ACTA OTORHINOLARYNGOLOGICA ITALICA 2022;42:569-581; doi: 10.14639/0392-100X-N1933

Otology

Exploratory tympanotomy in conductive hearing loss with normal pre-operative investigations

La timpanotomia esplorativa nelle ipoacusie trasmissive con esami pre-operatori normali

Michele Tomasoni[1], Daniele Borsetto[2], Alessandra Deretti[1], Mara Arcuri[1], Alessandra Sordi[1], Silvia Zorzi[1], Luca Oscar Redaelli de Zinis[1,3], Cesare Piazza[1], Alberto Deganello[1], Tommaso Sorrentino[1]

[1] Department of Otolaryngology-Head and Neck Surgery, ASST Spedali Civili, University of Brescia, Brescia, Italy; [2] Department of ENT Surgery, Cambridge University Hospitals, Cambridge, UK; [3] Department of Pediatric Otolaryngology-Head Neck Surgery, Children Hospital ASST Spedali Civili, University of Brescia, Brescia, Italy

SUMMARY

Objective. To investigate whether patients with conductive hearing loss (CHL) and normal preoperative investigations may benefit from exploratory tympanotomy (ET) and tailored treatment performed according to intraoperative findings.

Methods. Patients treated with ET for CHL with normal pre-operative otoscopy, tympanometry and CT scan from 2011 to 2019 were reviewed. Data regarding demographics, audiometry, intraoperative findings and surgery were collected and analysed to assess if they can predict post-operative air bone gap (ABG) closure and patient satisfaction.

Results. Forty-eight cases were included. Mean ABG significantly reduced ($p < 0.001$) from preoperative (38.4 dB) to postoperative (14.8 dB). Post-operative ABG closure within 10 dB was observed in 20 cases (41.7%). Overall satisfaction was reported in 60% of cases. Stapes fixation was the most common diagnosis (47.9%) and significantly associated with lower post-operative ABG and higher satisfaction.

Conclusions. In CHL with normal pre-operative investigations, ET represents the mainstay of treatment, even if audiological outcomes may widely vary. Intraoperative finding of stapes fixation (thus stapedotomy) ensures the best audiological and satisfaction outcomes.

KEY WORDS: hearing loss, conductive, exploratory tympanotomy, otosclerosis, stapes surgery, ossicular replacement

RIASSUNTO

***Obiettivo**. Studio dell'outcome audiologico nei pazienti con ipoacusia trasmissiva (CHL) e indagini preoperatorie normali trattati con timpanotomia esplorativa (ET).*

***Metodi**. È stata condotta una revisione dei casi di CHL con normale otoscopia, timpanometria e TC pre-operatorie trattati con ET dal 2011 al 2019. I dati demografici, audiometrici e relativi alla diagnosi intra-operatoria sono stati raccolti e analizzati per valutarne il valore predittivo in termini di riduzione post-operatoria dell'air bone gap (ABG) e di soddisfazione dei pazienti.*

***Risultati**. Sono stati inclusi 48 casi. L'ABG medio si è ridotto significativamente ($p < 0,001$) dal pre-operatorio (38,4 dB) al post-operatorio (14,8 dB). Un ABG post-operatorio entro i 10 dB è stato osservato in 20 casi (41,7%). La soddisfazione generale è stata riportata nel 60% dei casi. La fissità stapediale è stata la diagnosi più frequente (47,9%) e significativamente associata a un ABG post-operatorio più basso e a una migliore qualità di vita percepita.*

***Conclusioni**. Nella CHL con indagini pre-operatorie normali, l'ET rappresenta il trattamento di prima scelta, sebbene i risultati audiometrici possano variare. Il riscontro intraoperatorio di fissità stapediale si associa a migliori risultati audiologici e di soddisfazione del paziente.*

PAROLE CHIAVE: *ipoacusia trasmissiva, timpanotomia esplorativa, otosclerosi, chirurgia della staffa, ossiculoplastica*

Received: November 23, 2021
Accepted: July 6, 2022

Correspondence
Michele Tomasoni
Department of Otorhinolaryngology-Head and Neck Surgery, University of Brescia, piazzale Spedali Civili 1, 25123 Brescia, Italy
E-mail: tomasoni.michele@gmail.com

How to cite this article: Tomasoni M, Borsetto D, Deretti A, et al. Exploratory tympanotomy in conductive hearing loss with normal pre-operative investigations. Acta Otorhinolaryngol Ital 2022;42:569-581. https://doi.org/10.14639/0392-100X-N1933

Introduction

Conductive hearing loss (CHL) is a frequently encountered condition in the practice of otolaryngologists and can result from a variety of pathologic conditions [1-3]. An accurate diagnosis is essential to offer patients the best treatment option. Patients affected by CHL presenting with normal tympanic membrane, tympanometry and temporal bone computed tomography (CT) represent a clinical challenge. Exploratory tympanotomy (ET) is a diagnostic option that allows surgeons to assess the middle ear (ME), eventually tailoring treatment according to intraoperative findings.

The aim of this study is to investigate whether patients presenting with CHL, normal ME pressure and negative/non-diagnostic pre-operative CT scan may benefit from a surgical intervention of exploratory tympanotomy, quantifying the air bone gap (ABG) reduction that tailored surgery according to intraoperative findings may offer. Moreover, patient and treatment-related factors, as well as pre-operative audiologic data, were studied to assess their potential predictive role on restoration of air-conduction. We also collected data on the benefit perceived by patients following surgery, investigating variables that may influence patient satisfaction.

Materials and methods

A retrospective analysis of consecutive patients undergoing ET under local anaesthesia for CHL between September 2011 and November 2019 was conducted at the Department of Otolaryngology of the University of Brescia, Italy. All patients presenting with CHL and normal tympanic membrane underwent high-resolution temporal bone CT scan to confirm eligibility for surgical procedures of hearing restoration, and for better definition of ME anatomy and potential surgical risks. Advantages and disadvantages of any possible interventions were thoroughly discussed with patients.

Inclusion criteria were: a) patients undergoing elective ET; b) with a preoperative air-bone gap (ABG) ≥ 20 dB at least in 2 frequencies (500-3000 Hz) [4] determined with a pure-tonal audiometry (PTA); c) normal pre-operative microscopy and oto-endoscopy; d) normal tympanometry (i.e. pattern A); e) normal/non-diagnostic pre-operative ear CT scan. Exclusion criteria were: a) age < 18-years; b) previous surgery in the affected ear; c) reporting symptoms consistent with third window disorders.

Surgical strategies were tailored according to intraoperative findings to restore hearing.

Data regarding demographics, radiological, pre-and post-operative PTA, intraoperative findings and surgical details were anonymously collected in a dedicated database. PTA findings were analysed according to the "Committee on Hearing and Equilibrium guidelines for the evaluation of the results of treatment of conductive hearing loss" [5]. ABG was defined as the mean value of the differences between the air- and bone-conductions at 500, 1000, 2000 and 3000 Hz. ABG reduction was defined as the difference between pre-operative and post-operative ABGs. Patient-referred outcomes after surgery were measured by administration of the 18-question "Glasgow Benefit Inventory (GBI)" questionnaire at the latest follow-up evaluation [6]. Patients were also asked if they were satisfied by the surgical procedure overall, and if they would recommend the procedure.

Statistical analysis

Characteristics of patients were expressed in terms of percentages, mean and relative standard deviation, median, inter-quartile range (IQR) and range.

Continuous variables were tested for normal distribution with Shapiro-Wilk test. Parametric tests (ANOVA) and non-parametric tests (Mann-Whitney, Kruskall-Wallis, Wilcoxon signed-rank tests) were used as appropriate. Spearman's and Pearson's rho were calculated to study correlation between continuous variables. Relationship between discrete variables was conducted with Fisher exact and Chi-squared tests, as appropriate.

ROC curve analysis was used to determine the ideal cut-off according to Youden's index in age at presentation, pre- and post-operative ABG and ABG reduction according to overall satisfaction. AUC values > 0.70 were considered satisfactory.

Statistical analysis was performed using R (version 4.0.5, R Foundation for Statistical Computing, Vienna, Austria); p-values < 0.05 were considered statistically significant.

Results

During the period of investigation, 515 ears were scheduled for surgical treatment of CHL with normal pre-operatory tympanic membrane and ear pressure. In 467 patients, the preoperatory CT scan was diagnostic for otosclerosis and stapedotomy was performed.

The remaining 48 cases (9.3%) with a non-diagnostic pre-operatory CT scan were scheduled for exploratory tympanotomy and included in the current study. Cone beam CT (CBCT) was performed in 28 patients (58.3%). Of these patients, most were female (54.2%), with a mean age at surgery of 51.7 ± 14.0 years. Family history for otosclerosis was recorded in 2 cases. Medical history revealed previous contralateral ear surgery and long-standing head trauma in 1 (2.1%) and 4 (8.3%) cases, respectively (Tab. I). Stapedial reflexes were absent in all patients.

The most frequent intraoperative finding was stapes fixation (23 cases, 47.9%), followed by ossicular chain discontinu-

Table I. Most relevant patient and treatment-related variables.

Variable		N.	%
Mean age ± SD (range) - yr	51.7 ± 14.0 (20-78)		
Gender	Female	26	54.2%
	Male	22	45.8%
Side	Left	25	53.1%
	Right	23	47.9%
CT scan	MSCT	20	41.7%
	CBCT	28	58.3%
History	Family history of otosclerosis	2	4.2%
	Head trauma (long-term, > 1 year)	4	8.3%
Intraoperative findings	Stapes fixation	23	47.9%
	Incudo-malleolar ankylosis	6	12.5%
	Ossicular chain discontinuity	11	22.9%
	- Incudo-stapedial dislocation	*(6)*	*(54.5%)*
	- Erosion of the long process of the incus	*(2)*	*(18.2%)*
	- Severe erosion of the incus	*(2)*	*(18.2%)*
	- Stapes superstructure fracture	*(1)*	*(9.1%)*
	Tympanosclerosis	8	16.7%
Surgical procedure	Stapedotomy	24	50%
	Ossiculoplasty with remodeled incus	18	37.5%
	Interposition of bone or cartilage fragment between the incus and the stapes	4	8.3%
	TORP	1	2.1%
	Positioning of stapedial prosthesis without stapedotomy	1	2.1%
	Lysis of ME adherences	1	2.1%
Intraoperative complications	Injury of the chorda tympani	7	14.6%
Post-operative complications	Temporary dizziness	3	6.2%
Median GBI score (range)	18, IQR:33.3 (-47.2, 55.5)		
Overall satisfaction	Yes	24	60%
	No	16	40%
	Unknown	(8)	

CBCT: cone beam computed tomography; IQR: Interquartile range; ME: middle ear; MSCT: multi-slice computed tomography; TORP: total ossicular replacement prosthesis.

ity (11 cases, 22.9%), tympanosclerosis (8 cases, 16.7%) and ossicular chain ankylosis (6 cases, 12.5%) (Fig. 1). Ossicular chain discontinuity was mostly caused by incudo-stapedial dislocation (6 cases, 54.5%), followed by erosion

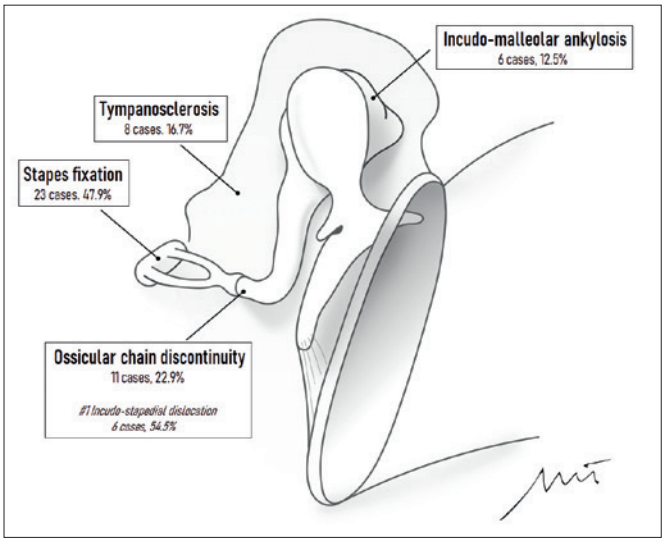


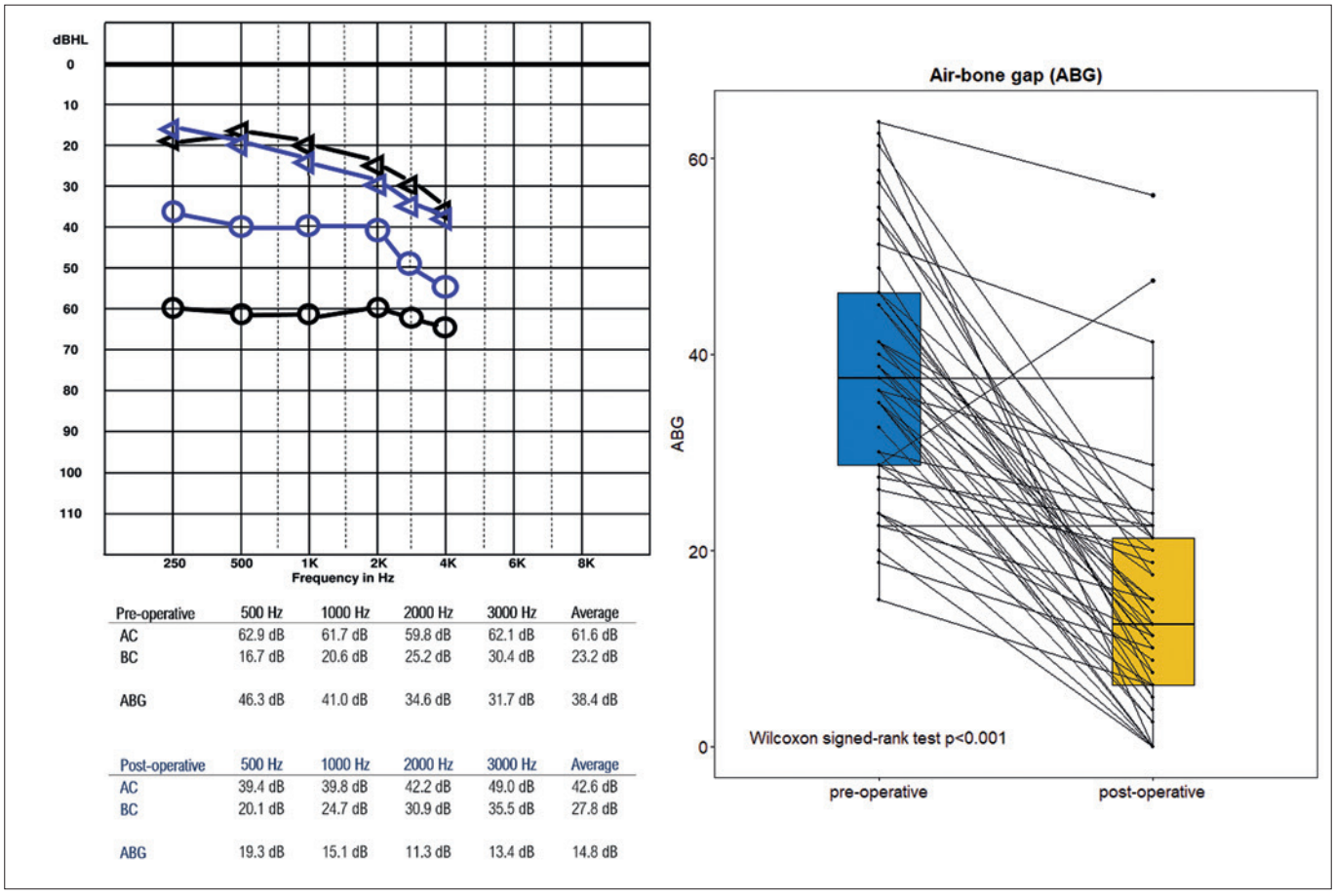
Figure 1. Intraoperative findings and relative frequency (drawing by Michele Tomasoni).

of the long process of the incus (2 cases, 18.2%). Ossicular chain ankylosis was always at the level of the incudo-malleolar joint. In patients affected by tympanosclerosis, along with ME adherences, an incudo-malleolar ankylosis was observed (4 cases, 50%), whereas stapes fixation, incudo-stapedial dislocation and malleolar partial erosion was found in 1 case each (12.5%).

Stapedotomy was the most common procedure performed (24 cases, 50%), followed by ossiculoplasty (23 cases, 47.9%) and lysis of ME adherences (1 case, 2.1%). Ossiculoplasty was mostly performed by interposition of remodeled incus (18 cases, 37.5%), whereas in the remaining cases interposition of bone or cartilage fragment (4 cases, 8.3%), total ossicular replacement prosthesis (TORP, 1 case, 2.1%) and stapedial prosthesis without stapedotomy (1 case, 2.1%) was performed. Intraoperative complications were limited to chorda tympani injury, reported in 7 cases (14.6%). Details of each patient included are reported in Table S1 (supplementary material). Except for 3 cases of temporary dizziness, no other post-operative complications were recorded.

Hearing outcomes

Mean values of pre- and post-operative air- and bone-conduction at 500, 1000, 2000 and 3000 Hz are depicted in Figure 2. Mean pre-operative and post-operative ABG were 38.4 (range: 15-64) and 14.8 (range: 0-56), with a significant ABG reduction after surgery (Wilcoxon signed-rank test, $p < 0.001$) of 24 ± 15 dB (Fig. 2). In 1 case, (2.1%) an increase of ABG after surgery was observed (stapedotomy performed for a pre-operative CHL of 29 dB).



Pre-operative	500 Hz	1000 Hz	2000 Hz	3000 Hz	Average
AC	62.9 dB	61.7 dB	59.8 dB	62.1 dB	61.6 dB
BC	16.7 dB	20.6 dB	25.2 dB	30.4 dB	23.2 dB
ABG	46.3 dB	41.0 dB	34.6 dB	31.7 dB	38.4 dB

Post-operative	500 Hz	1000 Hz	2000 Hz	3000 Hz	Average
AC	39.4 dB	39.8 dB	42.2 dB	49.0 dB	42.6 dB
BC	20.1 dB	24.7 dB	30.9 dB	35.5 dB	27.8 dB
ABG	19.3 dB	15.1 dB	11.3 dB	13.4 dB	14.8 dB

Figure 2. On the left, pure tone audiometry reporting the mean pre-operative (black) and post-operative (blue) air-conduction and bone-conduction thresholds. Values are reported with symbols for left ear by way of example. On the right, p-paired test showing the significant reduction in air-bone gap following surgery in our cohort of patients.

Post-operative ABG < 10 dB was observed in 20 cases (41.7%) and between 10-20 dB in 15 cases (31.2%). Non-satisfactory postoperative ABG (> 20 dB) was observed in 14 cases (29.2%) (Tab. S1). A significant positive correlation was observed between pre-operative ABG and ABG reduction (R = 0.62, p < 0.001) (Fig. 3A).

Age at surgery, gender and side of treated ear were not significantly associated with any auditory measure, namely pre- and post-operative ABG and ABG.

Pre-operative ABG was not significantly associated with intraoperative findings (p = 0.510), as well.

Post-operative ABG was significantly influenced by intraoperative findings (p=0.006) and surgical procedure (p = 0.009) (Fig. 4). Patients affected by stapes fixation had a median post-operative ABG of 8.7 (IQR = 7.5), and significantly lower than patients affected by ossicular chain discontinuity (17.5, IQR = 16.9), ankylosis (19.4, IQR = 5.9) or tympanosclerosis (21.2, IQR = 4.7). Similarly, patients treated with stapedotomy showed significantly lower ABG after treatment (9.4, IQR = 7.8) compared to patients treated with ossiculoplasty with remodelled incus (18.1, IQR = 8.1) or other procedures (22.5, IQR = 18.7). No significant differences in ABG reduction were observed according to intraoperative findings (p = 0.53) or surgical procedure performed (p = 0.39) (Fig. S1).

Patient-reported outcomes

GBI total score was available for 38 patients (79.2%) and ranged from -47.2 to 55.5, with a median value of 18 (IQR = 33.3).

Both post-operative ABG (R = -0.45, p = 0.004) and ABG reduction (R = 0.36, p = 0.024) were significantly correlated with perceived benefit (Fig. 3B-C). No correlation was found with pre-operative ABG (p = 0.660), age at surgery (p = 0.683), gender (p = 0.672), side (p = 0.110), or chorda tympani injury (p = 0.840). Better GBI scores were reported by patients affected by otosclerosis (p = 0.063) (Fig. S2).

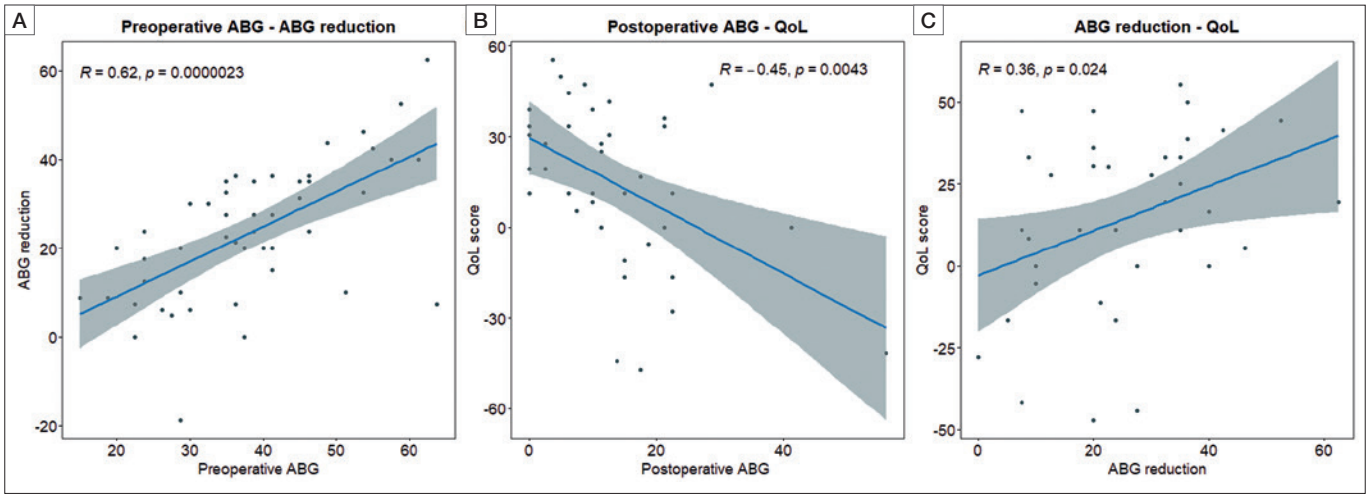


Figure 3. (**A**) positive correlation between pre-operative air-bone gap (ABG) and ABG reduction (r = 0.64, p < 0.001); (**B**) negative correlation between post-operative ABG (r = -0.44, p = 0.005) and perceived benefit from surgery reported by patients through the "Glasgow Benefit Inventory (GBI)" questionnaire; (**C**) positive correlation between ABG reduction and GBI score (r = 0.41, p = 0.009).

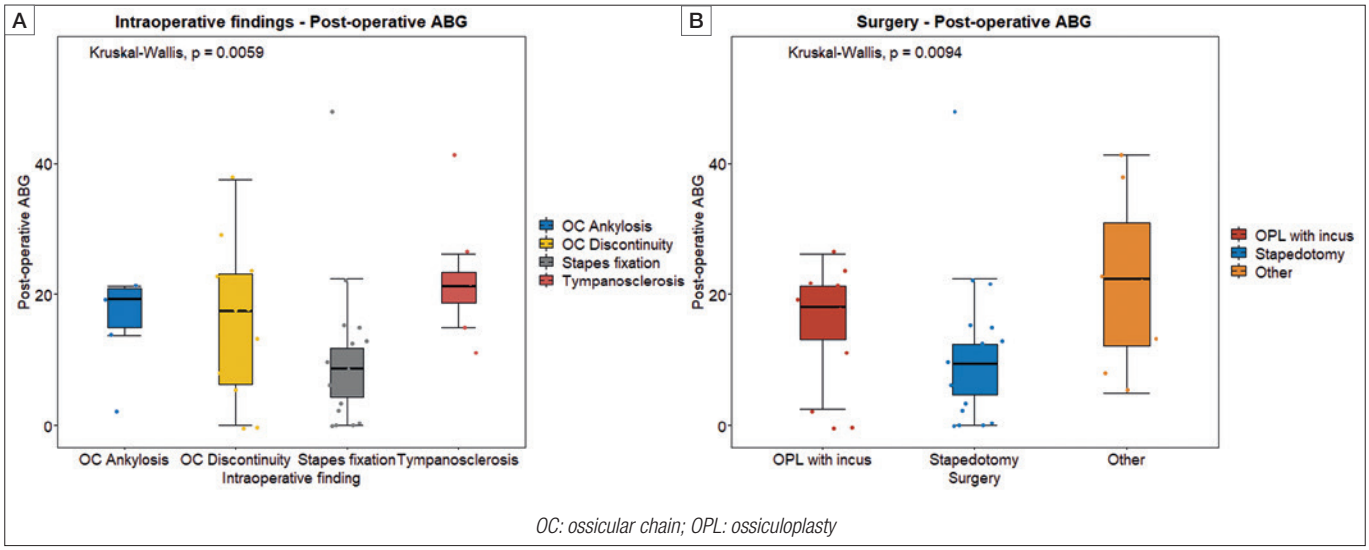


Figure 4. (**A**) box-plots showing the significant difference (p = 0.011) in post-operative ABG according to intraoperative findings; (**B**) box-plots showing the significant difference (p = 0.018) in post-operative ABG according to surgery performed, tailored on intraoperative findings.

Overall satisfaction was reported by 60% of patients, with a mean GBI score of 31.9 (IQR = 20.2, range: 11.1-55.5). Patients who declared not to be satisfied with the surgical procedure reported a mean GBI of -8.3 (IQR = 25, range: -47.2-11.2). Patients affected by otosclerosis were significantly more satisfied (p = 0.025), whereas no significant association was found between overall satisfaction and gender (p = 0.990), side (p = 0.486), chorda tympani injury (p = 0.844), pre-operative mean air-conduction thresholds (p = 0.280), or pre-operative ABG (p = 0.930).

ROC curve analysis showed better results in terms of personal satisfaction in patients aged < 57-years (AUC = 0.706), showing post-operative ABG closure < 13.1 dB (AUC = 0.855) or ABG reduction > 28.7 dB (AUC = 0.725) (Fig. S3). No ideal cut-offs were found according to pre-operative ABG.

Discussion

The main goal of the current study was to investigate intraoperative findings, auditory outcomes and related predictive factors in a population of patients affected by CHL

presenting with normal pre-operative otoscopy, ME pressure and CT scan.

In this subset of patients, pre-operative PTA showed mean threshold values of air- and bone-conduction of 61.6 and 23.2 dB, respectively, with a relative ABG of 38.4 dB. The wide pre-operative ABG may be explained with the fact that there were patients suffering from CHL with no pre-operative evidence of ME disorders. In this setting, the surgeon cannot provide a reliable prediction of hearing restoration and surgical risks, commonly resulting in a delay of the procedure.

The diagnostic accuracy of CT scan in the setting of CHL has been widely demonstrated in acute and chronic inflammatory disorders and otosclerosis, whereas it is not well established in the rare occurrence of ossicular malformations or dislocation [7-9]. In our experience, in 467 cases stapedotomy was scheduled following a radiological diagnosis of otosclerosis, whereas in 23 cases the exploratory tympanotomy revealed stapes fixation with normal pre-operative temporal bone CT scan. The overall accuracy of CT scan was 95.3%. Patients included in the current study often underwent preoperative CBCT (58.3%), which was at least as accurate as multi-slice CT or even superior in assessing structures related to conductive hearing loss, with lower radiation exposure [10].

In our cohort, a slightly higher proportion of female patients was observed (54.2%), with a mean age of 51.7 ± 14 years. These results reflect the well-known distribution of CHL in the general population, primarily driven by otosclerosis [7,11-13]. Previous head trauma (8.3%) was reported less frequently compared to similar studies (Choi et al., 29%) [7], whereas family history of otosclerosis was rarely reported (4.2%), even if we consider only patients with stapes fixation (8.7%). Since all these patients had a normal pre-operative CT scan, the form of otosclerosis might be considered "mild" and potentially unrecognised and misdiagnosed within the family [12].

As described by Hong et al. [14], patients with CHL and absent acoustic reflexes generally are affected by ossicular disorders, most commonly, but not exclusively, secondary to otosclerosis. The detection of even one acoustic reflex should prompt further workup prior to ME exploration in the suspicion of third-window disorders. In our cohort, all patients undergoing ET had absent acoustic reflexes. However, in the experience of Hong et al. [14], a non-negligible rate of patients with an ossicular aetiology of CHL had detectable acoustic reflexes, concluding that the reflex test should not be considered infallible. For this reason, we do not recommend considering the stapedial reflex as a relevant variable in the decision-making algorithm for an ET in the case of a CHL with normal otoscopy, radiology and tympanogram.

The relative frequency (47.9%) of occult otosclerosis in our cohort was also reported by previous studies [7,11,15]. In these cases, the degenerative otospongiotic process, originating from the fissula ante-fenestram, was probably wide enough to cause footplate fixation but not to be clearly depictable on pre-operative CT scan. In our experience, ossicular chain discontinuity (22.9%), ankylosis (12.5%) and tympanosclerosis (16.7%) were less common. The relative proportion of pathologic conditions underlying CHL is similar to previous publications [11,16].

As expected, stapedotomy was the most common surgery performed (50%), followed by ossiculoplasty with remodeled incus (37.5%). Similar results were reported by Kim et al., reporting most patients undergoing stapedotomy (77%) [11]. On the contrary, the most common surgical procedure reported by Choi et al. was ossiculoplasty with PORP (49%), followed by stapedotomy (23%) and TORP (23%), although in that study pre-operative CT findings were not considered [7].

In our cohort, ET was a safe and effective procedure. Intraoperative complications consisted exclusively of accidental injury of the chorda tympani (14.6%), whereas after surgery only 3 cases of transitory dizziness were observed. However, it should be kept in mind that occult otosclerosis is the most common finding during ET. Since stapedotomy carries a non-negligible rate of potentially severe complications, surgical indication is discussed with patients when at least 20 dB of ABG is present.

Mean air-conduction threshold on 0.5-3 kHz went from a preoperative value of 61.6 to 42.6 dB after surgery, with a net mean gain of 23.1 dB, regardless the undergoing disease or surgery performed. Similar findings were reported by Kim et al. (17.3 dB) [11] and Choi et al. (19.4 dB) [7].

Most of our patients showed an excellent (< 10 dB, 41.7%) or good post-operative ABG (10-20 dB, 31.2%), whereas non-satisfactory post-operative ABG (> 20 dB) was observed in 14 cases (29.2%). Only 1 patient (2.1%) experienced an increase in the ABG (secondary to stapedotomy). Similar results were reported by Kim et al. [11], with excellent, good and non-satisfactory ABG closure found in 47.8, 32.8 and 19.4% of cases, respectively. The increase in the proportion of cases of ABG was comparable as well (5.3%), but in the experience of Kim et al. [11] this occurred after surgery for ossicular fixation and discontinuity.

None of the preoperative variables under study (sex, side and age at diagnosis) were useful in predicting auditory recovery after treatment. The only positive association found was between preoperative ABG and postoperative ABG reduction, suggesting that good ABG closure is achievable even in worst-case scenarios of large preoperative gap.

Conversely, intra-operative findings and the surgical proce-

dure performed accordingly were better prognosticators of successful auditory recovery. When ET was diagnostic for stapes fixation and stapedotomy was performed, patients experienced better outcomes in terms of post-operative ABG closure, confirming what was previously described by Kim et al. and Choi et al. [7,11].

These results make audiological outcomes poorly predictable in the pre-operative setting, apart from the general expectation of greater ABG reduction in patients with higher pre-operative ABG [11].

As expected, higher GBI score was reported when lower postoperative ABG (R = -0.45) and greater ABG reduction (R = 0.36) were achieved, and when patients were diagnosed with otosclerosis, although only a close-to-significant association was found (p = 0.063).

When asked to express their general satisfaction, younger patients (< 57-years at surgery), with excellent post-operative auditory outcomes (ABG < 13.1 dB or ABG reduction > 28.7 dB) were more satisfied. The possible explanation for better satisfaction outcomes in younger patients may come from the higher proportion of otosclerosis, as confirmed by the significantly greater satisfaction reported by patients diagnosed with otosclerosis (p = 0.025).

The current study presents some limitations. First, this is a retrospective study based on a relatively small number of patients given the rarity of the condition. Second, the wide spectrum of disease and the low number of cases for each condition did not allow further sub-analysis. Third, GBI score was not available for all patients.

Conclusions

Despite the high accuracy demonstrated by CT scan, CHL with normal ME pressure, otoscopy and radiological findings is still possible. In this setting, ET represents the mainstay of treatment, but pre-operative predictions of both auditory recovery and patients perceived benefit after surgery are extremely challenging, with only younger age offering a partial clue of better results. Surgeons should be prepared to tailor surgery according to intraoperative findings with variable auditory outcomes. In our experience, occult otosclerosis was the most common diagnosis, with the best results in terms of post-operative ABG and patient satisfaction. Although rare (about 2%), patients should be informed of a non-negligible risk of worsening of their ABG.

Conflict of interest statement

The authors declare no conflict of interest.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Author contributions

Study design and concept: TS. Material preparation and ethical aspects: ADer, TS, ADeg. Data collection: ADer, MT. Data analysis: MT, DB, TS. Writing and editing: MT, DB, MA, AS, SZ. Critical Revision: LRdZ, CP, ADeg, TS.

Ethical consideration

This study was approved by the Institutional Ethics Committee of the University of Brescia (approval number N4357).

The research was conducted ethically, with all study procedures being performed in accordance with the requirements of the World Medical Association's Declaration of Helsinki.

Written informed consent was obtained from each participant/patient for study participation and data publication.

References

1 Lin FR, Niparko JK, Ferrucci L. Hearing loss prevalence in the United States. Arch Intern Med 2011;171:1851-1852. https://doi.org/10.1001/archinternmed.2011.506

2 Michels TC, Duffy MT, Rogers DJ. Hearing loss in adults: differential diagnosis and treatment. Am Fam Physician 2019;100:98-108.

3 Sooriyamoorthy T. Conductive hearing loss. Treasure Island: StatPearls Publishing 2021.

4 Lippy WH, Burkey JM, Schuring AG, et al. Stapedectomy in patients with small air-bone gaps. Laryngoscope 1997;107:919-922. https://doi.org/10.1097/00005537-199707000-00016

5 Committee on Hearing and Equilibrium. Committee on Hearing and Equilibrium guidelines for the evaluation of results of treatment of conductive hearing loss. Otolaryngol Head Neck Surg 1995;113:186-187. https://doi.org/10.1016/S0194-5998(95)70103-6

6 Robinson K, Gatehouse S, Browning GG. Measuring patient benefit from otorhinolaryngological surgery and therapy. Ann Otol Rhinol Laryngol 1996;105:415-422. https://doi.org/10.1177/000348949610500601

7 Choi JH, Lee MY, Park JH, et al. Conductive hearing loss with an intact tympanic membrane due to non-inflammatory causes. Auris Nasus Larynx 2016;43:144-148. https://doi.org/10.1016/j.anl.2015.06.004

8 Lagleyre S, Sorrentino T, Calmels MN, et al. Reliability of high-resolution CT scan in diagnosis of otosclerosis. Otol Neurotol 2009;30:1152-1159. https://doi.org/10.1097/MAO.0b013e3181c2a084

9 Shin YJ, Deguine O, Cognard C, et al. Fiabilité du scanner dans le diagnostic des surdités de transmission à tympan normal. Rev Laryngol Otol Rhinol (Bord) 2001;122:81-84.

10 Kemp P, Stralen JV, De Graaf P, et al. Cone-beam CT compared to Multi-Slice CT for the diagnostic analysis of conductive hearing loss: a feasibility study. J Int Adv Otol 2020;16:222-226. https://doi.org/10.5152/iao.2020.5883

11 Kim SH, Cho YS, Kim HJ, et al. Operative findings of conductive hearing loss with intact tympanic membrane and normal temporal bone computed tomography. Eur Arch Otorhinolaryngol 2014;271:1409-1414. https://doi.org/10.1007/s00405-013-2585-y

[12] Gapany-Gapanavicius B. The incidence of otosclerosis in the general population. Isr J Med Sci 1975;11:465-468.

[13] Cajade Frías J, Labella Caballero T. Aspectos epidemiológicos de la otosclerosis (II). Sexo, factores hereditarios, tiempo de evolución hasta el diagnóstico, edad de diagnóstico y de comienzo. An Otorrinolaringol Ibero Am 2003;30:17-30.

[14] Hong RS, Metz CM, Bojrab DI, et al. Acoustic reflex screening of conductive hearing loss for third window disorders. Otolaryngol Head Neck Surg. 2016;154:343-348. https://doi.org/10.1177/0194599815620162

[15] Robertson G, Mills R. Findings at exploratory tympanotomy for conductive hearing loss. J Laryngol Otol 2009;123:1087-1089. https://doi.org/10.1017/S0022215109005696

[16] Ghonim MR, Shabana YK, Ashraf B, et al. Traumatic ossicular disruption with intact tympanic membrane: treatment modalities in 42 patients: our experience. Clin Otolaryngol 2016;41:176-179. https://doi.org/10.1111/coa.12461

Supplementary material

Table S1. Details of each patient included in the study.

Patient	AGE	GENDER	SIDE	ABGPRE	Intra-operative findings	Diagnosis proposed	Surgical procedure	Intra-operative complications	ABGPOST	ABG reduction	ABG closure	Overall satisfaction	GBI total score
N1	68	F	Left	26.25	Incudo-malleolar ankylosis	Ossicular chain ankylosis	Ossiculoplasty with remodeled incus	None	20	6	< 10		
N2	67	F	Right	57.5	Incudo-stapedial dislocation, incudo-malleolar ankylosis	Ossicular chain discontinuity	Ossiculoplasty with remodeled incus	None	17.5	40	> 20	No	17
N3	78	F	Left	37.5	Incudo-stapedial dislocation	Ossicular chain discontinuity	Ossiculoplasty with remodeled incus	None	17.5	20	10-20	No	-47
N4	72	M	Right	28.75	Stapes fixation	Otosclerosis	Stapedotomy	Lesion of the Chorda Tympani	47.5	-19	X	No	
N5	49	F	Right	30	Erosion of the long process of the incus	Ossicular chain discontinuity	Ossiculoplasty with remodeled incus	None	0	30	> 20		
N6	32	F	Right	41.25	Incudo-stapedial dislocation	Ossicular chain discontinuity	Interposition of bone (from the EAC) between the incus and the stapes, stabilized with cement	None	5	36	> 20	Yes	50
N7	56	F	Left	23.75	Stapes fixation	Otosclerosis	Stapedotomy	None	11.25	13	10-20	Yes	28
N8	62	M	Right	36.25	ME adherences with incudo-malleolar ankylosis	Tympanosclerosis	Ossiculoplasty with remodeled incus	None	15	21	> 20	No	-11
N9	22	M	Right	20	Stapes fixation	Otosclerosis	Stapedotomy	None	0	20	10-20	Yes	31
N10	68	M	Left	28.75	Incudo-malleolar ankylosis	Ossicular chain ankylosis	Ossiculoplasty with remodeled incus	Lesion of the Chorda Tympani	18.75	10	10-20	No	-6
N11	38	F	Right	36.25	Stapes fixation	Otosclerosis	Stapedotomy	None	0	36	> 20	Yes	39
N12	58	F	Left	18.75	Stapes fixation	Otosclerosis	Stapedotomy	None	10	9	< 10	No	8
N13	20	M	Right	30	Erosion of the long process of the incus	Ossicular chain discontinuity	Ossiculoplasty with remodeled incus	None	23.75	6	< 10		
N14	35	M	Right	55	Stapes fixation	Otosclerosis	Stapedotomy	Lesion of the Chorda Tympani	12,5	43	> 20	Yes	42
N15	42	F	Left	45	Severe erosion of the incus	Ossicular chain discontinuity	Tympanoplasty type IV (interposition of cartilage fragment)	None	13,75	31	> 20		
N16	46	F	Right	35	Stapes fixation	Otosclerosis	Stapedotomy	Lesion of the Chorda Tympani	0	35	> 20	Yes	33
N17	34	M	Right	46.25	ME adherences and incudo-stapedial dislocation	Tympanosclerosis, ossicular chain discontinuity	Lysis of ME adherences, ossiculoplasty with remodeled incus	None	11.25	35	> 20	Yes	25

continues ▼

TTable S1. Details of each patient included in the study *(follows)*.

Patient	AGE	GENDER	SIDE	ABGPRE	Intra-operative findings	Diagnosis proposed	Surgical procedure	Intra-operative complications	ABGPOST	ABG reduction	ABG closure	Overall satisfaction	GBI total score
N18	50	F	Left	45	Stapes fixation	Otosclerosis	Stapedotomy	None	10	35	> 20	Yes	11
N19	31	F	Left	38.75	Stapes fixation	Otosclerosis	Stapedotomy	None	15	24	> 20	No	-17
N20	49	M	Left	27.5	ME adherences, malleolar partial erosion (incudo-malleolar dislocation)	Tympanosclerosis, ossicular chain discontinuity	Lysis of ME adherences, tympanoplasty type II	None	22.5	5	< 10	No	-17
N21	38	F	Left	63.75	Incudo-malleolar ankylosis	Ossicular chain ankylosis	Ossiculoplasty with remodeled incus	None	56.25	8	< 10	No	-42
N22	44	F	Right	61.25	ME adherences with stapes fixation	Tympanosclerosis	Stapedotomy	Lesion of the Chorda Tympani	21.25	40	> 20	No	0
N23	26	M	Left	36.25	Severe erosion of the incus and stapes superstructure	Ossicular chain discontinuity	TORP	None	28.75	8	< 10	Yes	47
N24	35	F	Right	23.75	Incudo-stapedial and incudo-malleolar dislocation	Ossicular chain discontinuity	Ossiculoplasty with remodeled incus	Lesion of the Chorda Tympani	0	24	> 20	Yes	11
N25	57	F	Left	40	ME adherences with incudo-malleolar ankylosis	Tympanosclerosis	Ossiculoplasty with remodeled incus	None	20	20	10-20		
N26	54	F	Left	35	Stapes fixation	Otosclerosis	Stapedotomy	None	12.5	23	> 20	Yes	31
N27	55	M	Left	48.75	Stapes fixation	Otosclerosis	Stapedotomy	None	5	44	> 20		
N28	37	F	Left	38.75	Stapes fixation	Otosclerosis	Stapedotomy	None	11.25	28	> 20	No	0
N29	42	M	Left	32.5	Incudo-malleolar ankylosis	Ossicular chain ankylosis	Ossiculoplasty with remodeled incus	None	2,5	30	> 20	Yes	28
N30	66	F	Left	37.5	Incudo-stapedial dislocation	Ossicular chain discontinuity	Interposition of cartilage fragment between the incus and the stapes	None	37.5	0	< 10	No	
N31	72	M	Right	15	Stapes fixation	Otosclerosis	Stapedotomy	None	6.25	9	< 10	Yes	33
N32	64	F	Right	41.25	Incudo-malleolar ankylosis	Ossicular chain ankylosis	Ossiculoplasty with remodeled incus	None	13.75	28	> 20	No	-44
N33	52	M	Right	28.75	Stapes fixation	Otosclerosis	Stapedotomy	None	8.75	20	10-20	Yes	47
N34	56	F	Left	23.75	Stapes fixation	Otosclerosis	Stapedotomy	None	6.25	18	10-20	Yes	11
N35	45	M	Left	62.5	Stapes fixation	Otosclerosis	Stapedotomy	None	0	63	> 20	Yes	19
N36	45	M	Right	35	Stapes fixation	Otosclerosis	Stapedotomy	None	2.5	33	> 20	Yes	19
N37	56	M	Right	22.5	Stapes fixation	Otosclerosis	Stapedotomy	None	22.5	0	< 10	No	-28

continues ▼

TTable S1. Details of each patient included in the study *(follows)*.

Patient	AGE	GENDER	SIDE	ABGPRE	Intra-operative findings	Diagnosis proposed	Surgical procedure	Intra-operative complications	ABGPOST	ABG reduction	ABG closure	Overall satisfaction	GBI total score
N38	60	F	Left	46.25	Incudo-stapedial dislocation	Ossicular chain discontinuity	Interposition of cartilage fragment between the incus and the stapes	None	22.5	24	> 20		11
N39	51	M	Right	35	Stapes fixation	Otosclerosis	Stapedotomy	None	7.5	28	> 20		
N40	71	M	Right	51.25	ME adherences	Tympanosclerosis	Lysis of ME adherences	None	41.25	10	10-20	No	0
N41	54	M	Right	46.25	Stapes fixation	Otosclerosis	Stapedotomy	None	10	36	> 20	Yes	39
N42	61	M	Left	53.75	ME adherences with incudo-malleolar ankylosis	Tympanosclerosis	Ossiculoplasty with remodeled incus	None	21.25	33	> 20	Yes	33
N43	55	M	Left	22.5	Stapes fixation	Otosclerosis	Stapedotomy	Lesion of the Chorda Tympani	15	8	< 10	Yes	11
N44	49	F	Right	38.75	Stapes fixation	Otosclerosis	Stapedotomy	None	3.75	35	> 20	Yes	56
N45	61	F	Left	41.25	Incudo-malleolar ankylosis	Ossicular chain ankylosis	Ossiculoplasty with remodeled incus	None	21.25	20	10-20	Yes	36
N46	63	F	Right	41.25	ME adherences with incudo-malleolar ankylosis	Tympanosclerosis	Ossiculoplasty with remodeled incus	None	26.25	15	10-20		
N47	67	M	Right	53.75	Stapes suprastructure fracture	Ossicular chain discontinuity	Positioning of stapedial prosthesis without stapedotomy	None	7.5	46	> 20	No	6
N48	71	F	Right	58.75	Stapes fixation	Otosclerosis	Stapedotomy	None	6.25	53	> 20	Yes	44

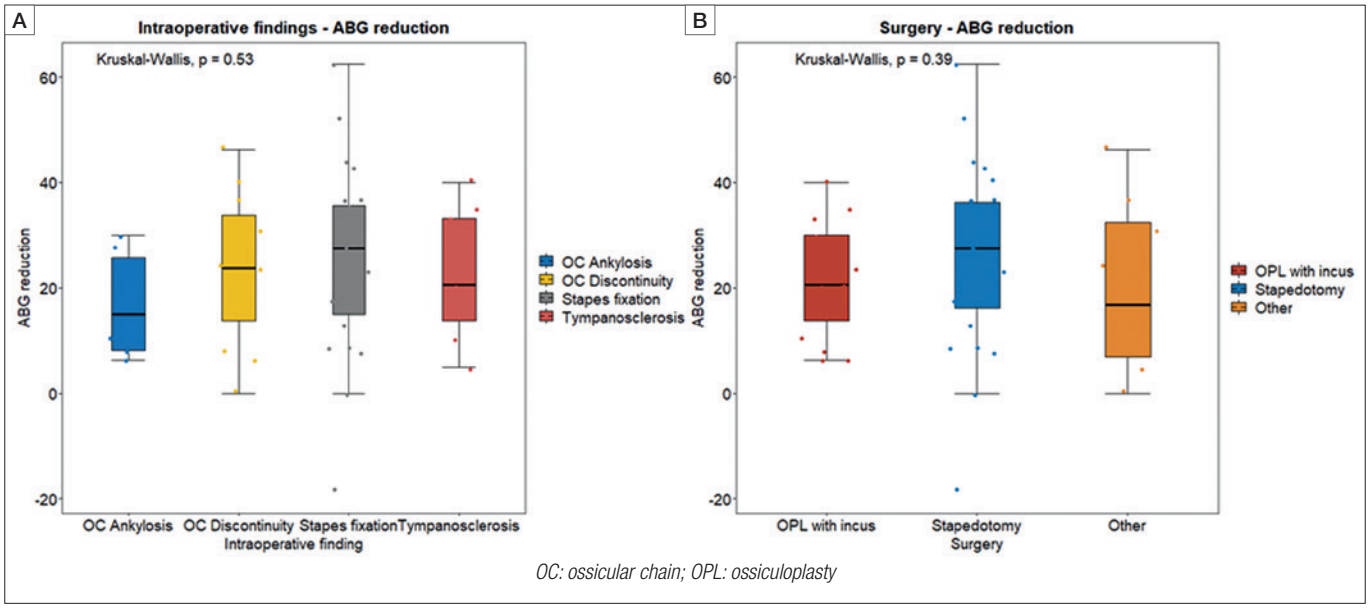


Figure S1. (**A**) Box-plots showing the non-significant difference in ABG reduction according to intraoperative findings; (**B**) Box-plots showing the non-significant difference in ABG reduction according to surgery performed, tailored on intraoperative findings.

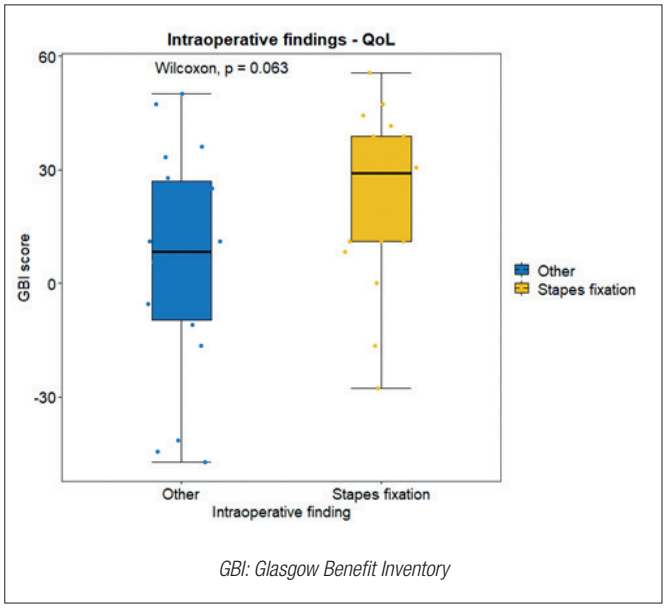


Figure S2. Box-plots showing the close-to-significant (p = 0.063) difference in GBI score according to intra-operative findings.

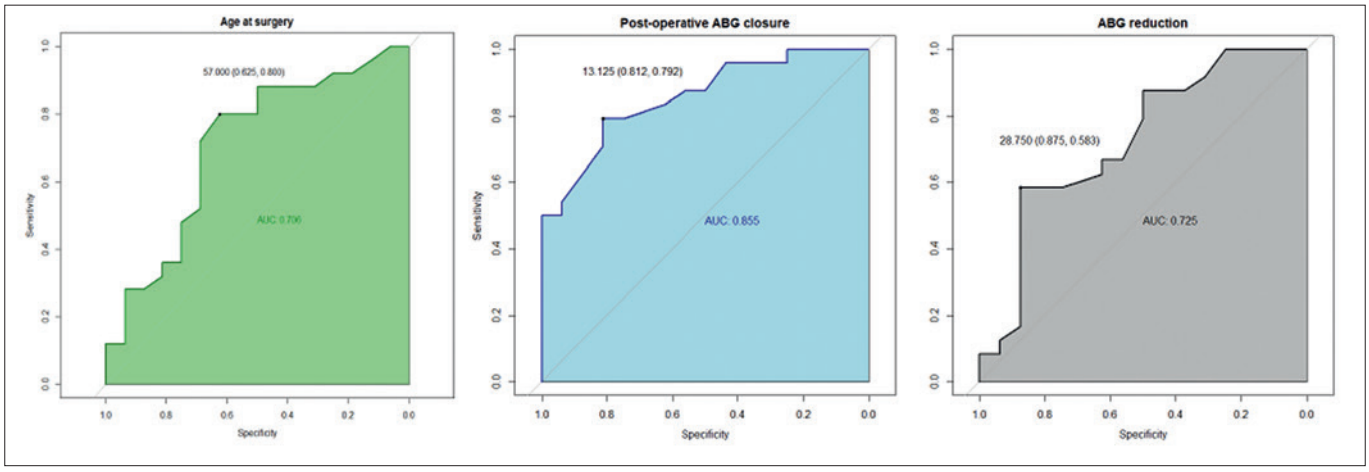


Figure S3. ROC curve analysis showing the ideal cut-off in age (57 years, AUC = 0.706), post-operative ABG closure (13.1 dB, AUC = 0.855) and ABG reduction (28.7 dB, AUC = 0.750) according to overall satisfaction reported by patients using the "Glasgow Benefit Inventory (GBI)" questionnaire.