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Clinical Results After Stapedotomy: A Comparison Between the Erbium: Yttrium-Aluminum-Garnet Laser and the Conventional Technique

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Objective: The objective of this study was to assess whether the use of the erbium: yttrium-aluminum-garnet (Er:YAG) laser has negative effects on inner ear function and to compare the short- and long-term hearing outcome of patients undergoing conventional stapedotomy versus laser stapedotomy.
Study Design: Retrospective review of prospectively collected audiometric data of patients with otosclerosis operated on by one experienced surgeon.
Setting: Academic tertiary referral center.
Patients: A total of 266 stapes surgeries were evaluated for intraoperative findings, of which 209 patients were evaluated for preoperative and postoperative hearing thresholds after a 6- to 452-week (mean, 22 wk) audiological follow-up.
Intervention: One hundred fifteen (43%) of the operations were performed conventionally, using manual perforators for stapedotomy (Group A); in 115 (43%) surgeries, the perforators were used in combination with the Er:YAG laser (Group B), and in 36 (14%) operations, the Er:YAG was used exclusively for footplate perforation (Group C).
Main Outcome Measures: Pure-tone audiometry was performed before surgery, 2 days postoperatively (bone conduction only) and at 5, 26, and 57 weeks postoperatively.
Results: A postoperative temporary threshold shift of the bone conduction could be found in all groups. In Group C, where the laser was used exclusively for footplate perforation, this threshold shift was not only the most significant, but also—in contrast to the other groups—not totally reversible. In all techniques, a satisfactory air-bone gap closure could be achieved. The best long-term results (96% of the patients had ≤20 dB air-bone gap after 57 wk) could be found in Group B.
Conclusion: If certain rules to minimize inner ear trauma are followed, the Er:YAG laser is a safe tool in middle ear surgery. Combining both the laser and the conventional technique, instead of the separate use of either technique, leads to superior postoperative hearing results. **Key Words:** Er:YAG laser—Long hearing results—Otosclerosis—Stapes surgery.
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During the last 25 years, different laser systems have proven to be interesting alternatives to conventional mechanical drilling methods, in an attempt to reduce the trauma to the middle and inner ear in stapes surgery. Main advantages of the laser include the high precision of its application, the high ablation efficiency, and the low risk of footplate mobilization due to the noncontact principle of these systems. After the first experimental studies had been performed with a Neodym system in 1967 (1), the argon laser became the first system to be clinically used for stapedotomy in 1980 (2,3). Since then, all different types of laser systems were evaluated for their suitability for stapes footplate perforation (4–8, 13–15,21).

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Whereas the KTP (potassium-titanyl-phosphate) and argon laser bear the risk of inner ear damage due to their light transmission through fluids, for example, perilymph, other lasers—such as the pulsed carbon dioxide laser or the excimer laser—were assumed to be unsuitable for stapedotomy because of their heat generation at parameters effective for footplate perforation (5). Another pulsed laser, the erbium:yttrium-aluminum-garnet (Er: YAG) laser, has the advantage of its high absorption in bone, the absence of heat generation in surrounding structures, and the very limited border damage zone (6). Nevertheless, the explosive ablation of tissue creates pressure waves which were considered as too traumatic to the inner ear, restricting the use of the Er:YAG laser in middle ear surgery (7,8). Another disadvantage is the absence of hemostasis, the bulkiness of the system, and the impossibility to reach structures outside the direct visual field (e.g., anterior crus) when integrated in the microscope, as it is the case in most of the systems in use. In recent times, a fiberoptic microhandpiece, which has formerly only been available for argon lasers, was invented for its use with the Er:YAG laser (7).

The aim of this study was to retrospectively analyze the intraoperative findings, as well as postoperative results, of stapes surgery performed by one surgeon in patients with otosclerosis. Results were analyzed comparing three different surgical techniques: conventional method of drilling the footplate with mechanical perforators, using an Er:YAG laser (Zeiss, TwinER, Oberkochen, Germany), and combining these two methods.

MATERIALS AND METHODS

All stapes surgeries consecutively performed between 1993 and 2003 by the senior author (T. L.) at the Medical University of Hannover were retrospectively analyzed. The records were reviewed with regard to the indication of operation, preoperative pure-tone audiograms, intraoperative (e.g., status of ossicles, course of facial nerve, and occurrence of gusher) and postoperative (tinnitus and vertigo) particularities, and postoperative hearing results.

In total, 266 stapes surgeries were performed because of otosclerosis; 115 of these were performed conventionally (stapedotomy performed mechanically, Group A, 43%), 115 were performed using the Er:YAG laser and perforators (Group B, 43%), and in 36 surgeries, solely the laser was used for footplate perforation (Group C, 14%).

Audiological results were analyzed and reported according to the guidelines of the Committee on Hearing and Equilibrium (9). Hearing tests were performed in soundproof chambers using standard audiometer equipment for air conduction and bone conduction.

As usual, not every patient was available for each of the hearing tests: audiograms of at least 87 patients in Group A, 87 patients in Group B, and 35 patients in Group C, with an audiometric follow-up of at least 6 weeks at the end of the trial in October 2004 were evaluated. Preoperative audiograms were performed on average 3 days before surgery (range, 50–0 d). To evaluate the risk of inner ear damage in the different forms of stapedotomy techniques, preoperative bone conduction thresholds were compared with early postoperative thresholds, measured after an average of 2 days (range, 1–4 d) postoperatively. Consequently, pure-tone air and bone conduction thresholds were measured after an average of 5, 26, and 57 weeks postoperatively.

The data were tabulated using Microsoft Excel 2002 (Microsoft Corp., Redmond, WA) and statistically analyzed using paired *t* tests (Tables 1 and 2). *P* values ≤ 0.05 were considered significant.

Surgical Technique

To allow the surgeon an "on the table" control of the success of the surgery, the majority of the operations are performed under local anesthesia (2% lidocaine with 1:100,000

TABLE 1. *Statistical Analysis (Paired t Test) of Bone Conduction for Frequencies 1, 2, and 4 kHz: 2 days (Postop. 1), 5 weeks (Postop. 2), and 26 weeks (Postop. 3) after Surgery*

		Group A	Group A	Group A	Group B	Group B	Group B	Group C	Group C	Group C
		BC 1	BC 2	BC 4	BC 1	BC 2	BC 4	BC 1	BC 2	BC 4
Preop.	Mean	23.17	32.25	30.00	25.14	36.67	29.42	14.29	30.29	26.18
	n	52	51	50	72	72	69	35	35	34
	SD	16.09	17.9	21.88	15.56	18.88	22.89	11.12	16.54	19.50
	SEM	2.23	2.51	3.09	1.83	2.22	2.76	1.88	2.8	3.34
Postop. 1	Mean	24.71	39.12	33.9	27.57	41.88	34.49	22.14	41.00	36.03
	P	0.244	**<0.001**[a]	0.007	0.054	**<0.001**[a]	**<0.001**[a]	0.001	**<0.001**[a]	0.001
	SD	16.37	17.94	21.1	15.56	20.13	21.76	13.89	17.27	20.74
	SEM	2.27	2.51	2.98	1.83	2.37	2.62	2.35	2.92	3.56
Preop.	Mean	19.41	28.63	27.97	24.08	35.08	27.34	14.41	30.74	26.67
	n	76	73	74	65	64	62	34	34	33
	SD	14.21	15.01	20.29	15.36	17.81	21.61	11.27	16.57	19.59
	SEM	1.63	1.76	2.36	1.9	2.23	2.74	1.93	2.84	3.41
Postop. 2	Mean	19.80	31.1	32.3	25.77	35.55	33.31	21.62	35.29	34.09
	P	0.717	0.136	**<0.001**	0.245	0.723	**<0.001**[a]	0.004	0.075	**0.008**
	SD	16.48	17.82	19.92	17.39	18.54	20.58	14.55	17.14	21.23
	SEM	1.89	2.09	2.32	2.16	2.32	2.61	2.50	2.94	3.70
Preop.	Mean	19.65	27.91	26.67	25.49	37.35	27.92	14.25	31.75	29.21
	n	57	55	54	51	51	48	20	20	19
	SD	15.55	15.11	20.9	16.07	19.81	22.02	12.06	18.52	21.56
	SEM	2.06	2.04	2.84	2.25	2.77	3.18	2.70	4.14	4.95
Postop. 3	Mean	17.89	27.55	28.15	22.94	32.65	32.4	17.25	29.75	31.58
	P	0.244	0.833	0.212	0.105	**<0.001**	0.030	0.124	0.483	0.420
	SD	17.37	17.21	21.24	17.01	19.63	22.36	8.96	16.34	20.48
	SEM	2.3	2.32	2.89	2.38	2.75	3.23	2.00	3.65	4.70

ABG, air-bone gap; BC, bone conduction; preop., preoperatively; postop., postoperatively.

Note that, in contrast to the descriptive audiograms given in *Figures 1*, *2*, and *3*, the statistical analysis is limited to the number of (paired) cases, which were both tested preoperatively and at the moment of the particular follow-up, hence the decreased number of cases. *P* values are ≤ 0.05 considered significant, printed in bold letters.

[a]Highly significant values.

TABLE 2. *Statistical Analysis (Paired t Test) of ABG for Frequencies 0.5, 1, 2, and 3 kHz: 5 weeks (Postop. 2), 26 weeks (Postop. 3), and 57 weeks after Surgery (Postop. 4)*

Group		A ABG 0.5	A ABG 1	A ABG 2	A ABG 3	B ABG 0.5	B ABG 1	B ABG 2	B ABG 3	C ABG 0.5	C ABG 1	C ABG 2	C ABG 1
Preop.	Mean	33.04	27.28	14.64	17.45	33.37	30.00	18.04	19.44	34.48	32.41	16.38	18.10
	n	56	57	55	55	46	46	46	45	29	29	29	29
	SD	14.48	10.98	11.34	12.39	13.62	13.94	12.63	11.14	9.85	11.62	10.60	11.45
	SEM	1.94	1.45	1.53	1.67	2.01	2.06	1.86	1.66	1.83	2.16	1.97	2.13
Postop. 2	Mean	17.05	16.32	10.18	12.09	12.39	13.80	8.70	9.89	20.00	16.72	11.72	15.28
	P	**<0.001**[a]	**<0.001**[a]	0.011	0.008	**<0.001**[a]	**<0.001**[a]	**<0.001**[a]	**<0.001**[a]	**<0.001**[a]	**<0.001**[a]	0.055	0.300
	SD	8.62	11.00	8.22	10.12	9.53	9.38	10.24	9.80	11.80	11.04	7.47	10.66
	SEM	1.15	1.46	1.11	1.37	1.41	1.38	1.51	1.46	2.19	2.05	1.39	1.98
Preop.	Mean	33.95	28.60	17.63	17.55	34.40	29.70	16.60	18.65	32.50	32.00	15.75	16.75
	n	57	57	55	55	50	50	50	48	20	20	20	20
	SD	16.00	13.45	16.50	12.54	13.23	14.01	10.81	9.66	8.19	8.80	11.04	11.04
	SEM	2.12	1.78	2.22	1.69	1.87	1.98	1.53	1.39	1.83	1.97	2.47	2.47
Postop. 3	Mean	19.30	16.05	9.82	9.73	18.30	14.70	7.10	9.48	18.00	15.75	9.75	9.75
	P	**<0.001**[a]	**<0.001**[a]	0.002	**<0.001**[a]	**<0.001**[a]	**<0.001**[a]	**<0.001**[a]	**<0.001**[a]	**<0.001**[a]	**<0.001**[a]	0.033	0.035
	SD	11.74	10.85	7.70	8.63	12.68	10.12	8.09	7.73	8.19	9.07	7.86	7.86
	SEM	1.56	1.44	1.04	1.16	1.79	1.43	1.14	1.12	1.83	2.03	1.76	1.76
Preop.	Mean	37.25	29.63	16.62	18.38	33.20	28.60	15.60	18.80	35.45	34.55	17.73	17.00
	n	40	40	37	37	25	25	25	25	11	11	11	10
	SD	16.09	14.34	14.63	14.10	13.38	14.33	11.49	10.54	8.50	9.61	10.81	9.49
	SEM	2.54	2.27	2.40	2.32	2.68	2.87	2.30	2.11	2.56	2.90	3.26	3.00
Postop. 4	Mean	17.63	15.25	7.30	9.86	13.80	10.80	5.80	7.40	11.82	15.00	8.18	9.00
	P	**<0.001**[a]	**<0.001**[a]	**<0.001**[a]	0.002	**<0.001**[a]	**<0.001**[a]	0.001	0.002	0.001	0.001	0.020	0.053
	SD	10.74	10.25	7.96	7.12	8.81	6.72	5.72	10.72	12.30	9.75	6.43	4.59
	SEM	1.70	1.62	1.31	1.17	1.76	1.34	1.14	2.14	3.71	2.94	1.94	1.45

ABG, air-bone gap; BC, bone conduction; preop., preoperatively; postop., postoperatively.

Note that, in contrast to the descriptive audiograms given in *Figures 1*, *2*, and *3*, the statistical analysis is limited to the number of (paired) cases, which were both tested preoperatively and at the moment of the particular follow-up, hence the decreased number of cases.

P values ≤ 0.05 are considered significant, printed in bold letters.

[a]Highly significant values.

epinephrine). To reduce bleeding, this kind of infiltration anesthesia is also applied if a general anesthesia is used. After an enaural incision and creation of a tympanomeatal flap in the classical manner, the landmarks of the middle ear are exposed, and the ossicular chain is tested for mobility. The distance between the incus and the footplate is measured, and the posterior crus of the stapes is dissected with the Er:YAG laser (if in use). The anterior crus can either be cut with the laser or be mechanically incised. The footplate is then perforated in the posterior third: either mechanically with perforators of increasing sizes (Group A), solely with the laser beam (Group C), or with both methods combined—the perforation is originally set by the laser, and the perforators are then used to enlarge the stapedotomy (Group B). A Fisch prosthesis (Teflon-platinum) is cut to the necessary size, inserted into the stapes footplate perforation in the usual manner, and crimped around the long process of the incus. The oval niche is sealed with fibrous tissue or, in case of flow of perilymph, with fresh venous blood. After the redressing of the tympanomeatal flap, the ear canal is plugged with a Vaseline strip for 5 days.

The Er:YAG Laser System

In our department, the Er:YAG laser has been in use for middle ear surgery since 1996. Since 1999, nearly all stapes surgeries have been performed with this laser. The system used is the commercially available micromanipulator-operated Zeiss system (TwinER), which is fully integrated into the microscope body. The laser beam has a wavelength of 2,940 nm (infrared scale) and is applied in distinct pulses in the 0-0 mode. The energy per pulse is usually set at 15 mJ with a pulse duration of 100 milliseconds. The main mechanism of tissue alteration is vaporization. Due to the fact that the laser light is nearly completely absorbed by bone, the effect on the surrounding field is a mechanical pulse with hardly any elevation of temperature (14). This mechanical energy is partly transformed into acoustic energy and is experienced by the patient as a shotlike event.

RESULTS

Demographics

The average age of the patients at operation was 49 years (range, 12–76 yr) for laser surgery (Groups B and C) and 43 years (range, 6–77 yr) for conventional stapedotomy (Group A). Fifty-eight percent (n = 154) of the patients were female, and 42% (n = 112) were male. The mean duration of the operation was 64 minutes (range, 30–145 min) for the laser stapedotomies and 53 minutes (range, 20–170 min) for the conventionally performed stapedotomies. Predominantly, the surgeries were performed under local anesthesia (78%); in 21% of the cases, general anesthesia was used, and in one patient (0.38%), local anesthesia had to be transformed into a general one because the patient did not tolerate the procedure. Sixty-eight percent of the patients underwent stapes surgeries for the first time; 32% of the cases were revision surgeries, with an almost equal distribution between the three groups (Group A: 66% first and 34% revision; Group B: 70% first and 30% revision; and

Group C: 67% first and 33% revision). In 53% (n = 140), the right ear and in 47% (n = 126) the left ear were chosen for operation.

Intraoperative Findings

Incomplete bony covering of the fallopian canal was found in 2.63% (n = 7) of cases. Eleven patients (4.14%) showed major or minor aberrant courses of the facial nerve. A floating footplate occurred in 1.99% (n = 3) of the laser surgeries and in 2.61% (n = 3) of the conventionally performed surgeries. In three cases of the laser group (1.99%), parts of the footplate were accidentally removed when removing the stapes suprastructure, compared with 8.7% (n = 10) of the patients operated on with the conventional technique. A cerebrospinal fluid fistula was encountered in 7.95% (n = 12) of all laser and in 1.74% (n = 2) of all conventional surgeries. In two patients (1.32%), the originally intended use of the erbium laser could not be performed due to either restrictive anatomic surroundings or profuse bleeding. In the laser group, 3.97% (n = 6) of the patients complained about intraoperative or immediate postoperative vertigo; in the conventionally operated group, 5.22% (n = 6) of the patients were found to have this problem. In 14 of all operations (5.26%), cortisone was administered intraoperatively. One patient in Group A (0.87%) and one patient in Group B (0.87%) complained about increased tinnitus postoperatively; the latter of them underwent revision surgery. Tympanic membrane perforations occurred in 3.38% (n = 9) of the surgeries. If so, these perforations were repaired in the same procedure. Malformed ossicles were encountered in 3% (n = 8) of all patients undergoing surgery. Rarefied or necrotic ossicles were found in 22 (8.27%) of all patients (Group A: n = 9, 7.83%; Group B: n = 8, 6.96%; and Group C: n = 5, 14.29%). In 9.56% (n = 11) of the operations in Group A, in 4.35% (n = 5) of the cases in Group B, and in 17.14% (n = 6) of the operations in Group C, glass ionomer cement was used to improve the fixation of the prosthesis on the long process of the incus. This unequal distribution between the three groups corresponds to the different incidence of necrosis or rarefaction of the long process of the incus in the three groups, despite the equal distribution in first or revision surgery. No patients in this series experienced complete sensorineural hearing loss or facial nerve injury.

Audiological Results

Bone Conduction

Figures 1 and 2 show the bone conduction thresholds over time for each of the three groups. In all groups, a temporary and statistically significant lowering of the hearing thresholds could be found. Whereas in Groups A and B, these threshold shifts were totally reversible, this observation does not hold true for Group C, where no complete recovery to preoperative values could be found (Fig. 2, B). In addition, hearing deteriorations were most significant in this group (Fig. 2; Table 1).

In the early postoperative audiogram (mean, 2 d postoperatively), we analyzed average bone-conduction thresholds at 1, 2, and 4 kHz, and we found unchanged or improved inner ear function in 77% of the conventionally (A), in 77% of the laser-assisted operated (B), but in only 53% of the "laser only"–operated (C) patients. Interestingly, after an average period of 26 weeks, 91% of the conventionally (A), 93% of the laser-assisted operated (B), and also 89% of the "laser only" (C) patients showed unchanged or improved bone conduction thresholds compared with preoperative values, indicating a disturbed inner ear function of solely temporary nature.

The statistical analysis of the hearing threshold changes is shown in Tables 1 and 2 (graphical depiction of results was limited to the most important frequencies for bone and air conduction, according to the Committee on Hearing and Equilibrium guidelines (9)). In keeping with the rules of statistics, the number of patients analyzed is limited to the number of (paired) cases, which were both tested preoperatively and at the moment of the particular follow-up. For bone conduction, the most significant changes (deteriorated thresholds) in comparison to preoperative thresholds were found in Group C.

Air Conduction

For all groups and in all frequencies, a continuous improvement of the middle ear function could be observed (Fig. 3; Table 2). The most significant improvement could be found in Group B, whereas in Group C, the least significant changes in middle ear function were observed. Preoperatively, 57% of the conventionally operated patients, 74% of the laser-assisted, and 69% of the "laser only" patients were found to have an air-bone gap (ABG) of 21 dB or more (mean values at 0, 5, 1, 2, and 3 kHz). After an average period of 57 weeks postoperatively, 51% of the conventionally, 64% of the laser-assisted operated, and 60% of the "laser only" patients were found to have an ABG closure of ≤10 dB. Again, this analysis proves distinct advantages in performance for Group B compared with the other groups. Eighty-six percent of the patients in Group A, 96% of the patients in Group B, and 80% of the patients in Group C achieved an ABG closure of ≤20 dB after the same period.

As far as statistical significance for ABG closure is concerned, significant changes could be found in more frequencies in Groups A and B than in Group C. In the descriptive audiograms averaged for all patients, a distinct superiority of hearing results in Group B can be identified (Fig. 3).

DISCUSSION

In stapes surgery, laser systems have proven to be an important tool to minimize the trauma to the inner ear, to avoid a floating footplate, and to create a precise perforation, even in cases with a mobile stapes. In stapes revision surgery, particularly with rarefaction of the long process of the incus or necrosis, the laser provides

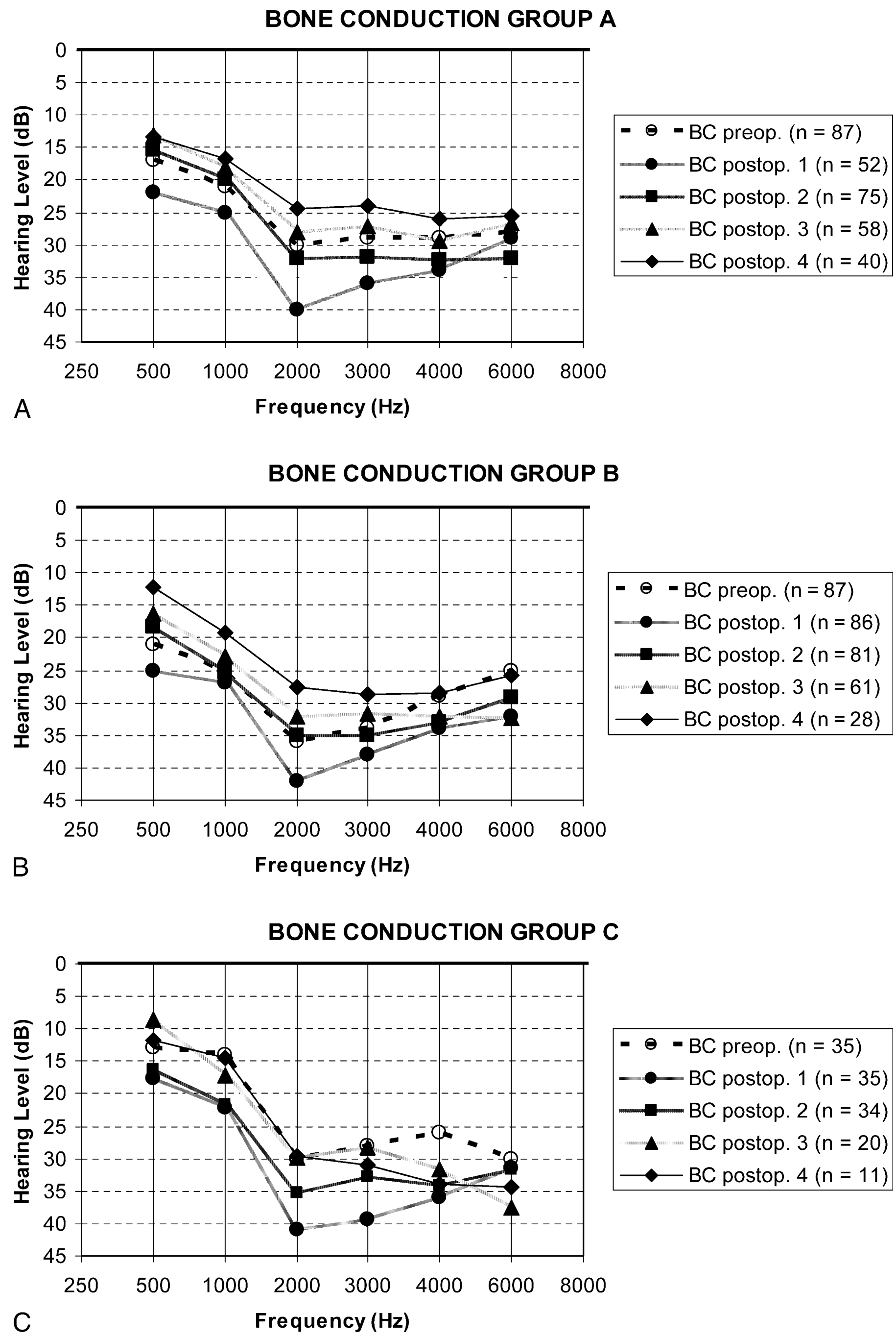

FIG. 1. *A–C*, Bone conduction thresholds for all of the three groups: preoperatively, 2 days (postop. 1), 5 weeks (postop. 2), 26 weeks (postop. 3), and 57 weeks after surgery (postop. 4).

the surgeon with new possibilities for fixation of the prosthesis, for example, by creating a groove to hook in the wire of the prosthesis (10,11). In this article, a comparison of different surgical techniques for the stapedotomy using the Er:YAG laser to a different extent is reported for the first time. The article also focuses on long-term hearing results. All surgeries have been performed by the same experienced otosurgeon (T. L.), who had already performed several hundred stapedotomies at the start of this retrospective study in 1993. Therefore, effects of the learning curve can be largely neglected. In terms of intraoperative complications, the nontactile mode of operation of the Erbium laser bears certain undeniable advantages as far as footplate mobilization and the accidental removal of parts of the footplate are concerned. In our series, a floating footplate occurred with almost the same frequency in both groups (laser, 1.99%; conventional, 2.61%), whereas the unintended

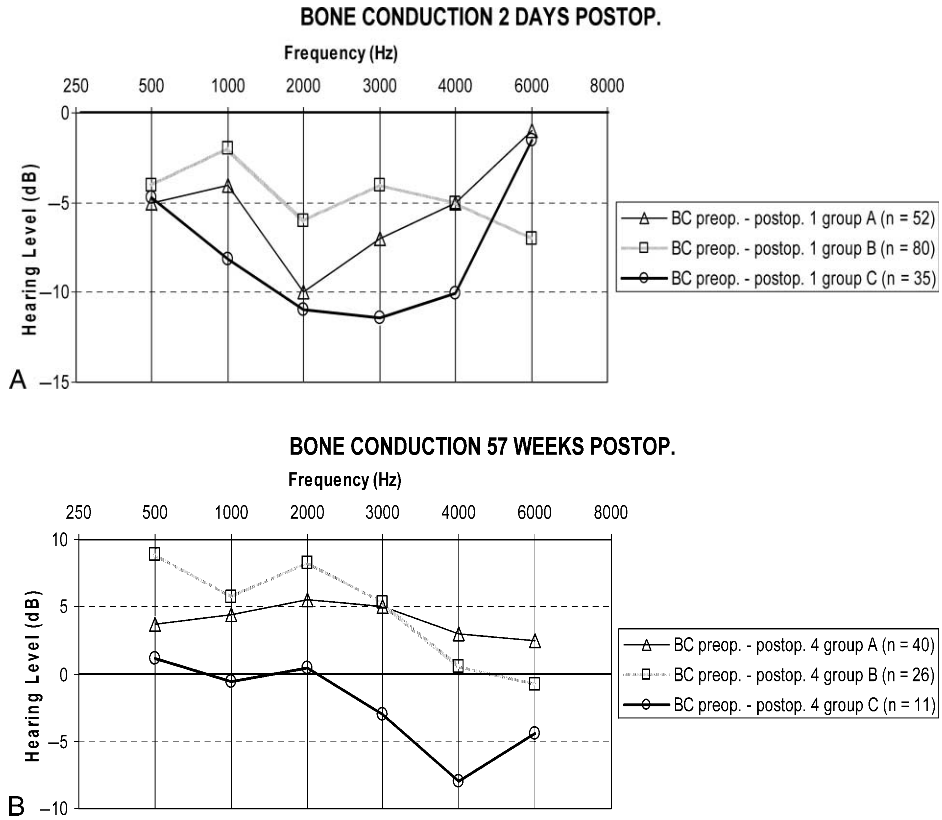

FIG. 2. *A* and *B*, Preoperative minus postoperative bone conduction thresholds over time for the three groups. In this manner, negative numbers yield deteriorated bone conduction thresholds and positive numbers improved thresholds. Note the temporary lowering of the hearing thresholds in all of the three groups (*A*). This threshold shift is most significant in Group C. Also, in this group—in contrast to Groups A and B—there is no complete recovery of the threshold shifts over time (*B*).

stapedectomy occurred in only 1.99% of the laser operations, in contrast to the 8.7% of the conventional surgeries. Interestingly, the incidence of cerebrospinal fluid fistula was markedly higher in the laser (7.95%) than in the conventional group (1.74%). Analyzing the postoperative short- and long-term hearing results, we found no difference in performance in the group of patients who showed this complication compared with the other patients. As to the question of tinnitus after stapes surgery, Gersdorff et al. (12) found that, in 64% of the patients undergoing stapes surgery, the tinnitus disappeared, whereas in 6% of the patients, there was a worsening of the tinnitus. In our pool of patients two patients (0.75%, one patient in Groups A and B) noticed a marked deterioration of their tinnitus, which demanded revision surgery in one patient. Therefore, no higher incidence of

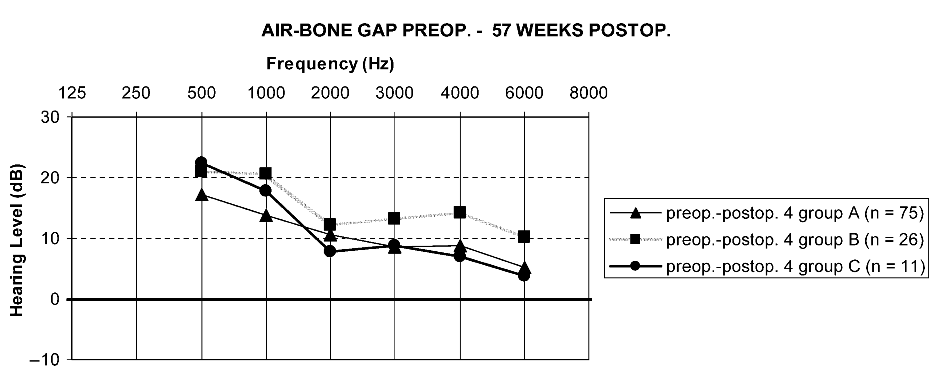

FIG. 3. The ABG was closed in all frequencies and in all groups 57 weeks postoperatively (postop. 4). The differences between the preoperative and the postoperative values are shown: the higher the figure, the better the ABG closure. Note that the most significant hearing gain can be found in Group B.

surgically induced tinnitus was found with the use of the Er:YAG laser. This contrasts the findings of other authors (7,19,21).

Disadvantages of the system are related to the missing hemostasis, which can render manipulations difficult in cases with inflamed mucosa, large amounts of connective tissue to be removed, or blood vessels crossing the footplate, as observed in one of our patients. Also, the fact that the infrared light of the Er:YAG laser cannot be transmitted through commercially available flexible light transmission systems limits its applicability for regions that lie outside the direct visual field. Some surgeons (7) use zirconium fluoride fibers for a more convenient handling of the laser, despite concerns about toxicity and the high price of such devices (14). The lack of tactile information when using a laser in stapes surgery was considered disadvantageous by Häusler et al. (7). Also, the additional expense of purchasing a laser system should be taken into consideration.

To date, numerous in vitro and in vivo studies have analyzed the suitability of the pulsed Er:YAG laser in middle ear surgery. In 1994, Frenz et al. (13) showed that there is no risk of inner ear damage by direct laser light transmission through the perilymph, and Pfalz (14) found the generated pressure wave to be below a critical limit. In experimental studies on cochleas from guinea pigs, Arnold et al. (15) found a laser-induced increase of neural activity of inner hair cell afferents. This observation was purely transient, suggesting the reversibility of the changes generated by the laser.

Nevertheless, some authors (7,8) have discouraged the use of the erbium laser because of postoperative bone conduction threshold shifts: Häusler et al. (7) found a postoperative sensorineural impairment of up to 75 dB in three patients operated on with an Er:YAG laser. Although these shifts were reported to be only transient, with hearing levels recovering to preoperative levels within the first 6 hours postoperatively, regardless of the small number of patients examined, the authors discontinued the clinical use of the Er:YAG laser for stapedotomy. Indeed, our data show that the postoperative bone conduction shift measured within the first 4 days postoperatively is more frequent and more significant (Figs. 1 and 2; Table 1) in patients operated on with the laser, than with conventional surgical technique. A crucial element of these figures is that the inner ear function recovers within several weeks after the intervention. Interestingly, the most frequent (47% of patients) and severe deterioration of bone conduction was found in patients with exclusive use of Er:YAG laser for footplate perforation. This fact underlines the results of Pratisto et al. (6), who found particularly dangerous pressure waves when the footplate is already perforated while the laser is aimed directly on the perilymph. In addition, we find confirmation of the common technique in our department to use both the laser and the manual perforators for footplate perforation to minimize the trauma to the inner ear. The laser can be used to thin out the footplate until only a last shell of bone remains, which can be easily perforated with the microperforators without the risk of inner ear damage or footplate mobilization. In addition, the power of each pulse should be restricted to 15 mJ, which is sufficient for bone ablation but avoids the formation of damaging high-pressure waves in the cochlea to our experience. The fact that the most significant bone conduction shifts occurred when the laser was used to thin out the footplate and to subsequently perform the perforation leads us to the conclusion that not only the energy per pulse but also the total energy load applied to the inner ear are crucial to avoid its damage. We therefore recommend to limit both energy per pulse and total energy administered and to strictly avoid a direct laser application into the opened vestibule.

The advantages of stapedotomy over stapedectomy have been demonstrated in a number of series (16–18) and are beyond question in the current understanding of state-of-the-art stapes surgery. Nevertheless, figures of hearing gain after stapedotomy reported in literature show a broad distribution. Keck et al. (19) found an ABG closure of less than 10 dB in 42% of 53 patients operated on with an erbium laser; Shabana et al. (20) reported this result in 63% of their patients operated on conventionally and in 77% of the patients operated on with a CO_2 laser, whereas Häusler et al. (21) found 98% of 54 patients operated on with an argon laser meeting these criteria. In our series, 51% of the conventionally, 64% of the laser-assisted operated patients, and 60% of the "laser only" patients were found to have an ABG closure of less than 10 dB after an average of 57 weeks postoperatively. For a better understanding of these figures, it has to be stated that we deliberately refrained from dividing the groups into first or revision surgery because, in this way, an artificial pool of patients would be represented with distorted results. In addition, the main purpose of this article was rather to compare the results between patients operated on with or without the Er:YAG laser and not to compare the results between first and revision surgeries. On the whole, the group in which the use of the laser was combined with the use of conventional instruments seems to slightly outperform the conventionally operated group in regard to ABG closure.

CONCLUSION

In summary, we conclude that, in the hands of an experienced surgeon, both the conventional and the Er:YAG-laser assisted technique yield lasting and satisfactory results. Coherent with other studies (13–15,19,22), our data show that the Er:YAG laser is a safe and promising instrument for otologic surgery. In fact, a postoperative transient lowering of the bone conduction thresholds could be found in each of the three groups. In the group where the laser was used exclusively for foot plate perforation, the threshold shifts were not only most significant, but also not totally reversible, restricting the further use of this particular technique. In addition, this group was found to have the smallest postoperative hearing gain in comparison with the other two groups. Taking into consideration the reversibility of the bone conduction threshold shift and the excellent hearing results after laser-assisted stapedotomy, we will continue the combined use of the Er:YAG laser and the manual perforators also in our future patients because of the advantages of the laser for footplate surgery.

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REFERENCES

1. Sataloff J. Experimental use of laser in otosclerotic stapes. *Arch Otolaryngol* June 1967;85:614–6.
2. Perkins RC. Laser stapedotomy for otosclerosis. *Laryngoscope* February 1980;90:228–40.
3. DiBartolomeo JR, Ellis M. The argon laser in otology. *Laryngoscope* 1980;90:1786–96.
4. Gülzow J, Lenarz T, Honerloh HJ. Experimental stapesplasty with the CO_2 laser. *Laryngol Rhinol Otol* 1986;65:208–12.
5. Jovanovic S, Schonfeld U, Fischer R, et al. Thermische Belastung des Innenohres bei der Laserstapedotomie. Teil II: Gepulste Laser. *HNO* 1996;44:6–13.
6. Pratisto H, Frenz M, Ith M, et al. Temperature and pressure effects during erbium laser stapedotomy. *Lasers Surg Med* 1996;18:100–8.
7. Häusler R, Schar PJ, Pratisto H, et al. Advantages and dangers of erbium laser application in stapedotomy. *Acta Otolaryngol* 1999; 119:207–13.
8. Jovanovic S, Schönfeld U, Scherer H. CO_2 laser stapedotomy with the “one-shot” technique—clinical results. *Otolaryngol Head Neck Surg* 2004;131:750–7.
9. American Academy of Otolaryngology–Head and Neck Surgery, Committee on Hearing and Equilibrium guidelines for the evaluation of results of treatment of conductive hearing loss. *Otolaryngol Head Neck Surg* 1995;113:186–7.
10. Lenarz T, Heermann R, Kempf HG. Erbium YAG laser in middle ear surgery. In: Hüttenbrink KB, ed. *Middle Ear Mechanics in Research and Otosurgery*. Baalsdorf: UniMedia GmbH, 1997:233–9.
11. Lesinski SG, Stein JA. Stapedectomy revision with the CO_2 laser. *Laryngoscope* 1989;99:S13–9.
12. Gersdorff M, Nouwen J, Gilain C, et al. Tinnitus and otosclerosis. *Eur Arch Otorhinolaryngol* 2000;257:314–6.
13. Frenz M, Romano V, Pratisto H, et al. Stapedotomie: Neue Experimentelle Resultate mit dem Erbium-Laser, Aktuelle Probleme der Otorhinolaryngologie, ORL 17. Edts. Sopko J, Gammert C, Guyot JP, Monnier P, Rohner Y, Wespi HH. Hans Huber, Bern. 1994;337–45.
14. Pfalz R. Eignung verschiedener Laser für Eingriffe vom Trommelfell bis zur Fußplatte (Er:YAG, argon, CO_2 s.p.-, Ho:YAG laser). *Laryngorhinootologie* January 1995;74:21–5.
15. Arnold A, Ehrenberger K, Frenz M, et al. Experimental erbium laser surgery in the guinea pig cochlea: its use in the study of afferent cochlear neurotransmitters. *Eur Arch Otorhinolaryngol* 1996;253:460–3.
16. Smyth GD, Hassard TH. Eighteen years experience in stapedectomy. The case for the small fenestra operation. *Ann Otol Rhinol Laryngol* 1978;87:S3–36.
17. Fisch U. Stapedotomy versus stapedectomy. *Am J Otol* 1982;4: 112–7.
18. Cremers CW, Beusen JM, Huygen PL. Hearing gain after stapedotomy, partial platinectomy, or total stapedectomy for otosclerosis. *Ann Otol Rhinol Laryngol* 1991;100:959–61.
19. Keck T, Wiebe M, Riechelmann H, et al. Ergebnisse nach Stapedotomie mit dem Erbium:YAG-laser. *Laryngorhinootologie* 2003;82:157–61.
20. Shabana YK, Allam H, Pedersen CB. Laser stapedotomy. *J Laryngol Otol* 1999;113:413–6.
21. Häusler R, Messerli A, Romano V, et al. Experimental and clinical results of fiberoptic argon laser stapedotomy. *Eur Arch Otorhinolaryngol* 1996;253:193–200.
22. Huber A, Linder T, Fisch U. Is the Er:YAG laser damaging to inner ear function? *Otol Neurotol* 2001;23:311–5.