# Early and Late Hearing Outcomes after $CO_2$ Laser Stapedotomy

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***Background:*** *Carbon dioxide ($CO_2$) laser stapedotomy is now one of the standard surgical treatments for otosclerosis. However, there are little normative data of the course of postoperative hearing acuity and the course of postsurgical depression of cochlear function of this technique.*

***Objective:*** *To compare the hearing outcomes between early(between 1 to 3 months) and late (more than 1 year) postoperative periods in otosclerotic patients who underwent $CO_2$ laser stapedotomy.*

***Material and Method:*** *The charts of 73 primary $CO_2$ laser stapedotomy procedures performed at Bangkok Metropolitan Administration Medical College and Vajira Hospital between 1997 and 2005 were reviewed. Only patients with early postoperative audiometric data between 1 to 3 months and with long-term postoperative audiometric data more than 1 year were selected for inclusion in the present study. Any patients who underwent $CO_2$ laser stapedotomy for diseases other than otosclerosis and those who had revision surgery were excluded from the present study. The early and the late postoperative hearing outcomes were compared using postoperative closure of air-bone gaps and postoperative sensorineural hearing loss at pure-tone average and different frequencies.*

***Results:*** *A group of 26 patients who underwent 30 $CO_2$ laser stapedotomies met the criteria for analysis. The hearing outcomes were followed at the early and the late postoperative periods for an average of 1.8 and 36.2 months, respectively. The present study indicated that closure of air-bone gaps at pure-tone average and individual frequencies began in the early postoperative period and continued to improve through the late postoperative period. Bone conduction hearing thresholds were stable even in the early postoperative follow-up and the improvement in bone conduction hearing thresholds at 1 and 2 kHz and worsening at 4 kHz were seen.*

***Conclusion:*** *After $CO_2$ laser stapedotomy, the stability of cochlear function begins in the early postoperative period and remains stable through the late postoperative period. The conductive component of hearing thresholds continues to improve through the late postoperative period. Thus, the early postoperative hearing outcomes reflect a side effect of postsurgical sensorineural hearing loss and the long-term postoperative hearing outcomes determine the efficacy of this procedure.*

***Keywords:*** *Laser, Stapedotomy, Hearing, Otosclerosis*

***J Med Assoc Thai 2007; 90 (8): 1647-53***
***Full text. e-Journal:*** *http://www.medassocthai.org/journal*

Since the first stapedectomy performed by John Shea[1] in 1956, the procedure has proven to be an effective treatment to correct a conductive hearing loss or a conductive component in a mixed hearing loss secondary to otosclerosis. Many different methods are used to perform stapedectomy but surgical technique has moved toward the advocacy of the small fenestra stapedotomy[2,3]. Lasers have been promoted as the least traumatic method of performing a small fenestra stapedotomy, because the inner ear is not subjected to the effects of mechanical trauma[4-7]. Carbon dioxide ($CO_2$) laser stapedotomy is one of the methods that have been reported with very high rates of successful

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hearing improvement[8,9]. Hearing results in $CO_2$ laser stapedotomy, usually reported as an audiological data at one moment in times, little data have been published as a long-term progression or trends and profiles of the postoperative hearing acuity and change of the results over time[8,10,11].

The purpose of the present study was to compare and report the hearing outcomes of $CO_2$ laser stapedotomy in the early postoperative period (between 1 to 3 months) with the long-term postoperative period (more than 1 year). A series of patients who were operated and with long-term follow-up were reviewed. Initial postoperative results were evaluated for long term changes of the results of this technique. Time course for postoperative closure of air-bone gaps and postoperative sensorineural hearing loss at different frequencies and pure tone average were closely followed and analyzed.

## Material and Method

The present study was approved by the Ethics Committee for Researches involving Human Subjects, the Bangkok Metropolitan Administration.

A retrospective review of all $CO_2$ laser stapedotomy cases performed at Bangkok Metropolitan Administration Medical College and Vajira Hospital between 1997 and 2005 were reviewed to find the primary cases that underwent $CO_2$ laser stapedotomy for otosclerotic disease. Only patients with early postoperative audiometric data, between 1 to 3 months and with long-term postoperative audiometric data more than 1 year, were selected for inclusion in the study. Any patients who underwent $CO_2$ laser stapedotomy for diseases other than otosclerosis and those with inadequate postoperative audiometric data were excluded. Patients who had revision surgery were also excluded from the present study.

### *Surgical technique*

All surgical procedures were performed under intra-aural local anesthesia supplemented by parenteral sedation. The external auditory canal was infiltrated with 2% lidocaine with 1:80,000 units of epinephrine. A tympanomeatal flap was elevated, exposing the middle ear structures. When necessary, bone was curetted until an oval window could be visualized on the pyramidal eminence. The stapes was palpated to confirm fixation. The distance from the long process of the incus to the oval window was measured, and the incudostapedial joint divided. Mobility of the remaining ossicular chain was confirmed. The $CO_2$ laser was used to divide the stapedial tendon and the posterior crus. A Sharplan 30C laser was used with a 0.6 mm spot size, 2-4 watts and superpulse mode with 0.1 second duration. The suprastructure was fractured inferiorly at the anterior crus. A stapedotomy was created with the laser at the power of 1-2 watts by creating a standard rosette pattern. Char was removed with a pick, and the stapedotomy enlarged to at least 0.6 mm diameter. Ossicular continuity was reestablished with a "Richards Piston" prosthesis (Fluoroplastic type, 5 mm length, 0.6 mm diameter; Smith & Nephew Richards, Memphis, TN) positioned between the long process of the incus and the oval window.

### *Audiometric evaluation*

Audiometric testing was performed in double-walled sound rooms using standard procedures. Preoperative audiometric data consisting of air conduction at 0.25, 0.5, 1, 2, 4, and 8 kHz and bone conduction at 0.5, 1, 2, and 4 kHz were recorded. Postoperative air and bone conductions were recorded at the same frequencies as preoperative air and bone conductions. Preoperative and postoperative speech reception thresholds (SRT) and speech discrimination scores (SDS) were also recorded. Pure-tone average (PTA) thresholds were calculated from 0.5, 1, and 2 kHz. Air-bone gaps for the PTA and for individual frequencies were computed from air and bone conduction thresholds obtained at the same test interval. A high pure-tone bone conduction average (HPTBCA) of 1, 2, and 4 kHz was also computed for evaluation of operative damage to hearing (postoperative sensorineural hearing loss). Hearing results from three time intervals were analyzed; preoperative period, early postoperative period (between 1 to 3 months), and late postoperative period (most recent follow-up).

The data were statistics calculated using STATA (version7) and SPSS for windows (version 11.5). The compared two proportions were used to evaluate the changes of proportion between the early and the late postoperative periods. The descriptive results were summarized with percent and mean $\pm$ standard deviation. The paired t-tests or Wilcoxon-sign-rank test was used to evaluate postoperative changes in closure of air-bone gaps and postoperative sensorineural hearing loss over time. Criterion for statistical significance was at two-tailed p-value less than 0.5.

## Results

The present review yielded 73 primary $CO_2$ laser stapedotomy procedures performed between

1997 and 2005, and 26 patients who underwent 30 $CO_2$ laser stapedotomies met the criteria for analysis.

The mean air conduction and bone conduction hearing thresholds at PTA from three time intervals: preoperative, early postoperative and late postoperative periods are summarized in Table 2.

When comparing the hearing outcomes between the early postoperative period and the late postoperative period, the results are as follows:

**Table 1.** Patient's characteristics

| Characteristics | No. of 30 ears | Percent |
|---|---|---|
| Gender | | |
| Female | 21 | 70.0 |
| Male | 9 | 30.0 |
| Ear | | |
| Right | 18 | 60.0 |
| Left | 12 | 40.0 |
| Case type | | |
| Unilateral | 22 | 73.3 |
| Bilateral | 8 | 26.7 |
| Age in years [mean (SD)] | | 42.5 (10.7) |
| Fallow-up time in months [mean (SD)] | | |
| Early postoperative | | 1.8 (0.7) |
| Late postoperative | | 36.2 (22.2) |

**Table 2.** Mean air conduction and bone conduction hearing thresholds at pure-tone average (PTA) (0.5, 1, 2 kHz) (dB)

| Time | Mean (SD) PTA hearing thresholds (dB) (n = 30) | |
|---|---|---|
| | Air conduction | Bone conduction |
| Preoperative | 61.8 (10.9) | 29.1 (9.3) |
| Early postoperative | 39.3 (10.3) | 27.5 (10.4) |
| Late postoperative | 33.1 (9.5) | 26.5 (10.4) |

***Changes in closure of air-bone gaps***

Table 3 shows postoperative PTA air-bone gaps (difference between postoperative air conduction and bone conduction thresholds). The surgical success rate(postoperative air-bone gaps within 10 dB) was 53.3% in the early postoperative and 83.3% in the late postoperative period p = 0.012. The change was significant.

Table 4 shows mean closure of air-bone gaps (difference between preoperative and postoperative air-bone gaps) for PTA and individual frequencies (the frequencies from 0.5 to 4 kHz). At these frequencies, the late postoperative follow-up had significantly better air-bone gaps closure than the early postoperative follow-up.

***Changes in postoperative sensorineural hearing loss***

In the present study, postoperative sensorineural hearing loss (SNHL) was defined as a postoperative bone conduction threshold that was more than 10 dB worse than preoperatively and HPTBCA indicated high pure-tone bone conduction average at 1, 2, and 4 kHz.

Table 5 shows rates of postoperative sensorineural hearing loss for HPTBCA and individual frequencies. There was no significant difference between the early and the late postoperative SNHL at HPTBCA and at all frequencies (the frequencies from 0.5 to 4 kHz).

Table 6 shows changes in mean postoperative bone conduction thresholds (Difference between preoperative and postoperative bone conduction thresholds) and SDS. There was no significant difference between the early and the late postoperative bone conduction thresholds at HPTBCA and at all frequencies (the frequencies from 0.5 to 4 kHz). At 1 and 2 kHz, there was significant improvement of bone conduction thresholds in the late postoperative follow-up. In contrast, bone conduction thresholds at 4 kHz worsened significantly during the early and the late

**Table 3.** Hearing results shown as a function of postoperative pure-tone average (PTA) (0.5, 1, 2 kHz) air-bone gaps (dB)

| Postoperative PTA air-bone gaps (dB) | No. (%) (n = 30) | | |
|---|---|---|---|
| | Early postoperative | Late postoperative | p-value |
| 0-10 | 16 (53.3) | 25 (83.3) | 0.012 |
| 11-20 | 10 (33.3) | 4 (13.3) | NS |
| 21-30 | 4 (13.3) | 1 (3.3) | NS |

NS = no significant difference

**Table 4.** Closure of air-bone gaps(Difference between preoperative and postoperative air-bone gaps) at pure-tone average (PTA) (0.5, 1, 2, 4 kHz) and individual frequencies (dB)

| Frequency (kHz) | Mean (SD) closure of air-bone gaps (dB) (n = 30) | | | |
|---|---|---|---|---|
| | Early postoperative | Late postoperative | Differences between early and late | p-value |
| PTA | 20.8 (7.3) | 25.7 (9.2) | -4.9 (6.4) | 0.000 |
| 0.5 | 27.0 (11.6) | 33.5 (12.6) | -6.5 (11.3) | 0.004 |
| 1 | 22.5 (10.3) | 27.6 (10.7) | -5.1 (7.8) | 0.001 |
| 2 | 13.1 (9.8) | 16.1 (10.7) | -3.0 (6.8) | 0.024 |
| 4 | 15.1 (14.2) | 18.8 (17.2) | -3.7 (9.8) | 0.050 |

**Table 5.** Rates of postoperative sensorineural hearing loss (SNHL) at high pure-tone bone conduction average (HPTBCA) (1, 2, and 4 kHz) and individual frequencies (dB)

| Frequency (kHz) | No. (%) (n = 30) | | p-value |
|---|---|---|---|
| | Early postoperative | Late postoperative | |
| HPTBCA | 4 (13.3) | 3 (10.0) | NS |
| 0.5 | 2 (6.6) | 2 (6.6) | NS |
| 1.0 | 0 (0.0) | 0 (0.0) | NS |
| 2 | 2 (6.6) | 0 (0.0) | NS |
| 4 | 6 (20.0) | 7 (23.3) | NS |

NS = no significant difference

**Table 6.** Changes in postoperative bone conduction thresholds(Difference between preoperative and postoperative bone conduction thresholds) at high pure-tone bone conduction average (HPTBCA) (1, 2, and 4 kHz) and individual frequencies (dB), and speech discrimination scores (SDS) (%)

| Frequency (kHz) | Postoperative bone conduction thresholds changes (dB) (n = 30) | | | | | |
|---|---|---|---|---|---|---|
| | Early postoperative | | Late postoperative | | Differences between early and late | |
| | Mean diff (SD) | p-value | Mean diff (SD) | p-value | Mean diff (SD) | p-value |
| HPTBCA | -0.5 (9.8) | NS | 0.7 (9.5) | NS | -1.2 (7.3) | NS |
| 0.5 | -2.3 (7.3) | NS | -0.8 (7.2) | NS | -1.5 (9.2) | NS |
| 1 | 3.9 (5.2) | 0.000 | 3.9 (6.1) | 0.002 | 0.0 (6.1) | NS |
| 2 | 3.5 (10.8) | NS | 6.0 (9.0) | 0.001 | -2.5 (8.7) | NS |
| 4 | -9.0 (19.7) | 0.018 | -7.9 (18.5) | 0.028 | -1.2 (12.0) | NS |
| SDS (%) | 4.2 (6.2) | 0.001 | 5.6 (6.8) | 0.000 | -1.3 (3.9) | NS |

NS = no significant difference
Mean diff = mean difference between pre and post

postoperative periods and did not improve over time. SDS was significantly improved at the early and the late postoperative periods but did not change over time.

## Discussion

The evolution in the surgical management of otosclerosis was aimed to improve the postoperative hearing results, reduce complications, and stable long-term results of hearing improvement. Many innovations in stapes surgery have been introduced in the past 50 years. Such innovations were tried to reduce the mechanical trauma to the stapes, causing decreased labyrinthine irritation and possibly better results. The course of postoperative hearing results may be affected by many causes. The causes of postoperative sensorineural hearing loss either transient or permanent may be due to a transient labyrinthine hydrops, vascular sludging and anoxia or surgical trauma(12,13). Another considered cause that affected postoperative hearing outcomes is the changes in the impedance and transformer mechanisms of the middle ear as a result of edema, transudates, microhemorrhage, and other factors directly related to the surgery of the tympanic cavity(12). In 1993, Colletti et al(14) reported that stapes surgery could also abnormally reduce the stiffness of the tympano-ossicular system.

$CO_2$ laser stapedotomy is now one of the standard surgical treatments for otosclerosis. However, there are little normative data of the course of postoperative hearing acuity and the course of postsurgical depression of cochlear function of this technique. The present study compared the hearing results between the early and the late postoperative periods after $CO_2$ laser stapedotomy. The authors observed that closure of air-bone gaps at PTA and individual frequencies (the frequencies from 0.5 to 4 kHz) was improved over time. It began in the early postoperative period and continued to improve through the late postoperative period. The improvement of closure of the air-bone gaps in the late postoperative follow-up may be due to improvement in the middle ear impedance and transformer mechanisms (e.g., edema, transudates, and bleeding) and the stiffness of the tympano-ossicular system.

The rates of postoperative sensorineural hearing loss and mean postoperative bone conduction thresholds were not significantly different between the early and the late postoperative periods. This means that the cochlear function was stable even in the early postoperative period (between 1-3 months postoperatively). The authors observed slight, but statistically significant improvement in bone conduction thresholds at 1 and 2 kHz and worsening at 4 kHz. The improvement seen at 1 and 2 kHz probably resulted from Carhart's pathogenetic hypothesis that correlates auditory gain with postoperative resolution of pressure imbalances existing in the cochlear of otosclerotic patients with a consequent improvement in functionality of the Organ of Corti(11,15,16). The higher frequency (4 kHz) sensorineural hearing loss is consistent with those reported previously for larger fenestra, conventional technique and small fenestra stapedotomies done by either microdrill or laser(5,8,17,18). They may have resulted from the mechanical trauma to the inner ear or be reflected as disease-specific injury resulting from cochlear otosclerosis as suggested by Meyer(19).

## Conclusion

After $CO_2$ laser stapedotomy, the stability of cochlear function begins in the early postoperative period and remains stable through the late postoperative period. The improvement in bone conduction hearing thresholds was seen at 1 and 2 kHz and worsening seen at 4 kHz. The conductive component of hearing thresholds continues to improve through the late postoperative period. Thus, the early postoperative hearing outcomes reflect a side-effect of postsurgical sensorineural hearing loss; however, the long term postoperative hearing outcomes determined the efficacy of this procedure.


## Acknowledgements

The present study was supported by a grant Vajira Medical Research Fund.


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# ระดับของการได้ยินระยะแรกและระยะยาวภายหลังการผ่าตัดเจาะฐานกระดูกโกลนด้วยคาร์บอนไดออกไซด์เลเซอร์

รณยุทธ บุญชู, พิชัย พัวเพิ่มพูลศิริ

***ภูมิหลัง***: ปัจจุบันการผ่าตัดเจาะฐานกระดูกโกลนด้วยคาร์บอนไดออกไซด์เลเซอร์เป็นวิธีมาตรฐานวิธีหนึ่งของการผ่าตัดรักษาโรคโอโตสเคอโรซีส อย่างไรก็ดีมีข้อมูลพื้นฐานจำนวนน้อยที่แสดงการเปลี่ยนแปลงของระดับของการได้ยินและการเปลี่ยนแปลงของประสาทรับฟังเสียงของหูชั้นในภายหลังการผ่าตัดเมื่อติดตามผลไปในระยะยาว

***วัตถุประสงค์***: เปรียบเทียบการเปลี่ยนแปลงของระดับของการได้ยินภายหลังการผ่าตัดเจาะฐานกระดูกโกลนด้วยคาร์บอนไดออกไซด์เลเซอร์ในระยะแรก (ระหว่าง 1 ถึง 3 เดือน) กับระยะยาว (มากกว่า 1 ปี)ในผู้ป่วยโรคโอโตสเคอโรซีส

***วัสดุและวิธีการ***: ทบทวนเวชระเบียนของผู้ป่วยโรคโอโตสเคอโรซีสจำนวน 73 ราย ที่ได้รับการผ่าตัดเจาะฐานกระดูกโกลนด้วยคาร์บอนไดออกไซด์เลเซอร์เป็นครั้งแรก ณ วิทยาลัยแพทยศาสตร์กรุงเทพมหานครและวชิรพยาบาลตั้งแต่ พ.ศ. 2540 ถึง พ.ศ. 2548 คัดเลือกผู้ป่วยที่มีผลการตรวจการได้ยินภายหลังการผ่าตัดในระยะแรกระหว่าง 1 ถึง 3 เดือน กับระยะยาวมากกว่า 1 ปี โดยไม่รวมผู้ป่วยที่ทำผ่าตัดจากสาเหตุอื่นหรือเป็นการผ่าตัดซ้ำสอง โดยเปรียบเทียบการเปลี่ยนแปลงของระดับของการได้ยินระหว่างระยะแรกกับระยะยาวภายหลังการผ่าตัด ในแง่ของประสิทธิผลในการปิดความต่างของระดับการได้ยินโดยการนำเสียงทางอากาศกับการนำเสียงทางกระดูก และการสูญเสียการได้ยินเสียงแบบประสาทรับฟังเสียงบกพร่องจากผลของการผ่าตัด ที่ค่าเฉลี่ยของเสียงบริสุทธิ์ที่ความถี่ 500, 1,000 และ 2,000 รอบต่อวินาทีและที่เสียงความถี่ต่าง ๆ กัน

***ผลการศึกษา***: ได้ผู้ป่วยจำนวน 26 ราย 30 หู นำมาศึกษา มีระยะเวลาติดตามผลเฉลี่ยภายหลังการผ่าตัดในระยะแรก 1.8 เดือน และในระยะยาว 36.2 เดือนตามลำดับ พบว่าประสิทธิผลในการปิดความต่างของระดับการได้ยินโดยการนำเสียงทางอากาศกับการนำเสียงทางกระดูกในระยะยาวจะดีกว่าในระยะแรกที่ค่าเฉลี่ยของเสียงบริสุทธิ์ที่ความถี่ 500, 1,000 และ 2,000 รอบต่อวินาที และที่เสียงความถี่อื่น ๆ ส่วนการนำเสียงทางกระดูกในทุกความถี่ในระยะยาวจะไม่มีการเปลี่ยนแปลงเมื่อเปรียบเทียบกับระยะแรกภายหลังการผ่าตัด นอกจากนี้ยังพบว่าการผ่าตัดทำให้การนำเสียงทางกระดูกดีขึ้นที่ความถี่ 1,000 และ 2,000 รอบต่อวินาที และเลวลงที่ความถี่ 4,000 รอบต่อวินาทีอย่างมีนัยสำคัญ

***สรุป***: ภายหลังการผ่าตัดเจาะฐานกระดูกโกลนด้วยคาร์บอนไดออกไซด์เลเซอร์ ประสาทรับฟังเสียงของหูชั้นในจะมีความเสถียรหรือคงที่ตั้งแต่ระยะแรกภายหลังการผ่าตัด ส่วนของการนำเสียงของระดับการได้ยินจะค่อย ๆ ดีขึ้นตั้งแต่ระยะแรกและจะดีขึ้นอีกเมื่อติดตามผลไปในระยะยาว ดังนั้นข้อมูลการตรวจการได้ยินภายหลังการผ่าตัดในระยะแรก จะบอกถึงการสูญเสียการได้ยินเสียงแบบประสาทรับฟังเสียงบกพร่องจากผลของการผ่าตัด แต่ข้อมูลการตรวจการได้ยินภายหลังการผ่าตัดในระยะยาวจะบอกถึงประสิทธิผลที่แท้จริงของการผ่าตัดชนิดนี้