



Stapes Surgery for Patients with Preoperative Small Air Bone Gap

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Abstract

Purpose of Review This review summarized the existing literature on the stapes surgery for patients with a preoperative air bone gap (ABG) under 30 dB.

Recent Findings Early surgery for otosclerosis appears to give good results without increasing the risks of complications, but the topic is still controverted.

Summary Stapes surgeries for patients with a preoperative ABG lower than the classical 30 dB are more common today and some studies support this change in paradigm. The risk/benefit balance needs to be discussed with the patients.

Keywords Otosclerosis · Stapes surgery · Small air bone gap

Introduction

Otosclerosis is a relatively common disease in the Caucasian population [1]. The diagnosis is based on clinical and audiological findings, and computerized tomography (to confirm the pathology, predict some anatomic difficulties, and exclude other etiologies of conductive hearing loss) [2, 3]. Stapes surgery was first performed by Shea [4] in 1956. The first surgeries consisted of a total removal of the stapes called stapedectomy. The surgical technique progressively moved to a small fenestra in the footplate with Perkins in 1980 [5] using micro-instruments and microdrills. Since the late nineties with the emergence of laser, this technique is becoming the first choice. Some controversies still exist in the field of laser or non-laser-assisted surgery. In their meta-analysis, Fang et al. [6] found that surgery with laser have better results in the closure of air bone gaps (ABG) compared to conventional surgery without laser. A recent systematic literature review [7] did not show evidences for a superiority of the laser use with regard to hearing outcomes

or immediate postoperative vertigo. Nevertheless, this review noticed an increased risk of footplate fracture and sensorineural hearing loss (SNHL) with the use of micro-instruments or microdrills. Therefore, the authors suggest choosing lasers rather than conventional methods for footplate fenestration in primary stapedotomies. All these refinements in the surgical technique have the same objective: less inner ear mechanical/thermal trauma, preventing sensorineural hearing deterioration, and improving the functional results on high frequencies [8–11]. Nowadays, stapes surgery is a safe procedure, with favorable hearing outcome and relatively low risk of complication in expert hands. Nevertheless, the dramatic consequence of permanent inner ear damage is still at risk after these surgeries. The incidence of this dreaded complication has been less than 1% in a large cohort [12, 13]. Of note, multiple other studies with smaller cohorts or less recent paper report SNHL ranging from 0.6 to 3% [14–16].

The usual audiometric criteria prior to stapes surgery are conductive or mixed hearing loss with an ABG of 30 dB or more at 250–2000 Hertz (Hz) and air conduction (AC) thresholds of 30 dB or greater in the conversational frequencies [17]. With the growing confidence in results and the decreasing risk for inner ear damage, surgeons progressively moved to earlier surgery called “small air bone gap” (sABG) procedures. The definition of a “small air bone gap” depends on the author and means a preoperative ABG inferior to classical level of surgery indication (30 dB) [17]. The present

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review discusses stapes surgery for sABG patients and audiologic outcomes based on literature search.

State of the Art

Methodology

Literature Search and Study Selection

In this paper, we independently searched publications in English in Medline-PubMed and Google Scholar databases for relevant papers published from 1960 to 2021. Terms of search were “stape*” that includes terms such as stapedotomy, stapedectomy, stapes surgery, stapedoplasty, and derivatives; “small air bone gap” and/or “predict* factors” which includes predictive and predicting factors. In addition, a manual search was performed with the authors’ references. Only studies comparing results for stapes surgeries performed on patients with preoperative small ABG (sABG) and large ABG (LABG), and studies analyzing factors influencing the audiometric results after stapedotomy were included. Excluded from our analysis were case reports, paper in other language than English, paper with no link to the subject of small ABG, paper about pediatric population, stapes revision surgery, and laboratory research. Fourteen studies were finally included in this review.

Results

A Few Studies Are Comparing Results of Stapes Surgery for sABG and LABG

This is important to take in account when analyzing results of sABG stapedotomy that the definition of small and large air bone gaps varies between studies (from < 10 dB to ≤ 25 dB). This review included any study with a defined small and large ABG. Five studies analyzing the audiometric results of stapes surgery in patients with preoperative sABG were found in the current literature [18–22]. Table 1 summarizes these studies and their conclusions. Only one study concludes that patients with sABG undergoing stapes surgery may not identify the benefit in the long term (10 years). In this publication, they compared the audiometric results of 22 patients with sABG (<20 dB) to those of 68 patients with LABG [18]. For both groups, the mean AC thresholds significantly improved after surgery at 3 months. However, considering the rate of deterioration of gain over time (dB/year), main AC thresholds remained significantly improved in the LABG group but this improvement was lost in the sABG group after 10 years of follow-up. The other studies analyzed pronounced in favor of an early surgery with good audiometric outcomes and low risk for inner ear lesion [19••, 20••, 21, 22]. Canale et al. [19••] obtained better results in terms of postoperative ABG closure in the group of 127 patients with preoperative sABG (<25 dB) compared to the 254 with LABG. A higher

Table 1 Audiometric results after stapedotomy in sABG patients

Authors	Year	Study design	sABG definition	Number of cases	Mean follow-up time (months)	Surgical technique	Results
Alberti et al.	2017 [18]	Retrospective	≤ 20 dB	sABG n=22 LABG n=68	120	Stapedotomy microdrill	-No long-term benefit of surgery for ABG < 30 dB
Canale et al.	2020 [19••]	Retrospective	< 25 dB	sABG n=127 LABG n=254	6	Stapedotomy microdrill	-Better results for the sABG group in terms of post op ABG < 10 dB
Lavy et al.	2018 [20••]	Retrospective	<21.25 dB	sABG n=254	1,5	Laser stapedotomy	-Excellent outcomes post op ABG < 10 dB 97.6% -Higher risk of stapes mobilization (4% vs. 1%)
Salmon et al.	2015 [21]	Retrospective	≤ 25 dB	sABG n=77 LABG n=105	1,5	Laser stapedotomy	-Post op ABG and AC better in sABG -No significative risk -BC overclosure in sABG
Lippy	1997 [22]	Retrospective	< 10 dB	sABG n=136	6	Stapedectomy/stapes mobilization/exploration	-Good AC gain and overclosure -No change in WRS

sABG Small Air Bone Gap, LABG Large Air Bone Gap, AC Air Conduction, BC Bone Conduction, WRS Word Recognition Score

percentage of patients reached an excellent result in the sABG group (post op ABG < 10 dB) at 6 months. They conclude that microdrill stapedotomy is safe and can be performed even in patients with preoperative sABG without increasing the risk of SNHL due to inner ear damage in cases of mobile footplate. Lavy and McClenaghan [20••] found excellent hearing outcomes at 6 weeks for 254 patients with a relatively small preoperative ABG (their definition of sABG is ABG < 21.25 dB) in terms of ABG closure. These authors noticed a slight increase in the risk of stapes mobilization in ears with a small ABG when compared to those with larger ABGs (4% vs. 1%) that can however be overcome by using a laser-assisted technique combined with a good surgical experience. Salmon et al. [21] compared the audiometric results at 3 months of 77 sABG patients (< 25 dB) and 105 IABG (\geq 25 dB) and found a significantly smaller ABG and AC thresholds, no further risk, and a slight but significant gain in BC after surgery in the sABG group. In their study, Lippy et al. [22] operated on patients with very small ABG (< 10 dB) and concluded that stapedectomy can be an effective procedure for improving the hearing of otosclerotic patients with small air bone gaps, regarding the good PTA results and the overclosure of the ABG. The word recognition score was unchanged.

Prognostic Factors for Stapes Surgery Results Were Analyzed in Several Studies

Several studies retrospectively search for factors that can influence the postoperative results. The potential predictive factors analyzed were age, gender, side, familial otosclerosis or not, bilaterality, tinnitus, vertigo, type of prosthesis, primitive versus revision, and preoperative audiometric data including preoperative ABG. Table 2 summarizes 9 studies looking for a relationship between sABG and postoperative results. Preoperative sABG appears to be a good factor of postoperative ABG < 10 dB in several papers [23–26]. However some authors concluded that the importance of the preoperative ABG did not have any impact on postoperative results [27, 28] With respect to absolute gain in AC or the absolute gain in ABG as main outcomes of the surgery, patients with large preoperative ABG have better results than sABG patients [23, 28, 29]. Dhooge et al. showed that at long term (32,5 month) no variable were predictive of good results regarding the ABG closure < 10 dB. However, at short term, preoperative IABG and positive family history of otosclerosis were negative factors of post-operative ABG < 10 dB at early postoperative period [30].

Discussion

Earlier stapes surgeries for patients with otosclerosis and preoperative sABG are becoming more common in the past several years. This is explained by the growing confidence

of the surgeons, based on the excellent outcome and the low risks, and on the other hand by the patients complaining early from hearing loss and more the before in demand for a surgical treatment. This change in the paradigm is supported by several recent papers, but needs to be nuanced.

Definition of Small Air Bone Gap

The definition of a small air bone gap varies from the authors within the range of 10 to 30 dB. It is important to be precise with this sABG notion when analyzing results. We can reasonably admit that a sABG is inferior to 30 dB which is ABG classically used for stapes surgery indication [17].

Postoperative Outcomes

Based on the literature data, successful outcome after stapes surgery is a reduction of the postoperative ABG and/or an improvement of thresholds in AC and no deterioration of bone conduction. A postoperative ABG of 10 dB or less and a gain in AC of 20 dB or more are considered as a good result. The postoperative ABG reflects the surgical effect. But a reduction of the ABG gap can be due to either a gain in AC or a degradation in BC, or both. For this reason, it is useful to have more than one outcome. Unfortunately, some studies do not always use the same criteria of success. The good results for patients with preoperative sABG depend of the choice of the criteria. Indeed, patients with preoperative sABG will easily reach a post ABG < 10 dB, but rarely a gain of > 20 dB in AC [23]. Most studies comparing the results of sABG and IABG after stapedotomy (Table 1) have better results in terms of post op ABG [19••, 20••, 21, 22] for the sABG group. Only one study did not find any benefit of surgery for sABG in terms of AC thresholds at 10 years post op. Several studies showed that a preoperative sABG is a factor of positive prognosis for a postoperative ABG closure < 10 dB, which is considered as a good result [23–26]. Some studies found also lower AC thresholds for patients who underwent surgery with a preoperative sABG [21, 22]. However, some authors who consider the absolute gain in AC or the absolute gain in ABG concludes that the benefit of the surgery is more important when patients have a preoperative larger ABG [23, 28, 29] (Tables 1 and 2).

Various authors [25, 26, 31] found that for some frequencies, the closure of the ABG is better in the population of patients presenting a small preoperative ABG. Ueda et al. [31] demonstrated that there was a significant correlation between pre- and postoperative ABGs at frequencies of 1 kHz and lower. Kishimoto et al. [26] showed that a small ABG of 250, 500, and 4 kHz was a factor of good prognostic

Table 2 Prognostic factors in stapes surgery

Authors	Year	Study design	Number of ears	Follow-up (months)	Outcomes	Pre op factors analyzed	Conclusions
Deniz et al.	2020 [24]	Retrospective	177	6	ABG \leq 10 dB	Gender/age/side/uni- or bilateral/ pre op ABG	-Better results (ABG < 10 dB) if pre op ABG < 34.5 dB
Yeh et al.	2019 [25]	Retrospective	181	3	ABG \leq 10 dB	Gender/age/side/uni- or bilateral/ pre op ABG/piston type/tinnitus/vertigo/ floating footplate	-Independent factors of good prognostic: ●Small pre op ABG ●No floating footplate
Koopman et al.	2015 [28]	Retrospective	162	0,5	-ABG -Absolute ABG gain -Relative ABG gain	Gender/age/tinnitus/ pre op ABG, AC, BC	-Post op ABG independent of all pre op factors -Relative ABG gain better if pre op ABG \geq 29 dB
Bitterman et al.	2011 [23]	Retrospective	666	3	-ABG \leq 10 dB -Gain in AC > 20 dB	Gender/age/uni- or bilateral/ pre op AC, ABG, BC	-Age > 40 and pre op ABG < 30 dB 1.3 \times risk of post op ABG \leq 10 dB -Pre op AC > 50 dB et ABG > 30 dB = 2.5 \times risk of gain of > 20 dB
Kishimoto et al.	2015 [26]	Retrospective	234	?	ABG < 10 dB	Gender/age/uni- or bilat/ pre op AC pre op ABG 250, 500 Hz, 1, 2, 4, 8 kHz/ surgical technique/prosthesis/cochlear otosclerosis	-sABG 250, 500, and 4 kHz good chance of closure ABG
Ueada et al.	1999 [31]	Retrospective	166	3–6	AC, BC, ABG 250, 500 Hz, 1, 2, 4, 8 kHz	Pre op ABG, AC, BC 250, 500 Hz, 1, 2, 4, 8 kHz Surgical technique	-250, 500 Hz, 1 kHz: sABG = good factor prognostic for sABG post op
Marchese et al.	2013	Retrospective	161	12	AC, ABG, BC pre post op + gain in ABG	Gender/age/uni- or bilat/ pre op ABG, AC, BC/side	-Preop ABG > 30 dB, age < 50 = good factors prognostics for gain ABG > 10 dB
Dhooghe et al.	2018 [30]	Retrospective	230	32.5	Early AC, BC, ABG Late AC, BC, ABG Post op ABG < 10 dB	Gender/age/side/familial history/ bilaterality/tinnitus/vertigo/ pre op ABG	-No variable determinant for audiometric results in long term -ABG and positive family history are negative factors for early post op ABG < 10 dB
Shah et al.	2018 [36]	Prospective	31	3	AC gain, post op ABG BC	Gender/degree of hearing loss/type of footplate	-Better gain in AC of severe and very severe degree of hearing impairment -ABG closure better for female, thin and thick foot plate
Shiao et al.	2013 [27]	Retrospective	109	18	ABG \leq 10 dB	Gender/age/side/uni- or bilat/ pre op ABG, AC/piston type/tinnitus/ vertigo/	-No regard to influence of pre op ABG -No influence of pre op factors

for ABG closure on these frequencies. In only one study evaluating the very long-term audiometric results for patients operated with a sABG, the authors concluded that they were not in favor of an early surgery, because 10 years after the surgery, the patients may not present an audiometric benefit [18]. The relevance of this paper is low because of the small size of the cohort of patients ($n = 22$).

Inner Ear Risk

One of the most important issues in this topic is the potential risk of inner ear trauma induced by a surgery for patients with sABG. Indeed, these cases are likely to be associated with less fixed stapes at the oval window and are potentially more at risk of inadvertent stapes mobilization during the surgical procedure, leading either to abandon the surgery, or to some degree of postoperative sensorineural hearing loss (SNHL). Lavy et al. [20••] described 4% stapes mobilization in the sABG group, higher than that in the lABG group (1%). They deplored no more hearing loss, thanks to the use of laser which allows the removal of the superstructure and the stapedotomy even on a partially mobile footplate. No additional risk for the inner ear was reported by other studies [19••, 20••, 21, 22] when an early surgery is performed even if the footplate is not totally fixed, thanks to the less traumatic modern techniques of stapedotomy. However, if the overall inner ear risk stays low even with small preoperative ABG (< 1%), worsened postoperative hearing or worse, a deaf ear, will be such difficult to accept especially in the case of mild to moderate preoperative functional impairment.

Age at Surgery

sABG usually goes together with younger age [28], which is considered by some authors as a good prognostic factor for overclosure of BC [32] and closure of ABG [29]. Two studies [23, 29] confirmed that the age at surgery was an independent factor of good postoperative results in otosclerosis stapes surgery. Delaying the surgery for these patients means letting them live with hearing handicap (even mild) for many years before performing the surgery.

Word Recognition Score

Most of the studies focused on postoperative pure tone audiometric data (AC, BC, ABG) and do not pay attention in the Word Recognition Score (WRS), nor in the quality of life. Among the five retrospective studies of Table 1, only Lippy et al. [22] compared pre- and postoperative WRS and they found no difference. But this particular paper focused on patients with very small ABG, with a preoperative nearly perfect WRS. It was demonstrated by de Bruijn [33] that

there was a larger correlation between the gain in AC and the gain in WRS than between the gain in ABG and the gain in WRS. This is particularly true when AC gain is calculated at the four frequencies (0.5, 1, 2, 3, or 4 kHz) as recommended by the Committee on Hearing and Equilibrium guidelines for evaluation of results of treatment of conductive hearing loss [34], to calculate the AC gain.

Bone Conduction and Overclosure

Bone conduction (BC) is difficult to assess and frequently overestimated in patients with preoperative small ABG. A part of this difficulty is due to the Carhart effect that relates to a false elevation in bone conduction with a peak at 2 kHz associated with a conductive hearing loss. This might lead to postoperative overclosure of the presumed ABG. Two studies [21, 22] found a significant degree of overclosure among patients operated with preoperative small ABG. Mosillo et al. [32] analyzed the bone conduction change 3 years after stapedotomies in 100 patients. They found a median significative improvement of BC which is more important for patients under 45 years of age. They concluded that a preoperative mixed hearing loss, or a mean ABG of 20 dB, especially for young patients, can be considered as surgical indication.

Quality of Life

No study compared the quality of life of patients with otosclerosis and sABG who underwent early surgery versus others.

Tinnitus and Vertigo

No study focused on the change in tinnitus or vertigo for patients with preoperative sABG.

Unilateral or Bilateral Surgery, and Stereophony

Preoperative contralateral hearing level is very important to take into account. Indeed, patients consider a postoperative good result when the interaural difference is ≤ 10 dB or lesser and bad if it is ≥ 15 dB. The definition of stereophony distilled from this observation is known as the Belfast rule of thumb. This can help taking decision if the surgery could give a new stereophony to the patient, even with a small preoperative ABG. The same consideration for bilateral cases, after the first ear (the worse one) if the patient keeps an interaural difference of ≥ 15 dB, he will not beneficiate of the stereophony. For these patients, even if there is a sABG, this is an argument to propose surgery for the second ear.

Conclusions

This review gives several proofs of the better audiometric short-term results in terms of ABG closure and postoperative AC in patients with preoperative small ABG. The inner ear trauma risk is not higher when surgery is performed with modern less traumatic techniques. These are arguments to dare proposing earlier surgery to our patients complaining from hearing loss and asking for solution. However, even it remains low, the risk of inner ear trauma exists and a postoperative SNHL will be such more difficult to accept for a patient with a preoperative mild impairment. The success criteria of a functional surgery according to the patient are different from those of the surgeon. In the patient's view, the surgery is considered successful when improvement in audiometric thresholds and absence of complications are achieved together with good stereophony and hearing abilities in various environments and the absence of sound distortion, tinnitus, and dizziness [35]. The patient's expectations also contribute to his perception of success: reduced benefits compared to patients over expectation could not be appreciated, even if surgery leads to slight functional benefits and good results. For these reasons, patient's impairments, desires, expectations, and clinical findings should be cautiously analyzed. The patient should be fully informed about possible benefits and risks of stapes surgery. It is the only way to try to make with each patient the best choice for him at the best moment.

Declarations

Ethics Approval Not applicable.

Competing Interests The authors declare no competing interests.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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