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Comparison of Free-Beam- and Fiber-Type CO_2 Laser Delivery Systems in Stapes Surgery

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Background and Objectives: A free-beam-type CO_2 laser, which use a micromanipulator mounted on a microscope as the delivery system, has the merit of not being affected by hand tremor at the time of shooting. However, this delivery system has several disadvantages, including a restricted operation range and a risk of incorrect focusing. A fiber-type CO_2 laser uses a hand-held delivery system and has the opposite merits and demerits. We compared the results of stapes surgery with free-beam and fiber type delivery systems. **Subjects and Methods**: The study enrolled 36 patients who underwent stapedotomy with free-beam- (n=26) or fiber- (n=10) type CO_2 lasers. The air-bone (AB) gap closure, bone conduction (BC) change, and operating time were evaluated. The AB gap closure was calculated by subtracting the preoperative BC thresholds from the postoperative air conduction thresholds. The BC change was calculated by subtracting the postoperative BC thresholds from the preoperative BC thresholds. **Results**: The mean operating time was significantly (p=0.035) shorter in the fiber-type group (72.5±8.2 min) than in the free-beam-type group (80.5±11.4 min). The mean AB gap closure did not differ significantly (p=0.297) between the free-beam- and fiber-type groups (5.8±10.1 and 1.4±6.8 dB, respectively). The mean BC change did not differ significantly (p=0.873) between the free-beam- and fiber-type groups (2.4±6.9 and 2.8±5.3 dB, respectively). The hearing outcomes did not differ significantly between the two groups. **Conclusions**: Operating times were significantly shorter using the fiber-type CO_2 laser, while hearing outcomes did not differ significantly between the two groups.

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KEY WORDS: Stapedotomy · CO_2 laser · Otosclerosis · Bone conduction.

Introduction

Hearing improvement is usually excellent after stapes surgery, although some patients may develop irreversible sensory neural hearing loss, painful tinnitus, and deafness. Surgical instruments, including lasers, have been adopted to minimize trauma to the inner ear during stapes surgery. Several kinds of laser with different physical properties have been introduced in stapes surgery. Non-contact perforation of the stapes footplate with an argon or potassium titanyl phosphate (KTP) laser has advantages [1]. However, argon and KTP lasers require high energy levels to vaporize the stapes footplate, and excess energy may be transmitted through the perilymph, predisposing the neurosensory epithelium to direct and thermal damage [2]. The wavelength of a CO_2 laser is 10.6 μm, which prevents a CO_2 laser from penetrating the perilymph in the inner ear [2]. CO_2 lasers have become one of the most commonly used devices in stapes surgery, because they can perforate the stapes footplate efficiently with minimal complications to the inner ear [3,4].

CO_2 and KTP lasers have different laser delivery systems. A KTP laser is delivered via a fiber-optic cable and used with a handpiece. In contrast, for the past 30 years, a CO_2 laser could not be delivered via a fiber optic cable and needed to be

coupled to a micromanipulator mounted on a microscope that directs the CO_2 laser beam to the target (free-beam-type CO_2 laser). This type of free-beam-type laser has the merit of not being affected by hand tremor at the moment of shooting. However, this delivery system also has several disadvantages, including a restricted operation range, the need for a guiding beam, and a risk of incorrect focusing. A new delivery system, a hand-held CO_2 laser device with a fiber optic cable (fiber-type), was recently introduced to surmount these shortcomings. We compared our surgical experiences with stapes surgery using fiber-type and free-beam-type CO_2 lasers.

Subjects and Methods

Subjects

This retrospective study was approved by the Institutional Review Board of the Clinical Research Institute of Seoul National University Bundang Hospital (B-1405-252-114). The study reviewed 46 patients who underwent primary incus stapedotomy using a CO_2 laser performed by one surgeon at Seoul National University Bundang Hospital between January 2011 and June 2015. Of the 46 patients, seven were excluded because of an ossicular or facial nerve anomaly interfering with the routine stapedotomy (n=6) or a postoperative infection (n=1). Of the remaining 39 patients, this study enrolled the 36 patients (92.3%) with available 6- or 12-month postoperative audiometric data. These patients were divided into two groups according to the CO_2 laser delivery system: the free-beam (n=26, patient no. 01−15 and 26−36) and fiber (n=10, patient no. 16−25) type groups. Table 1 lists the characteristics of the subjects.

Surgical stapedotomy procedures

All operations were performed under monitored anesthesia care or general anesthesia by one surgeon. Through an endaural approach, a tympanomeatal flap was elevated. The mobility of the ossicles was evaluated by gentle palpation, which confirmed the stapedial fixation. After dividing the incudostapedial joint, the posterior crus of the stapes was cut with the CO_2 laser (Lumenis, Tel Aviv, Israel) and the anterior crus was fractured in most cases. Then, the stapes footplate was perforated using multiple applications of the CO_2 laser. Table 2 summarizes the CO_2 laser settings. The spot size of the laser was 0.3 mm to avoid damage to surrounding tissue. After measuring the distance from the stapes footplate to the incus, the length of the prosthesis was chosen. The loop of the prosthesis was anchored to the long process of the incus and the mobility of the prosthesis was verified by palpation. The stapedotomy area around the prosthesis was sealed with small pieces of soft tissue and fibrin glue. Finally, the tympanomeatal flap was replaced. The operating times in the medical records were also reviewed.

Table 1. Clinical data of the patients who underwent stapedotomy according to the laser delivery system used

	Free-beam-type	Fiber-type
No.	26 (12 males)	10 (4 males)
Mean age	36.3 (range 9−58) years	44.6 (range 19−58) years
Lesion side	Right 15, left 11	Right 4, left 6
Anesthesia	General 5, MAC 21	General 1, MAC 9

MAC: monitored anesthesia care

Audiometric evaluations

Patients' preoperative and 1-year postoperative audiograms were analyzed. When 1-year postoperative audiograms were not available, the 6-month postoperative audiograms were analyzed (n=5). The air-bone (AB) gap closure, bone conduction (BC) change, and operating time were evaluated. The AB gap closure was calculated by subtracting the preoperative BC thresholds from the postoperative air conduction thresholds. A lower AB gap closure resulted in a better hearing outcome. The BC change was calculated by subtracting the postoperative BC thresholds from the preoperative BC thresholds. A higher BC change resulted in a better hearing outcome. A separate analysis of the AB gap closure and BC change was performed for six frequencies (0.25, 0.5, 1, 2, 3, and 4 kHz). The mean AB gap closure at 0.5, 1, 2, and 3 kHz was used to calculate the mean AB gap closure. The mean BC change at 1, 2, and 4 kHz was used to calculate the mean BC change. A mean BC change of less than -10 dB was considered a significant sensorineural hearing loss [5,6].

Statistical analyses

All statistical analyses were performed using SPSS 12.0 for Windows (SPSS Inc., Chicago, IL, USA). The Mann-Whitney U-test was used to analyze the mean thresholds and individual frequency thresholds. The criterion for statistical

Table 2. CO_2 laser settings in stapedotomy with the two laser delivery systems

	Free-beam-type	Fiber-type
Anterior and posterior crura of stapes	5−6 W	5−6 W
Footplate of stapes	3−4 W	3−4 W
Laser operating mode	Superpulse	Superpulse
Tissue exposure mode	Single	Single
Duration	0.05−0.1 sec	0.05 sec
Spot size	0.3 mm	0.3 mm
Coagulation	2 W, defocusing	2 W, defocusing

W: watt

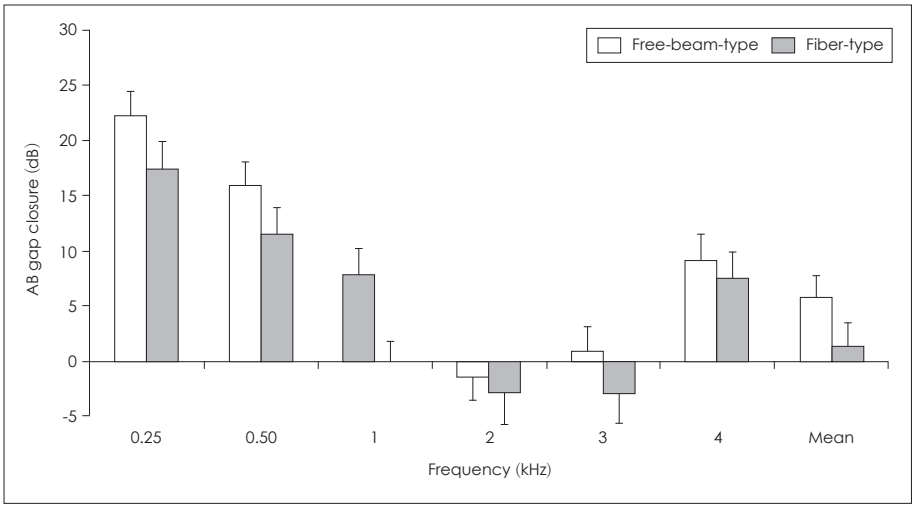

Fig. 1. AB gap closure with the two laser delivery system. The AB gap closure at 0.25, 0.5, 2, 3, and 4 kHz and the mean AB gap closure at 0.5, 1, 2, and 3 kHz did not differ significantly between the two groups. The error bar shows the standard error. AB: air-bone.

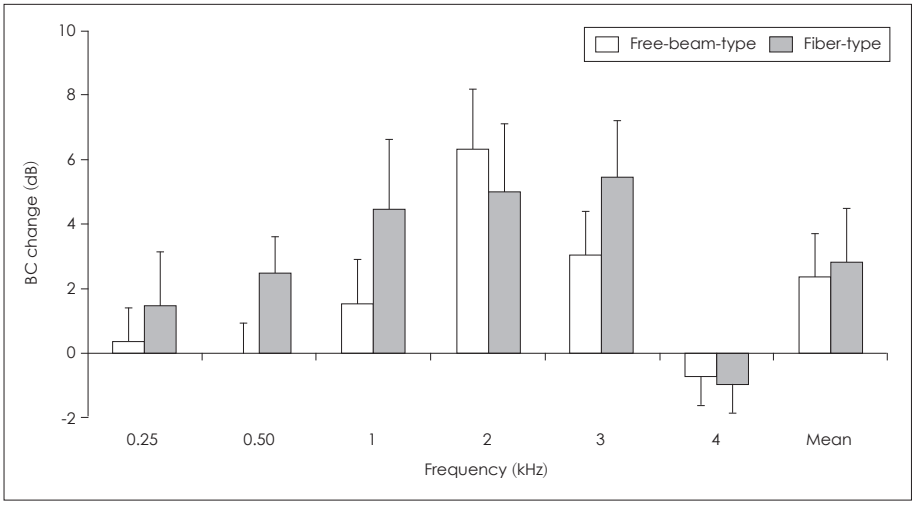

Fig. 2. BC change (preoperative–postoperative) using the two laser delivery systems. The BC changes for all frequencies (0.25, 0.5, 1, 2, 3, and 4 kHz) and the mean BC change at 1, 2, and 4 kHz did not differ significantly between the two groups. The error bar shows the standard error. BC: bone conduction.

significance was set at $p<0.05$.

Results

The mean operating time was significantly ($p=0.043$) shorter in the fiber-type group (72.5±8.2 min) than in the free-beam-type group (80.5±11.4 min). Fig. 1, 2 and Table 3 summarize and compare the postoperative hearing outcomes between the free-beam- and fiber-type groups. The mean AB gap closure of the 36 patients was 4.6±9.4 dB and was 5.8±10.1 and 1.4±6.8 dB in the free-beam and the fiber-type groups, respectively. The difference was not significant ($p=0.297$). The AB gap closure for all frequencies did not differ significantly between the two groups, except at 1 kHz (Fig. 1). The mean AB gap closure was within 20 dB in 24 of the 26 patients (92.3%) in the free-beam-type group and in all patients in the fiber-type group (Table 3).

The mean BC change of the 36 patients was 2.5±6.4 dB and was 2.4±6.9 and 2.8±5.3 dB in the free-beam- and fiber-type groups, respectively. The difference was not significant ($p=0.873$). The BC change for all frequencies (0.25, 0.5, 1, 2, 3, and 4 kHz) did not differ significantly between the two groups (Fig. 2). One patient had a significant sensorineural hearing loss after stapedotomy with a free-beam CO_2 laser.

Table 3. The mean AB gap closures after stapedotomy

Mean AB gap closure (dB)	Free-beam-type n (%)	Fiber-type n (%)
0–10	17 (65.4)	9 (90.0)
11–20	7 (26.9)	1 (10.0)
21–30	2 (7.7)	0 (0.0)
Total	26 (100.0)	10 (100.0)

The mean AB gap closures as the average of four frequencies (0.5, 1, 2, and 3 kHz) were determined by subtracting the preoperative bone conduction threshold from the postoperative air conduction threshold. AB: air-bone

Discussion

A free-beam-type CO_2 laser has several shortcomings because it is coupled to a micromanipulator mounted on a microscope. First, the operating range is restricted to the direct optical axis of the microscope [7]. Therefore, under certain anatomic conditions, such as a facial nerve overhang, a free-beam-type CO_2 laser cannot be used without manipulating the anatomical structure. Second, because a CO_2 laser beam is invisible, a free-beam-type CO_2 laser must be guided by a visible aiming beam. This delivery system involves the risk of an erroneous shot caused by misalignment between the CO_2 laser beam and the aiming beam [8]. Third, because a CO_2 laser is focused on the target indirectly by handling the micromanipulator, it cannot be focused as delicately as with a handpiece. There is a potential risk of incorrect focusing. These disadvantages might increase the difficulty of the surgical procedure. Conversely, a fiber-type CO_2 laser uses a handheld delivery system instead of a micromanipulator mounted on a microscope, avoiding the disadvantages of a free-beam-type CO_2 laser. It also shortens the operating time, as confirmed in this study. In this study, the operating time also did not include the time required for mounting the micromanipulator on the microscope, connecting tubes, testing the laser, and draping the micromanipulator-coupled microscope. Therefore, stapes surgery aided by a free-beam-type CO_2 laser definitely takes longer than that using a fiber-type CO_2 laser. A previous report did not consider the operating time when comparing the two types of CO_2 laser [9]. We believe that the operating time is a useful parameter that reflects the difficulty of the surgical procedure. Our results confirmed that the fiber-type CO_2 laser decreased the difficulty of the surgical procedure compared with the free-beam-type CO_2 laser. In particular, we expect that residents learning stapes surgery will have less difficulty with the surgical procedure and avoid inner ear damage by using fiber-type CO_2 lasers.

One study that compared the hearing outcomes of free-beam- and fiber-type CO_2 lasers also reported that there was no significant difference in the postoperative AB gap and BC change between the two delivery systems [9]. However, the follow-up period in that study was just 1 month, which was too short to accurately evaluate the hearing outcome. In comparison, we used 12-month postoperative audiograms to evaluate the hearing outcomes in 31 of 36 patients and 6-month postoperative audiograms in only five. Consequently, we achieved accurate comparison of the hearing outcomes between the two groups. The fiber-type CO_2 laser did not show statistically significant superiority than the free-beam-type CO_2 laser in the AB gap closure except 1 kHz though the mean AB gap closure of the fiber-type group was better than that of the free-beam-type group in every frequency. Considering convenient handling, ease of finer control and shorter operation time with the fiber-type device, the statistical insignificance in the rest of the frequencies might be attributed to the small number of subjects in the fiber-type group. Further study would be needed to overcome this limitation.

A study involving a series of operations performed by one surgeon usually has the limitation of a learning curve because the surgeon's ability improves as more cases are performed. To minimize the learning curve effect in this study, we enrolled only cases performed after the surgeon had 10 years of experience with stapes surgery.

In conclusion, we compared the operating times and hearing outcomes of free-beam- and fiber-type CO_2 lasers. The operating time was significantly shorter with the fiber-type CO_2 laser, while the hearing outcomes did not differ significantly between the two groups.

Conflicts of interest

The authors have no financial conflicts of interest.

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