to manage tooth wear. Some of these studies, as discussed below, have compared the performance of minimally invasive ceramic restorations to indirect composite resin onlays.

Edelhoff et al. [33] published the outcomes of a study investigating the longer-term (13-year) clinical survival and failure rates of single-tooth ceramic restorations made using either pressable lithium disilicate (*n* = 274) or CAD-CAM indirect resin composite (*n* = 162). The former showed a survival of 100% (mean observation time 8.5 ± 2.7 years) and a total failure rate of 5.5%. The latter also showed a survival of 100%. However, the total failure rate was much higher, 25.3% (mean observation time, 6.7 ± 0.5 years). The indirect resin composite restorations also showed higher abrasion rates and significantly higher levels of material fracture and discolouration rates. Differences in the manufacturing techniques used for each material – pressed versus CAD-CAM – may have also influenced the restoration types' optical and mechanical properties. Despite the relatively inferior performance of indirect composite-based restorations, the authors concluded that both forms of restoration could be recommended for the definitive restoration of severe tooth wear.

In another study, the wear rates over 3 years for lithium disilicate onlays and an experimental CAD-CAM polymer were investigated [23]. Amongst a sample of 12 patients, 96 restorations of each type were provided. Whilst their data set was more limited, the authors reported the wear rates of both materials to be reasonable. Although the wear rates of the composite-based material were higher, the restorations were less invasive than the lithium disilicate restorations – which required tooth preparation. The survival and success rates of the ceramic restorations were 100%; equivalent data for the indirect composite restorations was only marginally inferior (Tables 1, 2).

In a separate study [17], following the prescription of ultra-thin CAD-CAM glass-ceramic and composite resin (LAVA Ultimate) posterior occlusal veneers as part of a 3-year randomised clinical trial to 11 patients, survival rates of 100% and 84.7% were respectively reported. Analogous preparation designs were applied to both restoration types (Table 2). The composite resin restorations showed signs of chipping. Amongst the surviving restorations, there were

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significant differences in the surface roughness, with the composite-based restorations showing signs of surface degradation.

Overall, based on the available evidence, partial-coverage, adhesively retained ceramic restorations are more likely to facilitate the attainment of a more stable longer-term occlusion compared to indirect composite resin, concomitantly offering optimal form and aesthetics with lower maintenance needs – especially at molar teeth. However, the level of tooth preparation required to accommodate ceramic occlusal onlays is likely to be more invasive than the prescription of a directly bonded resin composite restoration for the same application and perhaps also for indirect composite onlays, with composite-based restorations (direct and indirect) offering the ease of repair in the oral environment.

Full-coverage tooth-coloured crowns

OVERVIEW OF FULL-COVERAGE TOOTH-COLOURED CROWN RESTORATIONS FOR TREATMENT OF TOOTH WEAR AND CLINICAL TECHNIQUES

Full-coverage crown restorations may also be prescribed to treat the worn dentition. This can include conventionally retained crowns that rely on mechanical preparation form to provide the necessary retention and resistance form or adhesively retained crowns, where the available chemical adhesion from the cementation material will also provide some retention. Full-coverage crowns may be prescribed for patients with tooth wear under circumstances when there may be some challenges with predictable bonding and the presence of multiple units of existing or failed crown restorations. Fabrication of conventionally retained full-coverage metal-ceramic crowns usually involves the firing of feldspathic porcelain onto a cast coping.

The preparation guidelines for full-coverage crowns are readily accessible from a reputable text on fixed prosthodontics. For tooth wear cases, to avoid the further loss of tooth tissue on preparation, precision preparation techniques involving the fabrication of an intra-oral mock-up from a suitable wax-up can be used, where depth reduction grooves can be made whilst the mock-up (using a provisional crown and bridge material) is in situ. The preparation designs applied by some of the investigations reporting the use of adhesively retained all-ceramic crowns for treating tooth wear have been described below.

Published in : Monographs in Oral Science (2025), vol.33, pp. 261-274
DOI: 10.1159/000543631

Status : Postprint (Author's version)

THE PERFORMANCE OF FULL-COVERAGE TOOTH-COLOURED CROWN RESTORATIONS FOR THE TREATMENT OF TOOTH WEAR: THE EVIDENCE BASE

Although the full-coverage porcelain fused to metal crown is a form of dental restoration with a very long service record, there is a lack of high-quality evidence about its performance in treating tooth wear. There is also a lack of clear evidence to support the concept that conventional crown restorations require lower levels of maintenance than some of the alternatives prescribed for the rehabilitation of worn dentition [16].

An investigation by Smales and Berekally [34] comparing the survival of direct and indirect restorations for the treatment of advanced tooth wear over a 10-year assessment period reported survival estimates of 58.9% for the directly bonded anterior resin composite restorations and 70.3% for the indirect, anterior metal-ceramic crowns. Restoration fracture was observed to be the most common mode of failure for the direct resin-bonded composite restorations; failures were often amenable to repair or replacement. In comparison, failures of crown restorations were generally of a catastrophic nature, often involving the complete loss of the restoration, which frequently necessitated subsequent endodontic treatment or the need for a dental extraction. With younger patients often presenting with signs of severe tooth wear, contingency planning must be a key consideration when planning care.

Favourable 4-year performance of all-ceramic crowns was reported by Burke [35]. In this prospective study, 59 crowns were placed (mainly amongst tooth wear patients at anterior and premolar teeth). A very low fracture incidence was observed, with excellent retention and an overall failure rate of 6%. The preparation form applied included a minimal knife-edge marginal finish with a reduction to provide 1.0–1.5 mm lingual/palatal clearance. However, the level of occlusal clearance was not clearly documented.

All-ceramic, full-coverage, adhesively bonded restorations may also be prescribed following a traditional, subtractive protocol. Milosevic [36] reported the survival of 161 zirconia-based (Lava™) crowns (a ceramic crown with a zirconia core) in 30 patients for the management of severe anterior tooth wear for a period of up to 7 years. The preparation designs were based on 'standard procedures', with a narrow circumferential chamfer finish line placed at or just above the gingival margin. All inter-proximal contact points were opened and depending on the level of wear present, dentine was exposed at least at one surface (usually at the incisal or palatal surfaces). A relatively low overall failure rate of 15.5% (25 crowns) was observed. The mean

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Status : Postprint (Author's version)

survival time for the crowns was 74 months. Failures were attributable to total de-bond or to minor delamination chips within the ceramic layer. The presence of an edge-to-edge incisor relationship and an underlying tendency towards developing tooth wear because of attrition or bruxism were also linked to a significant higher risk of failure. Consequently, this form of treatment intervention advised a protective bilaminar splint.

More recently, Hammoudi et al. [37] have reported longer-term success as part of a randomised clinical trial with an observation period of up to 6 years whilst evaluating the performance of pressed lithium disilicate crowns (361 restorations) and translucent zirconia crowns (351 restorations) for the treatment of extensive tooth wear. Crowns were applied at anterior and posterior teeth. Where possible, minimal tooth reduction was undertaken, with a chamfer finish margin that was at least 1.0 mm wide and 4.0 mm preparation height was concomitantly ensured, with the aim of a restoration thickness of at least 1.0 mm; however, at times, this was reduced by the dental technician to 0.6 mm. All crowns were adhesively luted using a resin-based cement and success rates of more than 98% were reported for both types of crowns. The aesthetic outcome offered by the translucent zirconia crowns may have been lower than for the lithium disilicate crowns – as per the rating of one blinded clinician. The authors concluded that using a high-strength ceramic material and reliable adhesive bonding were key factors in helping to attain the observed longer-term success, irrespective of the aetiology of the wear.

According to the available evidence, fullcoverage crown restorations can offer a predictable and lower-maintenance medium-term option for treating worn teeth. However, it is imperative to carefully discuss the risks of these restorations for treating tooth wear, including the well-known 'biological complications', such as the copious loss of coronal volume and the risks of irreversible pulp tissue pathology [5, 6].

Conclusion

Previous systematic reviews have not reported clear evidence demonstrating the superiority of any dental material or treatment technique to restore tooth wear [38]. Evidence has been presented that supports acceptable medium-term outcomes using direct and indirect techniques; however, more performance data are currently available for the former. Whilst direct composite can allow the operator to verify planned changes minimally invasively,

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treatment execution with this material and technique can be highly demanding of operator skill, with the additional need for favourable circumstances for predictable bonding. Molar tooth restorations may require higher levels of maintenance whether using indirect or direct composite-based materials. The wearing away of composite materials may also be problematic in the mid-long term, especially amongst higher-risk cases such as severe bruxism patients. Careful monitoring and maintenance will usually be required.

Ceramic materials (with partial and full coverage) may offer better longer-term survival, with superior wear resistance and aesthetic and occlusal stability. However, restorations fabricated in ceramic are more costly, usually more invasive than directly bonded composite, and may not be readily amenable to adjustment by addition of further dental material in the intra-oral setting. Full-coverage crowns, especially when adhesively retained, may also offer good medium-term survival. However, preparations are likely to be far more invasive than with directly bonded resin composites and partial-coverage indirect restorations, and failures with full-coverage crowns may be catastrophic. Effective contingency planning is essential, with higher levels of tooth wear being observed among younger people [39]. References

Overall, in the author's opinion, the primary focus of restorative interventions should be the preservation of the tooth tissues, with a secondary focus on the survival of the restoration. It is paramount to ensure appropriate consent is attained, and clear, complete and accurate patient records of any discussions about the restoration of tooth wear must be made and kept.

STATEMENT OF ETHICS

Written informed consent was obtained from patients for publication of the images/details.

CONFLICT OF INTEREST STATEMENT

Andrea Shepperson has key opinion leader roles with 3Shape, Ivoclar and Modjaw. The other authors have no conflicts of interest to declare.

AUTHOR CONTRIBUTIONS

Bas Loomans was the initiator of the work and made substantial contributions to the conception and design. He also drafted the manuscript and gave approval for the final version. Luuk Crins,

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Amélie Mainjot, Andrea Shepperson and Shamir Mehta made substantial contributions to the conception and design of the work. They drafted the manuscript and gave approval for the final version.

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