

# Endoscopic Ear Surgery for the Management of Traumatic Ossicular Disruption with Intact Tympanic Membrane

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## Research article

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# Abstract

**Background** Traumatic ossicular disruption (TOD) usually had a severe conductive hearing loss, the exploratory tympanotomy is critical for the diagnosis and improve hearing. Endoscopic ear surgery (EES) is becoming popular in the last decade, we conducted a retrospective study to explore the efficacy of EES for management of TOD and the accompanied injuries.

**Methods** A retrospective study was performed on 18 ears (16 patients) of TOD with intact TM from May 2017 to Jun 2019 in our department. EES was conducted to check the ossicular chain anomalies, and to perform the ossiculoplasty and facial nerve (FN) decompression depending on the intraoperative findings. Hearing outcomes and surgical complications were assessed at 6 months postoperatively.

**Results** The incus injury was the most common type of TOD, which was observed in 14 ears (77.8%), stapes suprastructure fracture was observed in 4 ears (22.2%). FN injury was found in 4 out of 13 ears with temporal bone fracture (TBF), the injury sites were mainly located in the perigeniculate area and the tympanic segment of FN. It showed the postoperative average pure-tone average (PTA) gain was  $22.9 \pm 9.5$  dB, and the average ABG closure was  $22.2 \pm 8.3$  dB, ABG closure to 20 dB or less and ABG closure to 10 dB or less were achieved in 18 ears (100%) and 14 ears (77.8%), respectively. The facial function achieved favorable recovery of House-Brackmann (H-B) grade Ⅲ (3 ears) and grade Ⅳ (1 ear) in all the 4 cases in 6 months after surgery. No iatrogenic FN paralysis and significant sensorineural hearing loss were observed.

**Conclusions** ESS was effective in diagnosis and management of TOD and the accompanied otologic injuries, such as FN paralysis, it showed favorable surgical outcomes. ESS provides an alternative method to manage TOD with the advantage of excellent vision and less invasion.

## Background

Traumatic ossicular disruption (TOD) is usually caused by a head trauma or direct and indirect injuries from auditory canal [1-3]. TOD patients usually had a severe conductive hearing loss, which is induced by tympanic membrane (TM) perforation, ossicular injury, or a combination [3]. Perforations of the TM could naturally heal and then present as an intact one, which is prone to being misdiagnosed [3]. Though high-resolution CT (HRCT) scans and modern imaging technology improve the diagnosis sensitivity before surgery, some TOD cases with the minor abnormalities were still missed in clinical practice [4]. The patients with a persistent severe conductive hearing loss after head or ear trauma, though an intact tympanic membrane upon examination, TOD should be suspected, the exploratory tympanotomy is critical for the diagnosis, and ossicular reconstruction could be performed at the same time according to the intraoperative findings.

Endoscopic ear surgery (EES) is becoming popular in the last decade, which is identical with microscopic ear surgery (MES), However, EES showed some obvious advantages, such as a wider surgical view and less invasive incision from the external auditory canal [5-7], the advantages of EES seem to be especially remarkable in minimally invasive middle ear surgery, such as ossiculoplasty [6, 8]. However, up to date, most TOD were treated by ossiculoplasty under microscope [1, 2, 9]. Moreover, TOD is usually accompanied with temporal bone fracture (TBF) and facial nerve (FN) injury in some patients [10, 11], whether the exclusive ESS could be qualified to manage these complex injuries is unknown. In order to explore the efficacy of EES for management of TOD and the accompanied injuries, we retrospectively collected and analyzed a series of TOD cases with intact TM which were performed EES for ossiculoplasty and FN decompression in a portion of cases accompanied with FN injury.

## Methods

### 1.1 Clinical material

We retrospectively analyzed a series of patients who visited our hospital due to hearing loss after trauma between May 2017 and Jul 2019. The cases met the following criteria were included in this study: (1) a persistent conductive hearing loss after head or ear trauma; (2) an open external auditory canal and intact TM. Exclusion criteria: (1) TOD combined with otitis media. (2) Severe bony fracture of skull base, CSF leakage, or meningoencephalocele. (3) the surgery under microscope with a post-auricular incision or mastoidectomy was performed. (4) preoperative radiologic evidence suggested the FN injury involvement was not limited from the

geniculate ganglion to pyramidal segment. (5) the case lost to follow-up and postoperative hearing outcome was not obtained. This study was approved by the Institutional Ethics Review Board of our institution and informed consent was obtained for our study from all participating patients.

A total of 85 ears were reviewed in this period, including 58 ears of traumatic TM perforation without TOD, 9 ears of traumatic TM perforation with TOD, 18 ears of TOD with intact TM. Finally, a total of 18 ears (16 cases) were included, the clinical characteristics and hearing status of these patients were summarized and analyzed (**Table 1**). The patient population was composed of 12 males (13 ears) and 4 females (5 ears), with an age range of 7-54 years and a mean age of  $36.6 \pm 13.6$  years. Fourteen patients showed unilateral TOD, and 2 patients showed bilateral TOD. The most common trauma etiology was fall down injury (9 cases), followed by traffic accident injury (5 cases) and blast injury (2 cases, **Table 2**). The average interval between trauma onset and surgery was 2.7 months (range: 0.5–24). Eight patients had complex injuries and were firstly treated in other departments, such as cerebral surgery, orthopedics department, maxillofacial department and so on.

Temporal bone HRCT scans and 3-D reconstruction of ossicular chain were routinely performed before surgery, TBF was observed in 13 ears, including 9 patients of longitudinal TBF, 3 patients of transverse TBF, and 1 patient of oblique TBF. Four patients (P3, P5, P13 and P15) presented with FN paralysis immediately after trauma onset, including 2 cases of House-Brackmann (H-B) grade  $\text{III}$  (P5, P13), 1 case of H-B grade  $\text{IV}$  (P15), and 1 case of H-B grade  $\text{V}$  (P3), all the cases were lack of response to corticosteroid therapy at least 10 days and radiologic evidence suggested FN injury. The preoperative pure-tone average (PTA) of four frequencies (0.5, 1.0, 2.0, and 4.0 kHz) ranged from 30 to 75 dB, the preoperative PTA and ABG were  $48.1 \pm 13.4$  dB, and  $32.4 \pm 9.1$  dB, respectively.

## 1.2 Surgical methods

All the EES procedures were conducted by the same senior surgeon (Z.C.) under general anesthesia via the transcanal approach with  $0^\circ$  and  $30^\circ$  endoscopes (2.7 mm of diameter and 11 cm of length) (Karl Storz, Germany). A posterior tympanomeatal flap was made and elevated to expose the tympanic cavity. The smaller amount scutum was removed using a curette for exposing the 3 ossicles, oval window and round window. The integrity and connection of the ossicular were explored. Various treatment strategies, including ossiculoplasty and FN decompression were applied depending on the intraoperative findings: (1) a partial titanium ossicular replacement prosthesis (PORP) was used in the case of incus injury with normal stapes; (2) a total titanium ossicular replacement prosthesis (TORP) was used in the case of stapes suprastructure injury with a normal stapes footplate; (3) a titanium piston prosthesis was used in the case of stapes footplate injury with a normal incus; (4) FN decompression was performed in the case of FN paralysis induced by injury from the geniculate ganglion to pyramidal segment. A small piece of tragal cartilage was harvested and placed on the PORP/TORP prosthesis. The operation time and amount of bleeding were recorded. Two weeks after surgery, the external auditory canal was cleaned and the TM was examined with ear endoscopy in our outpatient department. Interval hearing status was assessed by pure-tone audiometry. All patients were followed-up at least 6 months.

## 1.3 Statistical methods

A GraphPad Prism 7 statistical software was used for statistical analyses. A one-sample Kolmogorov-Smirnov test was used to analyze the normality of the data distribution. A paired-samples t-test or Wilcoxon signed rank test were used for comparisons before and after surgery. A P value  $< 0.05$  was considered to indicate statistical significance.

# Results

## 2.1 Intraoperative findings

A comprehensive description of the clinical characteristics, expletory findings and treatment strategies were shown in **Table 1** and **Figure 1**. It revealed that the incus injury was observed in 14 ears (77.8%), which was the most common type in this study, including 11 ears of incus dislocation involved both IMJ dislocation and ISJ dislocation, 2 ears of isolated ISJ dislocation, and 1 ear of the long process necrosis. Stapes suprastructure fracture was observed in 4 ears (22.2%), including 2 ears of stapes suprastructure fracture with normal footplate, 1 ear of suprastructure fracture with injured footplate, and 1 ear of suprastructure fracture accompanied with IMJ dislocation. All of the cases had edema mucus or fibrous tissue enveloped the injured ossicular. In the cases with FN paralysis, the injury sites were consistent with the suggestions of preoperative CT examination, including 3 ears of

perigeniculate ganglion injury and 1 ear of tympanic segment injury. We also observed a case with partial missing lateral bony wall of external auditory canal (P7), which was constructed by a piece of tragus cartilage.

## 2.2 Surgical results of EES

The operation time ranged from 45 to 95 min, the average of operation time was  $62.4 \pm 15.5$  min. The TM remained intact after surgery in all ears. An interval serial assessment of the hearing status was conducted postoperatively, a mean follow-up period was 18.4 months (range: 6.5-35.3). The mean PTA gain was  $22.9 \pm 9.5$  dB, and the ABG was  $22.2 \pm 8.3$  dB. The mean postoperative PTA was significantly reduced, and the mean postoperative ABG was obviously closed, respectively ( $P < 0.001$ ) (**Table 3**). The ABG closure to 20 dB or less and ABG closure to 10 dB or less were achieved in 18 ears (100%) and 14 ears (77.8%), respectively. The average bone conduction was not changed significantly ( $P = 0.236$ ). (**Table 3**). The FN function recovered very well in all the 4 patients with FN paralysis, it showed 3 cases of H-B grade Ⅱ, and 1 case of H-B grade Ⅲ in 6 months after surgery.

According to the involved ossicles, the TOD cases were divided into two subgroups, incuse injury with normal stapes and stapes injury with or without incus injury, the preoperative PTA and ABG showed no statistical differences, respectively ( $P=0.126$ ,  $P=0.386$ ). Accordingly, the hearing reconstruction adopted PORP implantation for incus injury, and TORP implantation or stapedotomy and piston prosthesis implantation for stapes injury, respectively, no statistical differences were found in postoperative PTA and ABG, respectively ( $P=0.975$ ,  $P=0.790$ ) (**Table 4 and Fig 2**).

## 2.3 Complications

The operative bleeding was less than 20 ml in all ears. A post-auricula approach, canalplasty or mastoidectomy was not necessary in any case. However, the chorda tympani nerve was transected in 1 case (right ear of Case 6), in which the chorda tympani nerve was tightly adhered with the dislocated incus and the fibrous tissues surrounding it. No major complication, such as iatrogenic facial nerve paralysis, significant sensorineural hearing loss ( $\geq 15$  dB) was observed.

## Discussion

Ossiculoplasty was the main treatment for TOD, which was traditionally performed under microscope [1, 2, 9]. In recent years, EES for tympanoplasty and ossiculoplasty has increased annually, showing some obvious advantages, such as a wider and multiangle field of view which allowed the surgeons to accurately assess and then reconstruct the ossicular chain [5-8]. However, ESS for the management of TOD have not been well studied, up to date, only Kim [12] reported 15 cases of TOD treated by ESS in 2019, the TOD cases with TM perforation were also included in their study, the diagnose of these cases was relatively easier, which could be observed directly using the endoscope through the perforation. As previously reported, the traumatic TM perforation of some TOD cases could be healed spontaneously in one or several weeks [13], which could lead to the diagnosis of TOD more difficult. To the best of our knowledge, this is the first study focused on employing totally ESS for the management of TOD with an intact TM. Our research showed the ABG closure to 20 dB or less and ABG closure to 10 dB or less were achieved in 18 cases (100%) and 14 cases (77.8%), respectively, which was well in accordance with the study of Kim [12], and better than those of MES, Ghonim [2] reported 42 cases of TOD with intact TM, which were performed MES, the postoperative PTA and ABG were significantly improved to  $20.2 \pm 9.8$  dB and  $4.2 \pm 7.3$  dB, respectively. However, so far, there is absent of a study on direct comparison between ESS and MES for TOD, further studies employing a larger cohort and including MES are needed for validation. Moreover, we also analyzed the postoperative hearing outcomes between incus injury reconstructed by PORP implantation and stapes injury mainly reconstructed by TORP or piston implantation, no significant differences were found, the results were different from our previous study of ossicular chain malformation [8], the possible reason was that the piston reconstruction was also adopted for stapes injury with footplate anomaly (P4), as many studies reported, the piston prosthesis usually obtained a better hearing result [2, 14, 15].

In this study, head trauma through fall from a height or traffic accident was the most common cause of TOD, which was well in accordance with previous studies [2]. Incus is prone to be involved in injury as it was suspended in the tympanic cavity between the firmly anchored malleus and stapes [10], the injury types included isolated ISJ dislocation, isolated IMJ dislocation, and a complex of both. Isolated malleus handle and long process of incus fractures were rarely reported in previous reports [16-18], we observed a case of isolated long process necrosis (right ear of P16), and a case of stapes suprastructure fracture which was still suspended upon the stapes footplate (P14), both the ears was misdiagnosed by preoperative examination. HRCT is the preferred modality due

to its ability to demonstrate the details of TOD and other associated injuries, such as TBF and FN injury. In this study, the diagnosis sensitivity of HRCT was 88.9% for TOD, which was in accordance with the previous reports [4], some TOD cases with the minor abnormalities were still missed in clinical practice. Therefore, exploratory tympanotomy is critical for the diagnosis, and could simultaneously perform ossiculoplasty to improve hearing.

TOD cases usually experienced a relatively long period of delayed diagnosis and treatment, it was still under controversy when to perform the tympanic exploratory [19], suggestions of previous studies were from immediate exploration to 3 months, in this research the average interval between trauma onset and surgery was 2.7 months (range: 0.5 - 24). Grant [19] reported conservative management was effective in traumatic TM perforation and hemotympanum, however, some TOD cases showed a worsened hearing, therefore, exploratory tympanotomy should be performed for the TOD cases with definite radiologic evidences. Moreover, we found that the dislocated ossicles were usually enveloped with fibrous tissues, forming soft connection between the ossicles, which induced a relatively small average preoperative ABG of  $32.4 \pm 9.1$  dB, compared with a larger average ABG of  $63.2 \pm 11.7$  dB in the cases of isolated middle ear malformation in our previous study [8]. On the other hand, the fibrous tissue may induce the ventilation blockage and provoke a dysventilation of the middle ear [20]. Therefore, the surgery should be considered once HRCT scan suggested the disruption of ossicular with an ABG of 30 dB or more.

TOD was usually accompanied with TBF, perilymphatic fistula, or FN injury [10]. The TOD cases accompanied with severe otologic complications should be treated timely, However, whether EES could be qualified to manage these associated anomalies at the same time is yet unknown. To the best of our knowledge, this is the first study to explore this question for TOD. According to previous reports, perilymphatic fistula commonly occurred in the stapes and round window [21], though after carefully examination, no occurrence of perilymphatic fistula was observed in our cases series, EES could provide a clear and magnified view for checking these areas, and reconstruction if necessary [22], the characteristic of endoscopic view ensured the surgical procedures being minimally invasive. TBF was found in 13 ears in this research, 4 ears were accompanied with FN injury, the perigeniculate area and tympanic segment was most commonly involved in the injury, which was in accordance with previous researches [4, 11]. Though the timing of treatment of traumatic FN paralysis was under controversy [23], the case of traumatic FN paralysis combined with TOD was a good indicator for timely surgery, especially for the cases with severe immediate-onset facial paralysis and lack of response to the corticosteroid therapy. A few approaches can be used for FN decompression depending on the injury sites, including transmastoid approach and the middle cranial fossa approach, however, it is a challenging to control these areas through traditional surgical approaches [11]. In this research, it showed EES was effective in the management of some selected FN injury, transcanal approach could allow the surgeons to control the whole tympanic segment, geniculate ganglion and lateral aspect of the labyrinthine portion, obviating the need of excessive removal of tympanic scute, canaloplasty, or a post-auricle incision and mastoidectomy, the FN function recovered very well in 6 months after surgeries in all cases. However, when radiologic evidence suggested the injury involved mastoid segment, the transmastoid approach should be conducted, 5 cases (excluded from this research) were performed transmastoid approach under microscope at the same period in our department, carefully preoperative imaging study was critical for selecting TOD patients with FN paralysis for EES exclusively or combined with transmastoid approach.

## Conclusion

In conclusion, this research showed EES was effective in diagnosis and management of TOD with intact TM, and some accompanied otologic injuries. It showed favorable surgical results. EES provides an alternative method to manage TOD, with the advantage of excellent vision and less invasion, which could be promoted in clinical.

## Abbreviations

**AC:** air conduction; **ABG:** air-bone gap; **EES:** endoscopic ear surgery; **FN:** facial nerve; **MES:** microscopic ear surgery; **PORP:** partial ossicular replacement prosthesis; **TM:** tympanic membrane; **TBF:** temporal bone fracture; **TOD:** traumatic ossicular disruption; **TORP:** total ossicular replacement prosthesis.

## Declaration

## Ethical approval and consent to participate

This study was approved by the Institutional Ethics Review Board of the Affiliated Hospital of Zunyi Medical University and written informed consent was obtained for our study from all participating patients.

## Consent for publication

All authors have agreed to publish this article.

## Availability of data and materials

Data is available upon request by contacting the corresponding author.

## Competing interests

The authors declare that they have no competing interests.

## Funding

No.

## Authors' contributions

ZC and LZ participated in the design of the study. LD, DY, YM and GD performed the statistical analysis, drafted the manuscript, and ZC revised the manuscript. All the authors have approved the manuscript as submitted.

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## Tables

**Table 1 Patients clinical characteristics, intraoperation findings, surgery strategies and hearing outcomes**

Case	Age(y) /Sex	Side	Trauma aetiology	Intraoperative findings	Operation time	Surgical strategies	Preoperative [dB]			Postoperative [dB]		
							PTA	BC	ABG	PTA	BC	ABG
P1	34/M	L	Blast injury	Stapes suprastructure fracture with normal footplate	55	TORP	63	23	40	39	21	18
P2	45/M	L	Fall down injury	Incus dislocation	53	PORP	41	10	31	20	11	9
P3 ✳	51/F	L	Fall down injury	Incus dislocation; H-B grade Ⅲ	92	PORP + FND	46	11	35	18	10	8
P4	54/M	R	Fall down injury	Stapes suprastructure fracture with  injured footplate	65	Piston	55	21	34	31	22	9
P5 ✳	43/M	R	Traffic injury	Incus dislocation, H-B grade V	95	PORP + FND	55	23	32	31	23	8
P6	21/M	R	Traffic injury	Incus dislocation	50	PORP	43	13	30	20	12	8
		L		Incus dislocation	45	PORP	35	16	19	22	15	7
P7	7/M	L	Fall down injury	Incus dislocation, partial missing lateral bony wall of EAC	65	PORP+ EAC reconstruction #	30	6	24	15	7	8
P8	34/M	R	Blast injury	Incodostapedial joint dislocation	55	PORP	45	13	32	20	10	10
P9	34/M	L	Fall down injury	Incus dislocation	57	PORP	63	10	53	16	8	8
P10	47/M	L	Fall down injury	Stapes suprastructure fracture and incudomalleolar joint dislocation	58	TORP	75	33	42	48	32	16
P11	41/M	R	Traffic injury	Incus dislocation	56	PORP	71	25	46	28	18	10
P12	11/F	L	Traffic injury	Incus dislocation	62	PORP	46	10	36	30	12	18
P13 ✳	41/M	R	Fall down injury	Incus dislocation, H-B grade V	88	PORP + FND	55	20	35	32	20	12
P14	36/M	R	Fall down injury	Stapes suprastructure fracture with normal footplate	52	TORP	36	8	28	20	12	8
P15 ✳	36/F	R	Fall down	Incus dislocation, H-B	78	PORP + FND	36	11	25	18	10	8

		injury		grade								
P16	51/F	R	Traffic injury	Incus long process necrosis	52	PORP	39	16	23	26	16	10
		L		Incudostapedial joint dislocation	46	PORP	32	14	18	20	12	8

ABG: air-bone conduction gap; EAC: external auditory canal; FND: facial nerve decompression; H-B: House-Brackman Grading System; EAC: external auditory canal;

PORP: partial titanium ossicular replacement prosthesis; TORP: total titanium ossicular replacement prosthesis;

Incus dislocation involved both incudomalleolar joint and incudostapedial joint dislocation;

※ the cases accompanied with facial paralysis.

# the tragus cartilage was adopted to repair the EAC.

**Table 2 Distribution of traumatic ossicular disruption and accompanied injuries**

Injury types	Case number and proportion
<b>Malleus injury</b>	<b>0 (0%)</b>
<b>Incus injury</b>	<b>14 (77.8%)</b>
Incus dislocation #	11
Isolated incudostapedial joint dislocation	2
Incus long process necrosis	1
Isolated incudomalleolar joint dislocation	0
<b>Stapes injury</b>	<b>4 (22.2%)</b>
Suprastructure fracture with normal footplate	2
Suprastructure fracture with injured footplate	1
Suprastructure fracture with incudomalleolar joint dislocation	1
<b>Temporal bone fracture (TBF)</b>	<b>13 (72.2%)</b>
Longitudinal TBF	9
Transverse TBF	3
Oblique TBF	1
<b>Facial never injury</b>	<b>4 (22.2%)</b>
Perigeniculate area	3
Tympanic segment injury	1

#: Incus dislocation: involved both incudomalleolar joint and incudostapedial joint dislocation;

**Table 3 Hearing comparison between Before and After Surgery**

Outcome	Preoperative	Postoperative	Statistical value	P value
PTA, mean (SD), dB	48.1 ± 13.4	25.2 ± 8.7	t=10.22	0.001
BC, mean (SD), dB	15.7 ± 7.1	15.1 ± 6.5	t=1.23	0.236
ABG, mean (SD), dB	32.4 ± 9.1	10.2 ± 3.5	t=11.29	0.001
ABG ≤ 20 dB, %	2 (11.1%)	18 (100%)	-	0.001*
ABG ≤10 dB, %	0 (0%)	14 (77.8%)	-	0.001*
Hearing Gain, Mean (SD), dB	-	22.9 ± 9.5	-	-
ABG closure (SD), dB	-	22.2 ± 8.3	-	-

ABG: air-bone gap; BC: bone-conduction; PTA: the pure-tone average;

\*: calculated by Fisher's exact test

**Table 4 Hearing Comparison between incus and stapes injury**

Outcome	Incus injury	Stapes injury※	Statistical value	P
Preoperative PTA, mean (SD), dB	45.5 ± 11.9	57.3 ± 16.4	t=1.162	0.126
Preoperative BC, mean (SD), dB	14.1 ± 5.4	21.3 ± 10.3	t=1.903	0.075
Preoperative ABG, mean (SD), dB	31.4 ± 9.7	36.0 ± 6.3	t=0.892	0.386
hearing Gain, Mean (SD), dB	22.9 ± 10.6	22.8 ± 4.7	t=0.032	0.975
ABG closure (SD), dB	21.9 ± 9.4	23.2 ± 2.8	t=0.271	0.790
ABG closure ≤10 dB, %	12 (85.7%)	2 (50.0%)	-	0.197#
SNHL ≥15 dB, %	0	0	-	-

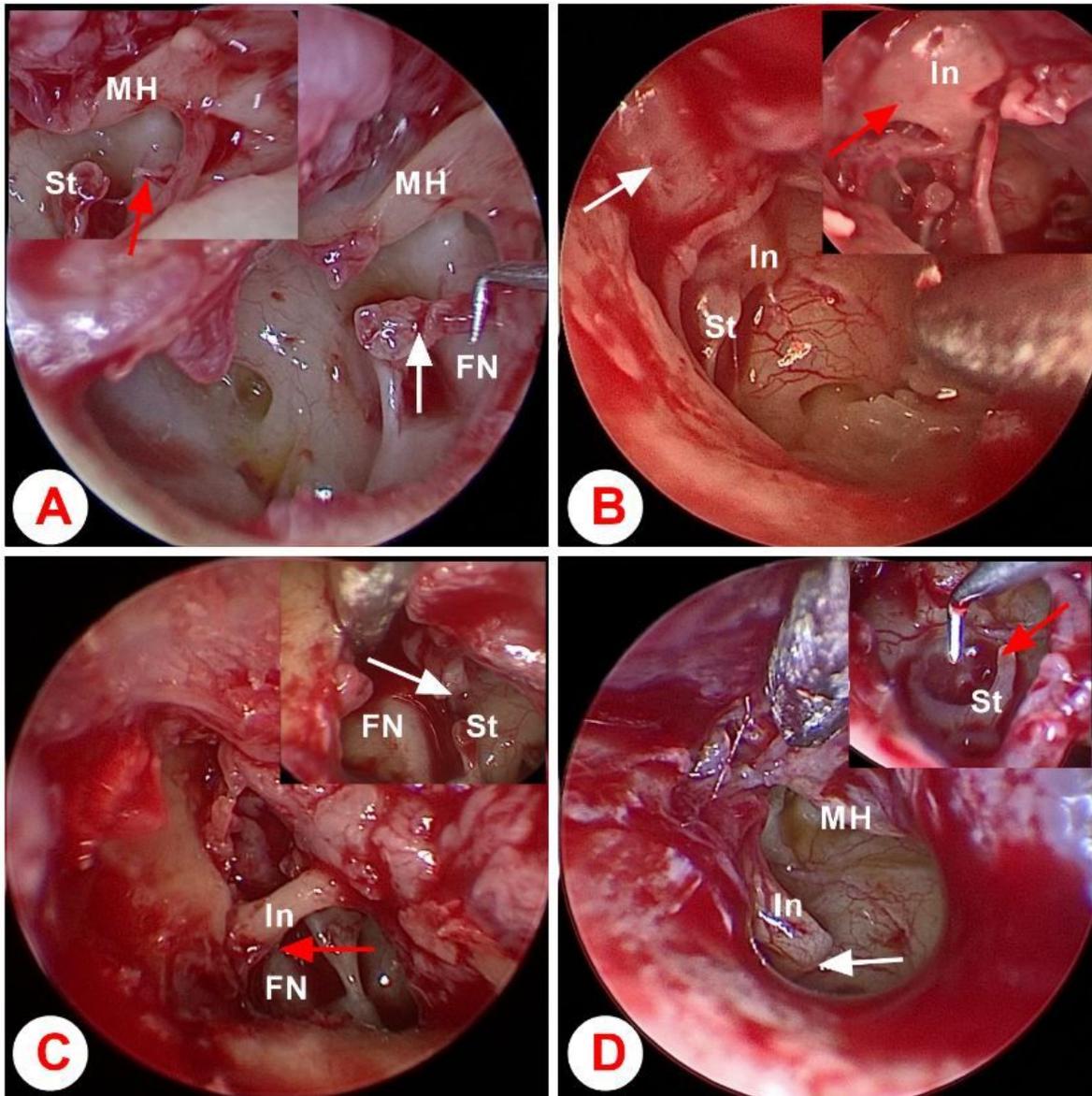
ABG: air-bone gap; BC: bone-conduction; PTA: the pure-tone average;

SNHL: sensorineural hearing loss

#: calculated by Fisher's exact test

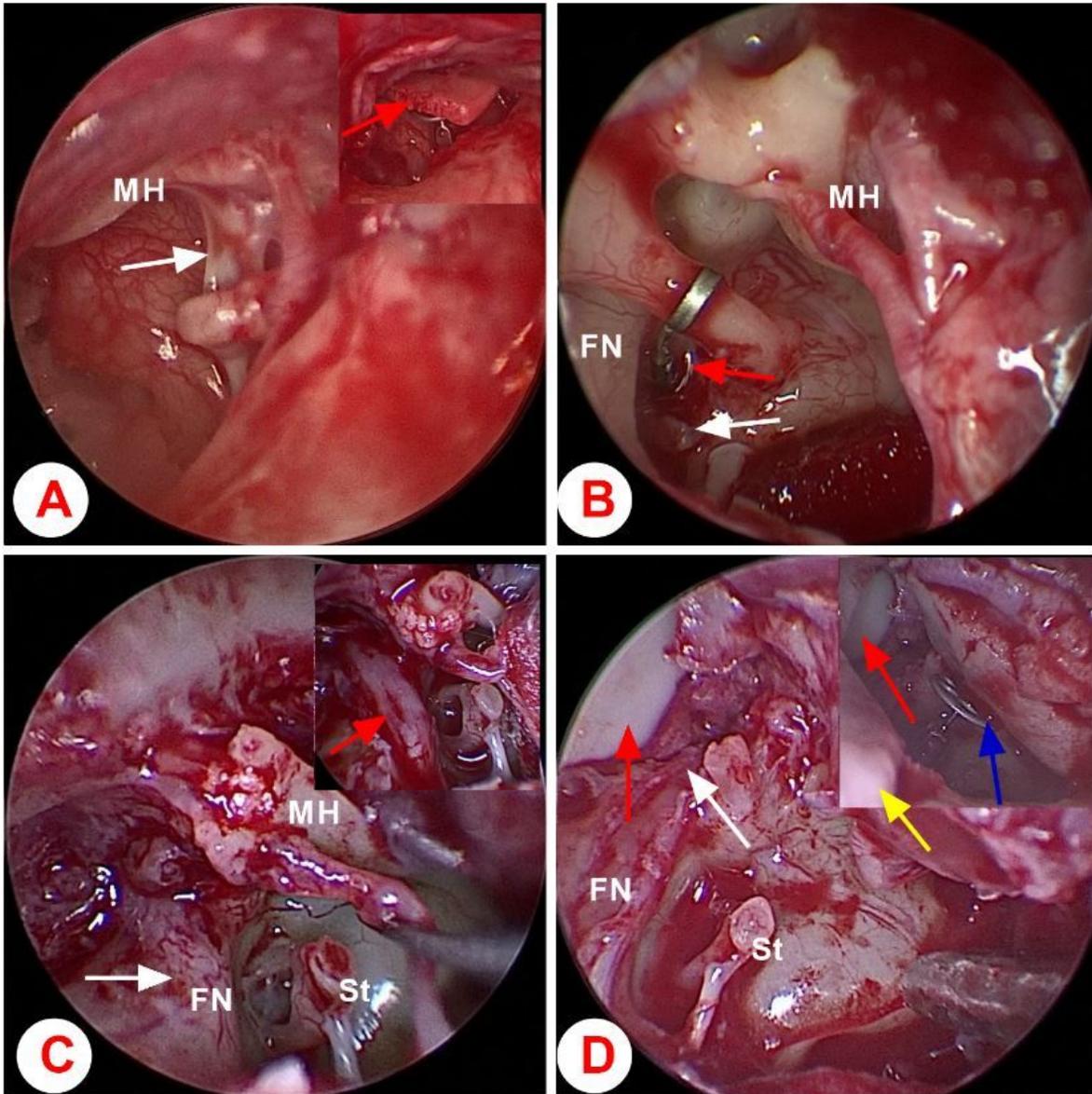
※: included the case involved both stapes and incudomalleolar joint dislocation.

## Figures



**Figure 1**

Various traumatic ossicular disruption types under endoscopic view FN: facial nerve; MH: malleus handle; In: incus; St: stapes. A: white arrow showed the necrosis of the incus long process, which was instead by the fibrous connection and appeared as normal; red arrow showed the minor missing of the incus long process after removal of the fibrous tissues. B: white arrow showed the disrupted incus which was enveloped by the edam mucus; red arrow showed the dislocated of incus which involved both the incudomalleolar joint and incudostapedial joint dislocation. C: red arrow showed the dislocation of incus, the FN nerve was depressed by the long process; white arrow showed the tissues connection between the lenticular process and the stapes. D: white arrow showed the normal connection of incudostapedial joint and the fractured stapes suprastructure which was suspended over the footplate; red arrow showed the complete fracture of stapes suprastructure after removal the dislocated incus.



**Figure 2**

Various strategies and skills of endoscopic ear surgery FN: facial nerve; MH: malleus handle; St: stapes; PORP: partial ossicular replacement prosthesis; A: white arrow showed the fibrous connection between the MH and incus long process; red arrow showed a small piece of cartilage placed on the PORP. B: white arrow showed the fracture of stapes suprastructure and the injured footplate; red arrow showed the piston implantation with the small fenestra stapedotomy. C: white arrow showed the injury of bone canal of tympanic segment FN; red arrow showed the local FN decompression. D: white arrow showed the FN injury in perigeniculate area, and the FN decompression from lateral aspect of the labyrinthine portion to the pyramidal segment; red arrow showed a piece of cartilage was used for reconstructing the fracture of skull base; yellow arrow showed a piece of perichondrium covered FN; blue arrow showed the ossiculoplasty using PORP implantation.