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Research Paper

# Audiological results of endoscopic surgical repair of the long process of incus

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**KEYWORDS**
Endoscopic ear surgery;
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**Abstract** *Objective:* The purpose of this study is to evaluate our experience with endoscopic repair of ossicular discontinuity at the incudostapedial joint, with or without an intact stapes suprastructure, and present our hearing results. We classify results based on the causative pathology, the type of ossiculoplasty, and type of lesion. We demonstrate the ability to endoscopically place a total ossicular replacement prosthesis (TORP), measuring 4.25 mm, between the stapes footplate and the incus remnant to reestablish ossicular continuity.
*Methods:* This was a retrospective case series conducted in tertiary referral center (Hopital de la Timone) Marseille, France. 25 patients underwent incudostapedial rebridging ossiculoplasty between 2009 and 2013. Fifteen cases of chronic otitis media and 10 otosclerosis revisions were included in the study. Three different materials were used in ossiculoplasty, hydroxyapatite cement, incus remnant, and partial/total ossicular replacement prostheses. Audiometric results were evaluated before and after ossiculoplasty. Twelve month follow-up data is provided.
*Results:* The mean postoperative air-bone gap was 15 dB (5—25 dB). Hearing results were better inotosclerosis revisions. Hydroxyapatite cement produced an air-bone gap of 5 dB, TORP placed under the incus produced a 12 dB gap, and TORP placed under the malleus resulted in a 12 dB gap and one deaf ear. In cases of chronic otitis media, the residual air-bone gap was 17 dB with PORP, 12 dB with TORP, and 20 dB with incus transposition.
*Conclusion:* The hydroxyapatite cement is effective in the reconstruction of ossicular discontinuity but the high price limits its utilization. TORP placed under the incus is a reliable and

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stable method of ossicular reconstruction that is cost effective and offers satisfactory hearing results in selected patients.
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## Introduction

The ossicular chain conducts the sound effectively into the inner ear. Middle ear disease and ossicle pathology disturbs the sound energy transfer and conductive hearing loss appears.[1] Erosion of the incudostapedial joint with an intact mobile malleus is the most common ossicular defect encountered in chronic middle ear disease. Austin estimates that an intact malleus and stapes suprastructure are present in 60% of ossicular defects.[2] In otosclerosis revision cases, a similar situation is encountered frequently, with discontinuity seen between the incus and the stapes prosthesis. The goals of surgery for chronic ear disease are eradication of the disease and reconstruction of the sound conduction mechanism.[3] Numerous ossiculoplasty techniques have been used to reconstruct the ossicular chain. Special consideration should be given to the opening of the footplate. The ideal ossiculoplasty material should be biocompatible, stable, safe, and easily applied.[4] Erosion of the long process of incus is the most common ossicular reconstruction dilemma faced by the otologic surgeon.

Since the origin of ossiculoplasty in the late 1950s, several surgical options have been suggested for incusdefects. The first type of repair is interposition of a biological autograft or allograft (e.g. sculpted incus, malleus or cortical bone), bypassing the malleo-incudal joint. This has been widely used since it was first described by Hall and Ritzier.[5,6] Although well tolerated by the body, these grafts can partially necrose and develop ossifying bridges, or become displaced. The second type of repair is a partial ossicular replacement prosthesis (PORP) made from one of several kinds of biomaterials (plastics, ceramics, metals, etc.). These prostheses have the advantage of being readily available, but stability problems and extrusion can occur.[5,7,8] Dedicated prostheses were developed to bridge the incudo-stapedial gap, i.e. the angular prosthesis by Plester and the more recent angular clip prosthesis.[9,10] The third type of repair involves the use of biocements, the latest materials in ossiculoplasty, allowing a "physiological" reconstruction of the ossicular chain in case of a small defect (the so called "bridging technique").[10] Monomeric cement has been the most used cement up to now, but inflammatory reactions have been observed when in contact with the soft tissues in the middle ear. Its use in otology is only approved in the middle ear and with no possibility of contact with the dura.[7]

The purpose of this study is to evaluate our experience with endoscopic repair of ossicular discontinuity at the incudostapedial joint, with or without an intact stapes suprastructure, and present our hearing results. We classify results based on the causative pathology, the type of ossiculoplasty, and type of lesion. We demonstrate the ability to endoscopically place a total ossicular replacement prosthesis (TORP), measuring 4.25 mm, between the stapes footplate and the incus remnant to reestablish ossicular continuity and improve the air-bone gap.

## Materials and methods

A retrospective review of 25 patients who underwent incudostapedial rebridgingossiculoplasty between 2009 and 2013 was performed to evaluate hearing results. One year follow-up was provided. All procedures were endoscope-assisted ear surgeries.

Under general anesthesia, the middle ear was entered through a postauricular incision, and the tympanomeatal flap was elevated. Before any surgical intervention, the middle ear was examined with an operating microscope (Karl Storz, Germany with Sony 3-CCD Color Video Camera, Japan) in different positions and in different bed positions. The visible anatomical areas and middle ear pathologies were evaluated and recorded while gently moving the patient's head. Status of the ossicular chain was assessed as well. The middle ear was then evaluated using a zero and 30-degree rigid endoscope (4 mm diameter, 18 cm working length, Karl Storz, Tuttlingen, Germany) and a 3-CCD high-definition camera (Karl Storz Image 1 HD H3 3-chip Camera Head, Karl Storz, Tuttlingen, Germany). All of the components of the middle ear were assessed using the endoscope.

There were 12 female and 13 male patients, ranging in age from 35 to 56 years (mean 40).

The indications for surgery were chronic otitis media with perforation in 15 patients and previously operated otosclerosis in 10 patients. The mean preoperative air-bone gap was 35 dB (25—40 dB). The patients were followed for at least one year postoperatively. Pure tone air- and bone-conduction thresholds were obtained preoperatively and postoperatively. The preoperative audiometric results were compared with the audiometric results obtained after 1 year.

Based on the underlying pathology, the approach was either transcanal or postauricular, followed by the elevation of the tympanomeatal flap and exposure of the ossicles. Any diseasedtissues, such as cholesteatoma or adhesions, were excised. In cases of otosclerosis revision, the existing prosthesis was either removed and replaced, or reused depending on the particular situation. The major portions of the procedures were performed under endoscopic vision. The surgical interventions were used based on anatomical observations and judgment of the surgeon, and can be divided into three groups:

### Group 1 — hydroxyapatite bone cement ossiculoplasty

Group 1 consists of the cohort of patients who underwent repair of their incudostapedial defect using bone cement. Bone cements are substances that have been used in dentistry as filling and luting materials. The formulated powder mixed with the dissolving liquid results in a mixture that hardens within minutes through an exothermic reaction. The cement used in this study contains a powder composed of calcium phosphate as well as a liquid composed of water and conservation agents. After quick mixing of the two components, the material hardens to a bone-like consistency in 5—10 min. The cement can be applied and shaped within a few minutes before hardening. The cement bonds directly to bone, and once the cement has set, it is no longer sensitive to surrounding fluids. These features make this material potentially useful in a variety of ossiculoplasty procedures. Two patients underwent this technique. In otosclerosis revision, the long process of the incus was augmented to stabilize the crimped loop of the stapes prosthesis onto the incus (Figs. 1 and 2).

### Group 2 — incus interposition ossiculoplasty

Group 2 consists of the cohort of patients who underwent repair of their incudostapedial defect by using a "turned incus" technique. This technique involves removing the incus remnant, remodeling the incus, and replacing the incus to bridge the ossicular gap. Four patients underwent this surgery. The incus was removed, then fashioned to appropriate shape and size by drilling. A hole is drilled into the base of the long process of incus, and the short process is drilled off. Controlled force is applied to fit the head of the stapes into the drilled hole on the incus. A piece of cartilage is interposed between the tympanic membrane and the transpositioned incus as shown in Fig. 3.

### Group 3 — ossiculoplasty using an alloplast prosthesis

Group 3 consists of the cohort of patients who underwent repair of their incudostapedial defect by using an alloplastic prosthesis. The materials used in group 3 were: titanium prosthesis (FLEX), either a partial ossicular replacement prosthesis (PORP) or total ossicular replacement prosthesis (TORP). Four patients had ossiculoplasty using a PORP. The cup-like opening of the PORP helps to stabilize the prosthesis on the head of the stapes by using the suction tip and a sickle knife. A piece of cartilage is applied to cover the prosthesis to prevent extrusion. Eleven patients had ossiculoplasty using a TORP. In these cases, a 4.25 mm long TORP was interposed between the stapes footplate and the incus remnant. The footplate was covered with a thin graft before prosthesis placement. In cases where the stapes was intact and leaning against the promontory, the prosthesis was placed between the stapes crura, resulting in stable positioning (Fig. 4). Four patients had ossiculoplasty using a TORP, 6 mm long. In these cases, the prosthesis was interposed between the footplate (covered by thin graft) and the malleus by using the suction tip and sickle knife, and further stabilized with pieces of Gelfoam (absorbable gelatin sponge, Pfizer, Inc., New York).

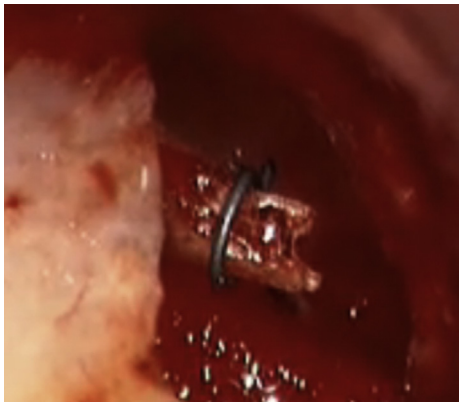

**Fig. 1** Erosion of the incus and fiting off of the stapes piston prosthesis.

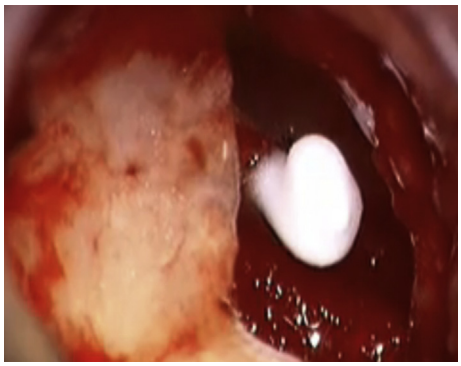

**Fig. 2** Augmentation of the long process of incus with bone cement.

**Fig. 3** Transposition of the incus covered by cartilage.

## Results

The mean postoperative air-bone gap was 15 dB (5—25 dB). The hearing results were better in the otosclerosis revision cases, where the bone cement resulted in a 5 dB mean air-bone gap, a prosthesis placed under the incus resulted in a 12 dB mean air-bone gap, and a prosthesis placed under the malleus resulted in a 12 dB mean air-bone gap and one deaf ear.

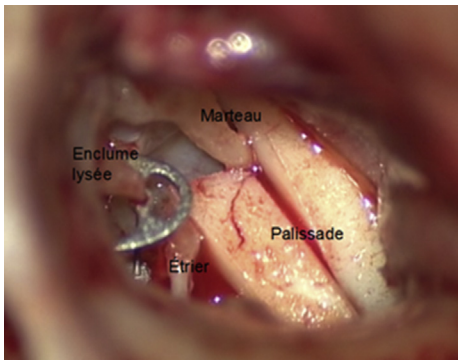


**Fig. 4** TORP 4.25 mm placed between the stapes footplate and the remnant of the long process of incus.

In cases of chronic otitis media, the mean residual air-bone gap was 17 dB with PORP, 12 dB with TORP, and 20 dB with transposition of the incus.

## Discussion

Incorporating the endoscope into otologic surgery contributes a great deal to the concept of minimally invasive surgery. The field of ear surgery has seen rapid technological advancement, first with the invention of the operating microscope, and more recently with the emergence of minimally-invasive endoscopic ear surgery techniques. When used in ear surgery, the endoscope has numerous advantages (and some disadvantages) when compared to classic otologic surgery using a microscope. It has become clear that despite some of the disadvantages of the endoscopic approach, such as technical skill necessary and increased training requirements, many ear surgeons recommend a move toward minimally-invasive endoscopic ear surgery.

A normal ossicular chain effectively transfers sound from the tympanic membrane to cochlear fluids. Ossicular chain defects due to bone erosion most frequently involve the long process of the incus (lenticular process).[11] Because of its anatomical position and blood supply, incus is more susceptible to trauma, infections and erosion than the other ossicles.[12] A defect of the long process of incus results in a conductive hearing loss. Various surgical techniques and materials have been used in tympanoplasty/ossiculoplasty since the 1950s.

Ossicular prostheses have been classified into three groups as autografts, homografts and allografts.[12] Tragal cartilage, cortical bone and native ossicles may be used as autografts. These have low extrusion rates, they are inherently bio-inert and there is no risk for transmission of infectious diseases.[12] Homografts are tissues obtained from human cadavers and they are not allowed in many countries due to the risk of viral transmission.[13] Allograft prostheses are made of synthetic materials. These are prefabricated, ready-to-use prostheses.[12] Several synthetic materials have been used for the production of incus replacement prostheses with a good record of biocompatibility. These include polyethylene, porous plastics, ceramics, glass ionomer, and various types of metals such as stainless steel, gold and titanium.[5,7] Partial and total ossicular replacement prostheses (PORP and TORP) have the advantage of being readily available, but may have extrusion and stability problems (with or without displacement). These are definite disadvantages, particularly in middle ears poorly aerated due to Eustachian tube dysfunction. In patients requiring revision PORP/TORP ossiculoplasty, half of the failures are indeed due to prosthesis displacement.[5,14] The risk of extrusions is much higher in inflamed and atelectatic ears.[12,15] The incidence of prosthesis extrusion can be lowered to a great extent by the use of cartilage interposed between the prosthesis and the tympanic membrane.[7] In our experience, TORPs are reasonably priced and present good hearing results. Operative time can be saved and prostheses can easily be reshaped or trimmed. The risk of exposure and extrusion is reduced by stabilizing the prostheses between the crura of the stapes and the incus remnant, while the tympanic membrane is reinforced with a piece of cartilage.

The application of bone cement is technically easy. Nevertheless, there are some important points that should be considered during cement application. It should be performed within minutes before the mixture hardens. Any hemorrhage should be controlled before application of bone cement because it may interfere with adherence of the cement to the target tissue. Mucosal covering of ossicles should be removed and bone cement should be applied directly over denuded bone since bone cement does not adhere to soft tissue.[16,17] Ionomeric bone cement should not come into contact with neural structures, perilymph, or dura because of its potential neurotoxicity.[17–19] In case such a contamination occurs, the cement should be immediately aspirated, removed and area irrigated to remove the cement. To prevent contamination, bone cement should be applied while it has the most suitable consistency, which happens during a short time window of a few minutes. Also, small pieces of Gelfoam can be placed over the facial nerve and stapes footplate during application to protect these areas.[20] Aluminum encephalopathy and death due to glass ionomeric bone cements have been reported.[21,22] There is still controversy about the long-term results of bone cement ossiculoplasty. Some authors claim that the bone cement bridge breaks over time, necessitating revision surgery. We found that the bone cement is a good material for ossicular reconstruction because of its ease of use, operative time savings, and good hearing results, but high prices might limit usage.

In the autologous incus transposition technique, the incudo-mallear joint has to bedisarticulated and the incus carefully retrieved. This maneuver is technically difficult if the incus long process is significantly shortened or if atticotomy is limited. There is also some risk of luxation of the malleus or stapes, or even inadvertent damage to a dehiscent facial nerve. Ossicle sculpting is a delicate "one-shot" procedure and should be done under copious irrigation to prevent heating and necrosis. The mounting of the turned incus should be stable, which is difficult to achieve in an ear that has been damaged by chronic otitis media since the malleushandle is often more medial and anterior than normal.[5,7,8] Incus transposition or use of cortical bone consumes operative time, gives the least desirable hearing results, requires extensive surgeon experience, and might provoke a local reaction resulting in ankylosis to the surrounding bones, presenting a difficult case for revision.

Celik et al[23] used glass ionomer in 31 patients and cortical bone in 35 patients for ossiculoplasty in their series of 66 patients and reported a postoperative air-bone gap of 16.8 dB in the glass ionomer group, and 18 dB in the cortical bone group. O'Reilly et al[12] performed incus interposition in 137 patients and reported preoperative and postoperative air bone gaps of 26.8 and 18.6 dB respectively. Siddiq et al[24] reported preoperative and postoperative air bone gaps of 28.0 and 21.0 dB respectively in 23 patients who had incus interposition. Berenholz et al[25] evaluated a porous polyethylene prosthesis (TORP) interposed between the footplate and a piece of cartilage separating it from the ear drum. They found that the percentage of patients closing their air-bone gap to within 10 dB was 44%, with 66% closing their air-bone gap within 20 dB. The mean four-frequency pure tone average hearing gain was 15.7 dB. The mean postoperative air-bone gap was 15.7 dB.

In our study the mean postoperative AB gap was 15 dB, 5 dB with cement, 12 dB with TORP and 17 dB with PORP and 20 dB with transposition of the incus.

## Conclusion

The erosion of the long process of the incus and the resulting ossicular discontinuity may be repaired in several ways. The surgeon should be well versed in the use of different techniques as the cases are not identical and decisions on repair techniques are often intraoperative. The cement is effective in reconstruction the ossicular discontinuity but high price limits its utilization. A total ossicular replacement prosthesis (TORP) 4.25 mm long, placed between the footplate and the incus remnantit is a reliable material for use in ossicular reconstruction because of its ease of application, reasonable price, tissue tolerance, and satisfactory hearing results. Patient selection is key to obtain optimal hearing results. Further studies with larger patient populations would be useful to help us understand the best approaches to repair incus defects, and the role of endoscopic ear surgery in these procedures. Longer follow-up times are necessary to further validate these techniques. The prices of different implanted materials should be considered.

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## Conflicts of interest

None.

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None.

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