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ORIGINAL RESEARCH

Laryngoscope Investigative Otolaryngology

The utility and safety of diode laser in endoscopic stapes surgery

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Abstract

Objective: The advantages of laser stapedotomy are less trauma and more precise and minimally invasive techniques; however, the potential risk of overheating from the laser combined with the endoscope tip must be considered. This study aimed to assess the efficacy and safety of diode lasers for endoscopic stapes surgery.

Methods: A retrospective review of 56 patients with otosclerosis who underwent primary endoscopic stapedotomy with a diode laser from 2017 to 2020 was conducted. Demographic data, intraoperative findings, preoperative and postoperative audiological assessments, and postoperative complications were analyzed.

Results: There was no statistically significant difference between the preoperative and postoperative bone conduction thresholds. The mean postoperative air-bone gap (ABG) improved significantly compared to the preoperative ABG (4.07 vs. 35.43 dB, $p < .001$). The postoperative ABG closure within 10 dB at 6 and 12 months was achieved in 87.50% and 91.07% of patients, respectively. The postoperative pain scores at 4 and 24 h were 2.55 and 0.39, respectively. Immediate postoperative vertigo was reported in 12.50% of patients, with 100% complete recovery 2 months after surgery. The chorda tympani nerve was preserved in all the cases. Postoperative taste disturbances at 2 and 12 months were observed in 17.86% and 1.79% of patients, respectively.

Conclusion: The diode laser in endoscopic stapedotomy is a safe and effective technique that provides satisfactory hearing outcomes. Temporary taste disturbances during the early postoperative period are a concern. The handheld diode laser delivery system is suitable for an endoscopic approach and is an alternative armamentarium for the treatment of otosclerosis.

Level of evidence: IV.

KEYWORDS
diode, endoscopic ear surgery, laser, stapedotomy, stapes surgery

1 | INTRODUCTION

Otosclerosis is abnormal bone remodeling that affects the bony labyrinth and stapes. This condition has a multifactorial etiology that affects the ability to perceive sounds in the inner ear. The treatment of choice for patients with otosclerosis is stapes surgery, which re-establishes sound transmission through the stapes prosthesis. Surgical techniques have evolved as minimally invasive methods according to the surgical approach and the small-fenestra technique. The endoscope-assisted approach has been gaining acceptance as an alternative to stapes surgery because it provides excellent visualization and a magnified view of the middle ear cavity.[1] Moreover, endoscopic stapes surgery is a less invasive technique while obtaining audiological and functional outcomes compared to a microscopic approach.[2–12]

Few studies have focused on the footplate fenestration technique in endoscopic stapedotomy. Fenestration of the stapes footplate is the most critical step with the potential risk of inner ear injury. Various surgical techniques have been proposed to accomplish a small fenestra, including handheld perforator, microdrill, and laser. There is still ongoing debate regarding which fenestration techniques are superior to each other concerning postoperative hearing results and complications.[13–17]

Endoscopic stapedotomy using a microdrill or manual perforator is widely used due to its availability, low cost, and good hearing improvement[10,13]; however, it is criticized for the loss of depth perception with possible deep advancement into the inner ear and more mechanical trauma that risks sensorineural hearing loss.[13,18] The utility of lasers for footplate fenestration has been popularized due to its advantages of high precision and avoidance of mechanical trauma to both the middle and inner ears. A variety of laser systems have been implemented for their use in stapedotomies, such as argon, potassium titanyl phosphate (KTP), erbium-doped yttrium aluminum garnet (Er-YAG), carbon dioxide (CO_2), and diode lasers; however, each laser has its risks and different characteristics. A diode laser is one of the lasers used in stapedotomies because it is generated through a semiconductor that produces coherent radiation in the infrared spectrum; it is highly absorbed in pigment structures and is less absorbed in water compared with other lasers. Kamalski et al.[19] investigated the safety of a 980-wavelength diode laser in an inner ear model. They found that this laser type has fewer mechanical, acoustic, and thermal effects on the inner ear. The diode laser is an attractive alternative laser because of the following reasons. It is a low-cost laser that is a cost-effective medical device even in low-volume otosclerosis surgery centers.[19] It is a safe method with good hearing outcomes.[20,21] It causes limited injury to nonpigmented structures, and its delivery system passes through a small fiberoptic cable suitable for endoscopic ear surgery.

However, the potentially harmful effects of heat dissipation when the laser is combined with the endoscope might cause undesirable thermal injury, damaging the surrounding structures such as the chorda tympani nerve, facial nerve, and inner ear. Very few studies have provided evidence of the safety of the laser used in the endoscopic stapedotomy approach. Therefore, this study aimed to investigate the safety of diode lasers in endoscopic stapes surgery in terms of postoperative hearing outcomes and complications.

2 | MATERIALS AND METHODS

2.1 | Ethics approval

Following Prince of Songkla University's institutional review board approval, a retrospective study was conducted on all patients diagnosed with otosclerosis who underwent primary endoscopic stapedotomy with a diode laser at the Department of Otolaryngology Head and Neck Surgery, Songklanagarind Hospital, Prince of Songkla University between January 2017 and December 2020.

2.2 | Patients

The inclusion criteria were patients between 18 and 70 years who were diagnosed with otosclerosis with stapes fixation and underwent primary endoscopic stapedotomy with a diode laser. The exclusion criteria were patients who underwent revision surgery, other ossicular chain abnormalities, intraoperative use of different fenestration techniques, concomitant chronic ear infection, tympanic membrane perforation, or retraction pocket.

All patients underwent an exclusive transcanal endoscopic approach under local anesthesia with monitored anesthesia. Preoperative variables, including age, sex, signs, symptoms, duration of symptoms, family history, and medical conditions, were collected from the medical records. Intraoperative endoscopic findings included: (1) the chorda tympani nerve status; (2) the status of the ossicular chain; (3) the occurrence of perilymph gusher, fractured footplate, floating footplate, or incus dislocation; (4) the status of the facial nerve; (5) prosthesis length; and (6) operative time. Clinical follow-up was performed at 2 weeks and 2, 6, and 12 months postoperatively. The postoperative variables included: (1) vertigo; (2) pain score: all patients were instructed to score their pain level on a visual analog scale, comprising a 10-cm long line, at 4 and 24 h postoperatively. We asked the patients to mark the line corresponding to their pain. The left indicated no pain, and the right indicated the worst imaginable pain; (3) taste disturbance; (4) tinnitus; (5) facial nerve function; and (6) tympanic membrane perforation or retraction.

The audiological assessment was performed using an audiometer (AC40 Clinical Audiometer; Interacoustics). Pure-tone threshold averages of air conduction (AC-PTA) and bone conduction (BC-PTA) were calculated from frequencies of 0.5, 1, 2, and 4 kHz according to the Committee on Hearing and Equilibrium Guidelines.[22] The air-bone gap (ABG) was calculated from the AC-PTA minus the BC-PTA. The audiological assessment was performed within 3 months before the surgical date and at 2, 6, and 12 months postoperatively.

2.3 | Surgical technique

Two rigid endoscopes, one of 3 mm in diameter and 14 cm in length with a 0° angle of view, and a second endoscope of 2.7 mm in diameter and a 14 cm length with a 30° angle of view, were used together with a 4U camera platform with a 4k resolution (Karl Storz).

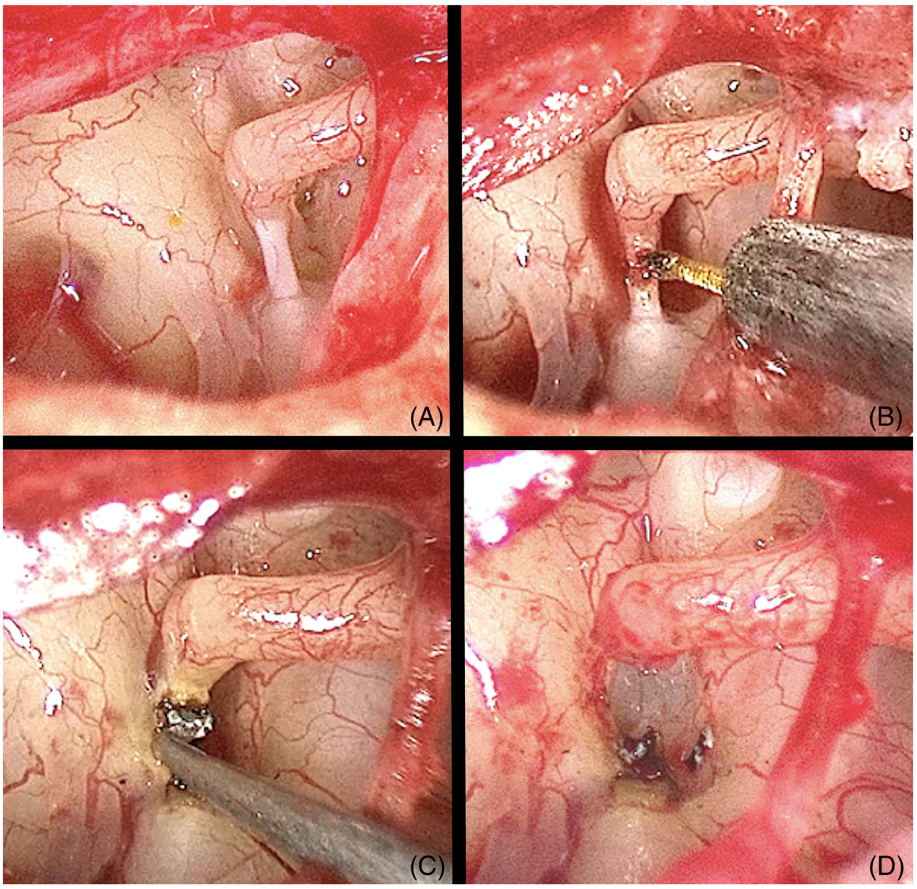

FIGURE 1 (A) Endoscopic view of an adequate exposure for performing stapes surgery. (B) Stapedial tendon cauterized using a diode laser. (C) The posterior crus of stapes cauterized using a diode laser. (D) Exposure of a stapes footplate after removing the stapes suprastucture.

A standard ear surgery setup was used. A canal incision was created, and the tympanomeatal flap was elevated. The bony canal in the posterosuperior quadrant was removed with a bone curette to visualize the entire stapes. Optimal exposure for endoscopic stapes surgery requires excellent visualization of the long process of the incus, the whole stapes, the transverse portion of the facial nerve superiorly, the round window niche inferiorly, the malleus anteriorly, and the pyramidal eminence with stapedial tendon posteriorly (Figure 1). Ossicular chain mobility was also assessed. A right-angle pick was used to separate the incudostapedial joint. A 980-nm wavelength diode laser with a 300-μm fiberoptic handpiece delivery system was used (SMARTXIDE2, DEKA). The fiber tip of the diode laser was carbonized by firing it on a wooden tongue depressor. The stapedial tendon and posterior crus of the stapes were vaporized with a diode laser power setting of 1 W, 60 ms pulse duration, and 60 ms pulse intervals. The charred posterior crus was then removed. The residual stapes supra structure was then down-fractured using a Rosen pick toward the promontory and removed. The distance from the long process of the incus to the fixed footplate was measured. A rosette of chars was created on the stapes footplate using a diode laser (Figure 2), the fenestra was smoothened, and a sharp circular stapedotomy was created using a 0.7-mm microdrill (Skeeter Otologic Drill System; Medtronic Xomed Surgical Products, Inc.). The piston prosthesis (fluoroplastic Causse-loop prosthesis with 0.6 mm diameter and 6 mm in length; Medtronic Xomed Surgical Products, Inc.) was inserted into the footplate fenestra and crimped to the long process of the incus. The tympanomeatal flap was repositioned, and a whisper test was performed immediately. A gel foam soaked with antibiotic ointment was placed on the tympanomeatal flap.

2.4 | Statistical analysis

Statistical analyses were performed using R Statistical Software (ver. 3.6.2, Foundation for Statistical Computing). Continuous variables are presented as means with standard deviations or medians with interquartile ranges when not normally distributed, whereas categorical variables are reported as numbers and percentages. For comparison between preoperative and postoperative means or medians, paired *t* test and Wilcoxon signed-rank test were used for normally and non-normally distributed continuous variables, respectively. A value of *p* less than .05 was considered statistically significant.

3 | RESULTS

3.1 | Clinical characteristics

Fifty-six patients (26.78% males and 73.21% females) who underwent exclusive endoscopic stapedotomy with diode laser were enrolled in

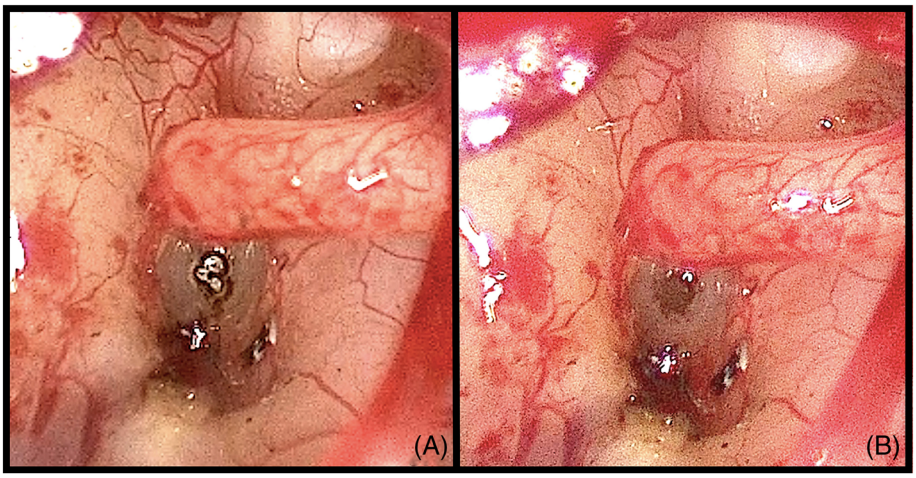

FIGURE 2 (A) Footplate fenestration using a diode laser. (B) Polishing and creation of a sharp round shape fenestra using a 0.7-mm microdrill.

TABLE 1 Preoperative and postoperative audiologic results.

Audiological outcomes	Preoperative	Postoperative 2 months	*p* Value	Postoperative 6 months	*p* Value	Postoperative 12 months	*p* Value
Mean AC-PTA (dB HL)	60.52	30.77	<.001	27.75	<.001	27.84	<.001
Mean BC-PTA (dB HL)	25.09	23.62	.096	23.51	.052	25.00	.916
Mean ABG (dB HL)	35.43	6.96	<.001	4.69	<.001	4.07	<.001
SD (%)	95.41	96.57	.071	96.40	.092	97.05	.007

Abbreviations: ABG, air-bone gap; AC-PTA, pure-tone threshold average of air conduction; BC-PTA, pure-tone threshold average of bone conduction; dB, decibel; HL, hearing level; SD, speech discrimination score.

this study. The mean age of the patients was 46.25 ± 9.11 years (range 26–63). A total of 51.78% underwent right-sided surgery. Preoperatively, 98.21% presented with progressive hearing loss, 33.92% reported tinnitus, and three patients had a history of dizziness or vertigo. None of the patients had a history of otological surgery. Two patients had a family history of hearing loss.

3.2 | Postoperative audiologic results

The preoperative and postoperative hearing thresholds are compared in Table 1. No statistically significant differences were observed between the preoperative and postoperative BC-PTA groups. At 2 months postoperatively, the ABG was closed to within 10 and 20 dB in 42 (75%) and 54 (96.43%) of all cases, respectively. At 6 and 12 months postoperatively, the ABG was closed to within 10 in 49 (87.50%) and 51 (91.07%) of all cases, respectively.

3.3 | Intra-postoperative complications

The median operative time was 87 min (range, 65–122 min). Intraoperative complications included a floating footplate ($n = 1$) and a fractured footplate ($n = 1$). No complications were noted, such as perilymph gusher, incus dislocation, facial nerve palsy, tympanic membrane perforation, or retraction. The chorda tympani nerve was

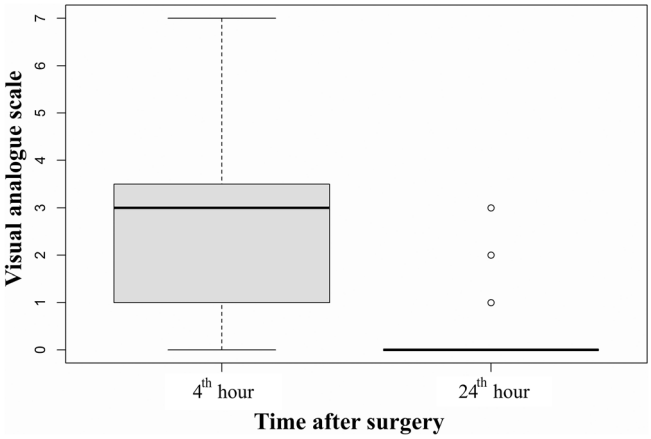

FIGURE 3 Box plot showing the postoperative visual analog scale score of the diode laser-assisted endoscopic stapedotomy.

preserved in all the cases. A total of 17.86% ($n = 12$) of cases reported taste disturbance at 2-month follow-up, of which 11 resolved at 6-month follow-up. At the last follow-up, one patient (1.79%) had persistent taste disturbance. Postoperative vertigo or dizziness was reported in 12.50% ($n = 7$) of patients, and the spontaneous resolution was observed within 2 weeks in 100%. Postoperative tinnitus was reported in 14.29% ($n = 8$) of patients, which resolved in three at 2-month follow-up, in four at 6-month follow-up, and one had persistent tinnitus. The mean postoperative pain score at 4 and 24 h were 2.55 ± 1.93 and 0.39 ± 0.98, respectively (Figure 3).

4 | DISCUSSION

Stapes surgery has been revolutionized by its ability to be a less invasive technique. The endoscope in stapes surgery provides a transcanal approach while obtaining the optimum operative view with minimal bony removal and without sacrificing the chorda tympani nerve. Moreover, the use of the laser in stapes surgery continues to increase in popularity due to its advantages, such as its minimally invasive nature, precise application of energy to create a fenestra, avoiding mechanical trauma to the inner ear, reducing the risk of footplate mobilization, as well as comparable hearing outcomes to the conventional technique.[16,17] Regarding the microscopic approach, Kamalski et al.[23] sought to compare hearing results and surgical complications in different types of lasers used for fenestration and found that CO_2 is favored over KTP, Er-YAG, and thulium. Similarly, Poe[24] stated that pulse lasers have acoustic shock properties that may cause labyrinth injury. Several studies stated that using thulium laser-produced bubbles within the labyrinth has more thermal effects and a high rate of tinnitus and sensorineural hearing loss, thus making it less safe compared to CO_2 and KTP.[25,26]

However, the suitable laser type that should be used for the endoscopic stapedotomy approach and the temperature change effects on the surrounding structures produced by combining the laser and endoscope are controversial. The incorporation of endoscope and laser in various otological procedures have been increasing.[27] Poe[24] was the first to describe the clinical use of an argon laser with endoscopic-assisted stapedioplasties. In addition, the successful application of KTP laser in endoscopic stapedotomy has been published and demonstrated satisfactory audiological outcomes comparable to the traditional technique.[18,28–31] Özdek et al.[32] described using fiberoptic CO_2 laser in fully endoscopic stapes surgery to make a fenestra with favorable results. Güneri and Olgun[33] reported their endoscopic stapedotomy outcomes in 32 ears of 31 patients using a handheld CO_2 laser to create a fenestra, wherein they found less scutum removal, postoperative vertigo, and chorda tympani manipulation with comparable hearing results to the microscopic group. Although some studies reported better hearing outcomes of the CO_2 laser than other laser types,[23,34] the drawback of CO_2 laser fiber is the high surgical supply cost (852.60 ± 285.53 US$).[35] Reducing the cost of stapes surgery while maintaining postoperative results is necessary, especially in health care systems with limited resources.

This study aimed to investigate the feasibility and safety of diode lasers, which are relatively inexpensive for use in stapes surgery. However, the utility of diode lasers in a fully endoscopic stapedotomy has yet to be reported. The diode laser was studied for potential inner ear injury by Kamalski et al.,[19] who examined the mechanical, acoustic, and thermal effects in an inner ear model and found that the diode laser has a safe penetration depth, in which the high pigmented tissue absorption and low water absorption of the diode laser may prove to be safe and beneficial in stapedotomy. Poe[24] also evaluated the vestibule temperature change and vaporization crater using a diode laser in guinea pigs, demonstrating that this laser was suitable for minimally invasive otological surgery.

The first clinical results of diode use were reported by Nguyen et al.,[36] who performed stapes surgery via an endaural approach under the microscopic technique; the author achieved 93% of ABG closure less than 15 dB with a mean postoperative ABG 9 ± 0.6 dB and also reduced the rate of footplate fracture. In the clinical setting of the endoscopic approach, a 532 nm diode laser was first used in two studies. Fan et al.[37] described the use of this laser type for cutting the stapedial tendon and then created a fenestra using a microdrill. Zhu et al.[38] utilized the diode laser in pediatric patients with a congenital ossicular fixation to divide a congenital stapes bar, remove the footplate, and address malleus fixation. In the present study, a diode laser was used in three steps, including vaporizing the stapedial tendon, cauterizing the posterior crus of the stapes, and fenestrating the footplate. A diode laser setting of 1 W and a short pulse time of 60 ms were used to create a small fenestra in a round fashion combined with a microdrill to create a clear-sharped footplate fenestra, avoiding excessive pressure from the drill to the footplate, and preventing excessive heat penetration deep into the vestibule. The statistically significant improvement in the ABG and AC-PTA without reducing the BC-PTA in this study confirms the utility of the diode laser used in endoscopic stapedotomy. The postoperative 1-year follow-up of ABG closure to within 10 dB was 91.7%, which compares favorably to the previous endoscopic stapedotomy series using different techniques that showed the rate of ABG closure to 10 dB or less between 56% and 86.7%.[39]

Although the chorda tympani nerve was preserved in all cases, 17.86% of our cases reported taste disturbance at the early to follow-up, of which 1.79% had persistent taste disturbance at 1-year follow-up. The taste disturbance rate was higher than the previous literatures on endoscopic stapes surgery, which reported taste disturbance in 0%–10.2% of cases.[7,39] The result is in line with the retrospective study by Molinari et al.,[9] which reported early postoperative taste disturbance in 27% of cases and was still present in 15% of cases at late follow-up; interestingly, negative impact on the taste function has been found at a higher rate in the CO_2 laser group than in the microdrill group. We hypothesized that the temperature elevation from the laser combined with the heat dissipation from the endoscope's light might harm the adjacent structures, such as the chorda tympani nerve, that can become desiccated or develop facial palsy. However, our study had no cases of facial palsy or sensorineural hearing loss, and almost all cases of taste dysfunction were temporary.

Postoperative pain score reduction is necessary to decrease opioid requirements and improve patient satisfaction. In the present study, we performed surgery under local anesthesia, which can provide actual pain score levels (Figure 3). The mean pain score was 2.55 at the fourth hour after surgery, indicating mild pain that could be resolved using acetaminophen without adjuvant therapy and almost no pain within 24 h postoperatively. A systematic review and meta-analysis by Toulouie et al.[40] reported significantly reduced postoperative pain scores in endoscopic surgery compared to the microscopic technique, which provides a reduced need for extraincision or extensive bone removal and leads to minimizing postoperative pain.

The limitations of this study include its small sample size and retrospective design, in which the outcomes are underpowered to

evaluate the difference in the results between handheld, microdrill, or laser stapedotomy in the endoscopic approach. Larger sample sizes and prospective randomized control study with extended follow-up periods could be further investigated to confirm the results. The ablative effects of the diode laser depend on the degree of carbonization at the tip of the laser fiber. However, it is not easy to standardize the exact degree of carbonization at the tip of the diode laser fiber. Finally, the choice of laser type depends on availability, experience, surgeon preference, and cost-effectiveness.

5 | CONCLUSION

The diode laser is an effective and safe minimally invasive endoscopic stapes surgery technique. A fiberoptic handheld delivery system, along with the exclusive endoscope approach, is easy to utilize and is a cost-effective device. It also provides satisfactory audiological outcomes and has low postoperative complications. However, temporary taste disturbances in the early postoperative period are a concern.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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