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Review

A Review of Surgical Nuances and Outcomes of the Reverse Stapedotomy

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The stapes surgery has evolved through different eras of technical and technological development. The current standard of care is creating a stapedotomy with piston placement, and both these aspects have multiple variations and show well-established technological advances. The conventional technique has been fairly standardized,and it offers gratifying results to both the surgeon and the patient. To overcome certain procedural risks and potential complications, the reversal of steps technique was developed and streamlined by Ugo Fisch in the early 1980s. Since its beginning, the technique has been adopted by various centers, and surgical outcomes have been demonstrated to be at par with the conventional technique, with a reduced risk of complications. The aim of the present review is to detail the various surgical nuances and outcomes of this particular technique in a comprehensive narrative manner.

KEYWORDS: Hearing loss, otosclerosis, stapes surgery, risk, treatment outcome

INTRODUCTION

The stapes surgery is a perfect example of an elegant combination of science and art. A myriad of technical and technological variations implicated in this precision-demanding surgery in a small confined space signifies the complexities involved in the procedure. When performed successfully, the surgery is highly rewarding for both the surgeon and the patient. It takes some time for the young surgeons to get used to working in the middle ear microenvironment, which is reflected in the learning curve associated with the perfection of any particular technique. Although a surgeon's personal bias toward a particular technique giving consistent results that he or she has mastered is understandable, being familiar with the technical armamentarium of the surgical skills is desirable to improvise in the case of unforeseen circumstances in the best interest of the patient. The stapes surgery has evolved through different eras of beliefs, philosophy, and understanding, and the surgical technique in the current era has been fairly standardized [1]. The present review is centered on the technique of *reversal of steps* or *reverse stapedotomy*, proposed originally by Ugo Fisch, and it details the surgical nuances and the surgical outcomes as mentioned in the literature.

Methods

This article is a narrative review of the literature focusing on the reverse stapedotomy technique. A Pubmed literature search was conducted with the keywords "(stapes surgery or stapedotomy or otosclerosis) AND (reverse or reversal or Fisch)". Additional search was performed using Google Scholar. The articles published before December 2018 were included in the review.

RESULTS

The Conventional Stapes Surgery

The conventional stapes surgery involves the trans canal approach by raising a tympanomeatal flap and checking the mobility of ossicular chain components before embarking on the disarticulation of incudostapedial joint (ISJ). Following the joint disarticulation, the stapedius tendon is excised. Next, the posterior crus followed by anterior crus of stapes is removed and the stapes footplate is perforated atraumatically. Finally, an appropriately sized piston is inserted in the footplate opening and crimped to the long process of incus (LPI) [2].

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Reversal of Steps Technique: Introduction and Application

The early dislocation of the ISJ and removal of the stapes suprastructure (SSS) leads to a more vulnerable footplate and incus to further surgical manipulations. This vulnerability may lead to dislocation of the footplate or the incus during stapedotomy and piston crimping, respectively.

In view of these limitations, Ugo Fisch in 1980 suggested changes in the steps of the procedure [3]. He advocated creating a 0.6 mm stapedotomy in the footplate with an intact ISJ and SSS, followed by the ISJ disjunction and SSS removal before inserting the prosthesis. He suggested that the early creation of stapedotomy reduces the risk of a floating footplate, without worsening the rate of fistula formation, compared to a total stapedectomy.

Later the same author proposed a total reversal of the conventional stapedotomy technique to further reduce the risks of complications, while maintaining the equivalent (at 0.5-2kHz)/better (at 4kHz) long-term outcomes than stapedectomy [4]. In this technique, after removing the posterosuperior canal wall overhang and displacing the chorda away, he proposed creating the stapedotomy hole in the footplate first, followed by insertion of a 0.4mm Teflon piston into footplate and crimping to the LPI. Hence, till the piston is secured, the ISJ and SSS are kept intact. This serves the following purposes:

1. During creating the stapedotomy opening, the support provided by the intact ISJ resists the natural tendency of the stapes footplate to give way to the force applied and sink into the vestibule creating a floating footplate.

2. During crimping the piston loop to the LPI, the counterforce provided by the intact ISJ, keeps the LPI in a stable position, preventing subluxation/luxation of the incus.

3. While removing the SSS, the piston secured in place prevents the footplate from coming out of the oval window niche and the resulting total platinectomy.

Creating a larger stapedotomy and putting a large size piston may not be achievable through the restricted space provided with the intact ISJ and SSS assembly, and hence the best way to perform the reverse steps would be to use a smaller-size piston (Teflon platinum piston in initial series of Fisch) 0.4mm in diameter, as applied in the Fisch's original reverse step technique. The small size of the hole and the short interval of time for which it is exposed also ensure minimal, if any, entry of the blood into the vestibule. The audiological consequences of the same will be discussed subsequently. Following the securing of the piston, the ISJ is separated with the joint knife, and the stapedius tendon is cut. Next, the posterior crus is removed with the crurotomy scissor, followed by the removal of the anterior crus with the crurotomy scissor or by fracture by a downward rotational force with a 2.5mm, 45° pick introduced between the handle of the malleus and LPI.

Experience of Reverse Steps Stapedotomy by Ugo Fisch

Fisch demonstrated that by using this technique, the restoration of the air–bone gap (ABG) (conductive loss) with stapedotomy as compared to stapedectomy was equivalent at lower frequencies (0.5kHz-2kHz) and better at high frequency (4kHz). The results of bone conduction (sensorineural reserve) were significantly superior on long-term follow-up (3 years) for stapedotomy compared to stapedectomy (impairment of 10dB in 9% in the former compared to 0% in later). However, sensorineural loss on short-term follow-up was not significantly different. When comparing the 0.6mm and 0.4mm diameter pistons, it was found that using the smaller fenestra, the ABG closure was worse at the short-term (3 weeks) but similar at the long-term (1 year) follow-up.[4] This initial delay in reaching the maximal improvement in ABG becomes appreciably larger (2-3 years) when the piston size is reduced to 0.3mm.[5] Hence, a small piston was proposed to be advantageous in terms of procedural ergonomics and compatibility for performing reverse stapedotomy, and the 0.4mm piston was set to be the lower limit of "smallness" to attain the results in a reasonable timely fashion (3 months versus 2-3 years with 0.4mm versus 0.3mm, respectively).

Multiple reports have shown the advantage of small-hole stapedotomy over a partial or total stapedectomy [4, 6-12]. The effect of piston diameter on hearing is still surrounded by controversies despite multiple cadaveric and clinical studies. A traditionally resonating concept in the literature has been that a larger piston gives better hearing at lower frequencies and a smaller piston at higher frequencies [5, 13-17]. The clinical studies, however, do not show unanimity in this respect. A recent systemic review by Wegener et al. [18] mentioned six studies, [19-24] evaluating the effect of different piston diameters on the success of the ABG closure to with in £10dB. The mean post-op ABG was found to vary from 3dB in favor of the small piston to 3dB in favor of the large piston in four studies[20,21,23,25](comparing two different diameter pistons). One of the studies,[24] comparing the 0.3, 0.4, 0.5, and 0.6mm pistons gave inconsistent results between the smaller and larger pistons, while another study, [19] comparing three pistons diameters (0.4, 0.6, and 0.8mm), showed a clear improvement in the post-op ABG closure with an increasing diameter of the piston.

Another aspect of looking at the results of different piston diameters is from the piston"mass" point of view. Merchant and Rosowski, [14] in their mathematical model analysis, showed that an increase of stapes suprastructure of up to 16 times leads to a decrease in ABG of less than 10dB. Hence, the mass may not be the dominant factor for determining the purported difference in hearing outcome with the difference in piston diameters. Better results in a more standardized fashion with randomized controlled trials are expected to unfold in the future (www.trialregister.nl/trialreg/admin/rctview.asp?TC54509).

The Experience and Variations of the Reverse Stapedectomy Technique Outside of "Zurich"

Using the reversal of the steps technique, Pedersen [26] carried out stapedotomy and insertion of a 0.4mm Teflon wire piston in 100 consecutive patients and was able to obtain optimal hearing (ABG closure with in £10 dB or speech reception threshold within 25 dB) in 92% of patients without any incidences of sensorineural hearing loss on the short and long-term follow-up.

Fisch in his series noted that performing a reverse stapedotomy was not feasible and wise in cases of a narrow oval window niche and in cases of obliterative footplate since a crumpled space available in the

Table 1. Results of Reverse Stapedotomy: Literature Review

SN [ref]	Author and Year	n	Technical Specifications	Outcome Measures	Results and Recommendations
1. [4]	Fisch et al. 1982 (results elaborated in text)	222 (170+ 52)	0.4mm wire Teflon piston versus 0.6mm Teflon piston	ABG ≤10 dB	1) Poorer results with a 0.4mm piston at 3 weeks 2) Equivalent results after this delay 3) 0.4mm piston better suited for reverse stapedotomy
2. [26]	Pedersen et al. 1987	100	0.4mm, Teflon wire piston	ABG ≤10 dB or SRT≤25 dB	1) 92% (follow up 1 to 4 years) 2) No cases of SNHL
3. [31]	Herzog et al. 1991	56	0.4mm diameter fenestra	ABG ≤10 dB	87% No cases of PLF or SNHL
4. [35]	Lescanne et al. 1999	87	Reverse stapedotomy (with [52] or without [35] CO2 laser)	ABG ≤10 dB	Oneyear post surgery: 1) Manual perforator reversed stapedotomy: 80% 2) CO2 laser reversed stapedotomy: 88% 3) The differences in hearing and complications: not statistically significant
5. [32]	Golabek et al. 2001	270 (50+ 167+ 53)	Comparison of classical steps, control hole creation, and total reverse stapedotomy	Complications in the three groups	1) Creating a stapedotomy hole before the SSS removal prevents a floating footplate. 2) Inserting the piston before the SSS removal prevents incus subluxation
6. [30]	Lang et al. 2004	73	0.4mm Teflon platinum piston	ABG ≤10 dB	Reversal group: 84% Standard group: 81%
7. [34]	Szymanski et al. 2007	420 (51+ 169+ 146+ 54)	Comparison of classical steps, control hole creation, and total reverse stapedotomy (with or without CO2 laser)	Complications in the four groups	1) Creating a stapedotomy hole before the SSS removal prevents a floating footplate. 2) Inserting the piston before the SSS removal prevents incus subluxation. 3) Laser stapedotomy with reversed sequence is the safest technique
8. [36]	Fiorino et al. 2008	81	Partial reverse stapedotomy	ABG≤10 dB	1) 86% (6 months post-surgery) 2) No cases of SNHL 3) Early abolition of the posterior crus removes the main obstacle in reverse stapedotomy
9. [33]	Arsovic et al. 2009	105 (45+ 60)	Comparison of classic and reverse stapedotomy	1) Hearing results (ABG≤20 dB) 2) Complications in the two groups	1) Similar hearing results in both the groups: ~80% 2) A better intra- and post-operative side effect profile with reverse stapedotomy
10. [28]	Malafronte et al. 2009	46	0.4mm platinum–Teflon ribbon loop piston	ABG≤10 dB	Blue footplate: 100% White footplate: 66%
11. [29]	Ueda et al. 2013	230 (126+104)	1) Various piston types 2) Removal of the SSS before (126) or after (104) piston	Footplate preservation insertion (stapedotomy) in relation to the sequence of piston insertion	Footplate preservation rate: 1) 72% when the SSS is removed after piston insertion. 2) 58% when the SSS is removed before piston insertion
12. [37]	Freni et al. 2014	84 (49+ 35)	1) CO2 laser stapedotomy (classical stapedotomy and "modified" reverse stapedotomy) 2) 0.5mm self-crimping titanium piston	1) ABG≤10 dB 2) THI scale 3) Intraoperative complications	Oneyear post-surgery 1) ABG: 7.99 dB (classical); 7.75 dB (reverse steps) 2) THI scale: 7.96 (classical); 4.17 (reverse steps) 3) No difference in post-operative discomfort or complications
13. [38]	Kwok et al. 2017	70 (58+ 12)	KTP laser-assisted reverse stapedotomy; 0.4mm NiTiBOND prosthesis	Hearing results between 1) the experienced and novice surgeon 2) Learning curve for the beginners	1) Statistically non-significant difference in ABG (except at 4 kHz) 2) No learning curve with the described technique

SN: serial number; ref: reference; n: number of ears operated; ABG: air–bone gap; dB: decibel; SSS: stapes suprastructures; THI: tinnitus handicap index; PLF: perilymphatic fistula; SNHL: sensorineural hearing loss; KTP: potassium titanyl phosphate; mm: millimeters; kHz: kilohertz

former and the need for extensive drilling for a fragile footplate in later cases carried more potential for risk than benefit with this technique. Based on the macroscopic appearance of the stapes footplate before removing the suprastructure, Malafronte et al. [27] classified the footplate into the blue footplate (blue appearance in all of visible footplate areas), white footplate (white in all or most of the visible part), and obliterative footplate (massive spongiotic focus making the footplate indistinguishable). When comparing the results of reverse stapedotomy outcomes on 46 patients (34 blue otosclerosis, 12 white otosclerosis), they came to the conclusion that the blue otosclerotics are the cases most suitable for the reversal step technique [28]. The ABG closure within 10 dB was achieved in 100% of blue footplate cases and in 66% of the white footplate cases. It is noteworthy that none of the patients had a footplate complication while making the stapedotomy hole or crimping the prosthesis, but it was the removal of the anterior crus that led to the fracture and luxation of the footplate (in the area of the hole) in cases of the white footplate, which is by nature non-elastic and brittle compared to the elastic and healthy blue footplate. It was during the conversion of the fractured cases to stapedectomy and disengaging the crimped incus for repositioning that led on to subluxation of the incus and these subluxated cases then were responsible for a >30dB conductive hearing loss in the white otosclerosis operated using the reverse technique. None of the operated patients had deterioration of the bone conduction.

The anterior crus is a relatively hidden area after the piston has been positioned, and the fracture on the anterior half of the footplate can occur with attempted removal of the anterior crus. In these cases, Ueda et al. [29] suggest packing the vestibular opening with a connective tissue seal to effectively avoid a post-operative perilymphatic fistula. They documented that with the reversal of the steps technique, they had to resort to partial or total stapedectomy less often than with the classical steps technique (stapedotomy in 72% vs. 58%, respectively). The audiological differences between the two groups, however, were not statistically significant. Also, they did not find a significant effect of the morphology (blue or white) of the footplate or the use of the laser on the results. Lang et al. [30] found no statistically significant difference rates between audiological results and complication rates between the conventional and reversal techniques in their series of 73 cases. Herzog [31], in his series of 56 patients operated by the reverse stapedotomy technique found that the ABG closure within 10 dB could be achieved in 87% and within 20 dB in 97% of cases without any otologic complications. Golabeket al. [32] divided 270 patients into three groups: classical stapedotomy, control hole followed by classical stapedotomy steps, and reverse stapedotomy, respectively. They concluded that creating the stapedotomy hole while keeping the ISJ and SSS intact prevents the occurrence of the floating footplate, and the placement of prosthesis with an intact ISJ and SSS protects against the incus subluxation. Arsovic et al. [33] performed 105 stapedotomies (60 with the reverse technique and 45 with classical technique) and reported the reverse stapedotomy resulting in lesser intra- and post-operative complications/complaints without any significant difference in audiological outcomes compared to classical stapedotomy.

Szymanski et al. [34] inferred that the early perforation of the footplate (with footplate stabilized by the ISJ and SSS) reduces the risk of floating footplate (from 7.8% to 0.6%), and placing the piston before removing the SSS reduces the risk of the incus subluxation/luxation (from 13.6% to 2%). The use of a CO_2 laser (Sharplan 30C) and scanner system (SurgiTouch, Sharplan) further reduced the complication rates related to the incus subluxation and footplate fracture/floater. Lescanneet al. [35] used a CO_2 laser to carry out reverse stapedotomy, and they found out that the reversal of steps is useful to avoid a floating footplate and incus dislocation, but fractures of the footplate can still occur with the manual perforators, and this can be avoided using the laser in place of perforators.

The end aural approach used universally by Fisch gives an end-on view of the stapes and the facial nerve–SSS interval. However, in the much more commonly used transcanal approach, the posterior crus of stapes offer some visual and operational hindrance. Fiorino et al. [36] used the partially reversed stapedotomy by early removal of the posterior crus of the stapes (+/- stapedius tendon) before drilling a hole in the stapes footplate. By doing this, they were able to achieve ergonomically superior working conditions and did not have to resort to the conventional technique even in cases of a facial overhang/narrow oval window niche or obliterated footplate. In a cohort of 76 patients, they were able to achieve an ABG closure to within 10 dB in 86% without any instances of sensorineural hearing loss over a follow-up period of 6 months. The only complication they had was that of the fracture of the footplate when creating platinotomy in one patient. They concluded that the partial reversal stapedotomy maintains the benefits of the totally reversed steps technique in terms of stabilization of the footplate and incus with added benefits of superior exposure without compromising the audiological results.

Freni et al. [37] compared the conventional and reversal (modified) technique for stapedotomy using a CO_2 laser (Sharplan 1040, Sharplan lasers Ltd., London, UK) and self-crimping titanium prosthesis and found that the results in terms of audiological outcomes as well as complications were not significantly different between the two groups when the conventional tools were replaced by the advanced technologies.

Overcoming the Bridge between Novice and Experienced: Integration of Reverse Stapedotomy into a Standardized Protocol

Kwok et al. [38] incorporated the use of laser-assisted techniques and the use of a 0.4mm NiTiBOND prosthesis (Kurz GmbH, Dusslingen, Germany) (a thermal shape-memory prosthesis) to the Fisch's reversal technique and found that the surgical outcomes were similar between the novice and the experienced surgeons, and the learning curve could be avoided by standardizing the stapedotomy technique in this manner. All these strategies remove the obstacles out of the way of a novice practicing surgeon by simplifying the most delicate steps prone to complications, while at the same time not compromising the audiological results.

CONCLUSION

- Reversal of steps stapedotomy offers better results in terms of footplate and incus-associated complications, compared to the conventional technique.
- Audiological outcomes of the two techniques are comparable.
- A smaller piston (0.4 mm) allows for the steps of the stapedotomy to be reversed by being able to engage in the narrow facial nerve-SSS space with an intact SSS.

- Narrow oval window niche and obliterated footplate situations are unfavorable for performing the reversal technique; however, in these situations, a "partial reversal stapedotomy" may be undertaken to obtain the benefits offered by the reversal technique.

- Adding a laser and self-crimping piston to the reversal steps stapedotomy technique may standardize the technique to reduce the learning curve associated with this precision-demanding surgery.

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