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A Reevaluation of the 512-Hz Rinne Tuning Fork Test as a Patient Selection Criterion for Laser Stapedotomy

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Objective: This study aimed to challenge the classical hypothesis that a negative preoperative 512-Hz Rinne tuning fork test (bone conduction greater than air conduction) is a necessary condition to allow consistent objective and subjective hearing improvement with surgery for otosclerosis.
Study Design: The study design was retrospective (chart review and questionnaire).
Setting: The study was conducted at a Florida Ear and Sinus Center at Sarasota, Florida, a tertiary otology–neurotology referral center.
Patients: Patients who underwent primary laser stapedotomy with equivocal (air = bone) preoperative 512-Hz Rinne test results participated.
Intervention: KTP laser stapedotomy was performed.
Main Outcome Measures: Audiologic measurements of air–bone gap closure and patient assessment of hearing improvement and satisfaction were conducted.
Results: The air–bone gap was closed to within 10 dB in all cases. There were no complications. Eighteen patients were questioned about their results. Hearing improvement was subjectively described as "excellent" or "good" by 17 (94%), and 16 (89%) thought the surgery was "absolutely" worthwhile.
Conclusions: The preoperative 512-Hz Rinne test results need not be negative to achieve significant air–bone gap closure and subjective appreciation of improved hearing. **Key Words:** Otosclerosis—Rinne test—Stapedotomy.
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A negative Rinne test result (bone conduction greater than air conduction) with a 512-Hz tuning fork has long been considered a criterion for selecting patients with otosclerosis for surgery (1,2). This tenet appears to address two concerns. First, because the test is an indicator of conductive hearing loss, it is conceivable that only patients with negative 512-Hz Rinne test results are likely to appreciate postoperative hearing gains. Second, equivocal (equal bone conduction and air conduction) or positive (air conduction greater than bone conduction) results may imply incomplete stapes fixation. Surgery in these cases may, theoretically, be associated with a higher rate of "footplate complications."

Despite its historic importance as a surgical selection criterion, in clinical practice, the Rinne test often is used solely for corroboration of the audiometric results. The aim of this study is to critically challenge the role of the Rinne test as an independent selection criterion for stapes surgery.

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An examination of the audiometric results and patient satisfaction after stapes surgery in patients with equivocal preoperative 512-Hz Rinne test results serves to challenge the two aforementioned concerns. Although subjective results of satisfaction are not ordinarily a standard for evaluating surgical results, they were necessary in this study to evaluate the hypothesis that patients would not be able to appreciate hearing improvement unless the Rinne test result was negative before surgery.

As a prerequisite to determining its role, the accuracy of the Rinne test should be examined as well. Stankiewicz and Mowry (3) concluded "results indicate the Rinne, Weber, and Bing Occlusion tests do not accurately predict the type of hearing impairment as frequently as the literature suggests." Gelfand (4) found that an air–bone gap of 55–60 dB was necessary for the 512-Hz Rinne test "to meet a 75% correct detection criteria" and concluded that "the Rinne test cannot be validly employed as a criterion against which other measures can be evaluated."

The data presented in graphical form by Browning and Swan (5) show a sensitivity of approximately 80% for the 512-Hz Rinne test in the detection of conductive hearing losses in patients with air–bone gaps of 40 dB. Stated conversely, the 512-Hz Rinne test yielded equivocal or

positive results in 20% of patients with a 40-dB air–bone gap. The sensitivity was correspondingly lower in patients with smaller gaps.

The data from Chole and Cook (6) indicated that with an air–bone gap of 40 dB, the results from only 17 (74%) of 23 512-Hz Rinne tests were negative. In the same study, positive results were found with air–bone gaps ranging from 0–45 dB, equivocal results were found with gaps ranging from 25–40 dB, and negative results were found with air–bone gaps as small as 20 dB. With this degree of overlap, one could reliably predict the Rinne test result only for air–bone gaps of ≤15 dB or ≥50 dB.

METHODS

Patients were selected for surgery on the basis of a negative or equivocal 512-Hz Rinne test result and a clinical diagnosis of otosclerosis. This diagnosis was determined by the presence of an audiometrically determined air–bone gap, an absence of other identifiable outer or middle ear pathology on otoscopy, and confirmation of malleus mobility on pneumatic otoscopy. Acoustic reflex findings also were considered. Rinne tests were performed using the loudness comparison method in which the stem of the tuning fork is held firmly against the mastoid process and then with the tines near the outer ear. In all cases, the Rinne test was performed by the senior author. The Rinne tests and audiograms were repeated (with insert earphones) in cases in which the correlation between the Rinne test and the initial audiogram was questioned. Charts of postsurgical patients were reviewed. Patients were included in this study if the preoperative 512-Hz Rinne test results were equivocal.

The surgical technique has been described previously (7). All cases were performed with a KTP laser (Laserscope; San Jose, CA, U.S.A.). In 1988, the initial laser power setting used on the footplate was decreased from 1.8–0.8 W. Power then was increased in small increments, if needed, to penetrate the footplate. The status of the footplate at the time of surgery (fixed, incompletely fixed, or unintentionally mobilized) was determined by review of the dictated operative report.

The preoperative air–bone gaps at 500 Hz and for the three-frequency average of 500, 1,000, and 2,000 Hz were recorded. Postoperative closure of the air–bone gap was calculated by subtracting the postoperative three-frequency bone conduction average from the postoperative air conduction average at the same frequencies. The published committee guidelines for reporting air–bone gap results recommend the use of a four-tone average, including 3,000 Hz for "future prospective studies" (8). The data in this retrospective study were accumulated before these recommendations. Bone conduction thresholds at 3,000 Hz were not obtained. Following the recommendation by Monsell (9), air–bone gaps also were calculated using a four-frequency average in which the 3,000-Hz bone conduction threshold was estimated by using the mean of the thresholds at 2,000 Hz and 4,000 Hz.

Overclosure or operative damage to hearing loss was assessed following committee guidelines (8) (preoperative minus postoperative bone conduction threshold average at 1K, 2K, and 4K Hz). Patient satisfaction was assessed by responses to the following closed-set (multiple choice) questions:

- Question 1: To what degree did your hearing improve from the surgery?

  a. excellent improvement
  b. good improvement
  c. fair improvement
  d. no improvement
  e. worse

TABLE 1. *Laser stapedotomy with equivocal 512 Rinne*

No.	Preoperative air–bone gap at 500 Hz (dB)	Status of footplate	Hearing loss	Follow-up (months)	Satisfaction[b] (questions 1,2)
1	20	Fixed	Unilateral	36	
2	45	Fixed	Unilateral	29	a,a
3	35	Fixed	Bilateral	66	a,a
4	50	Fixed	Unilateral	12	a,a
5	35	Fixed	Unilateral	29	b,a
6	25	Fixed	Unilateral	12	a,a
7	35	Fixed	Unilateral	30	a,a
8	30	Mobilized	Unilateral	18	b,a
9	30	Mobile[a]	Bilateral	10	a,a
10	35	Fixed	Unilateral	1	b,a
				13	d,c
11	30	Fixed	Unilateral	14	a,a
12	40	Fixed	Unilateral	14	b,a
13	35	Fixed	Unilateral	25	b,a
14	30	Fixed	Unilateral	10	c,b
15	25	Mobilized	Bilateral	21	a,b
16	25	Mobile[a]	Unilateral	15	a,a
17	25	Mobile[a]	Bilateral	12	b,a
18	25	Mobile[a]	Unilateral	1	a,a
19	40	Fixed	Unilateral	21	b,a

[a]Slight mobility (incomplete fixation).

[b]Satisfaction:

1) To what degree did your hearing improve from the surgery? a. excellent improvement; b. good improvement; c. fair improvement; d. no change; e. worse.

2) Do you think the surgery was worthwhile? a. absolutely; b. probably; c. unsure; d. no.

- Question 2: Do you think the surgery was worthwhile?

  a. absolutely
  b. probably
  c. unsure
  d. no

It was stressed that the responses should be subjective and not based on what the patient may have been told about hearing test results. It also was explained that the first question refers solely to the perceived hearing improvement, whereas the second question was intended to take into account any other considerations (e.g., postoperative discomfort or complications, hearing status of the contralateral ear, expense). Because patient satisfaction could be influenced by the hearing status of the contralateral ear, this status was noted. The status of the footplate as described in the operative report also was noted.

RESULTS

Nineteen primary KTP laser stapedotomies were performed in 18 patients with equivocal results on the 512-Hz Rinne test. This represents 23% (19 of 81) of all primary stapedotomies performed from January 1990–March 1993. All preoperative and postoperative data are presented in Tables 1 and 2. The preoperative audiometric air–bone gap at 500 Hz ranged from 20–50 dB (mean = 32.4 dB, standard deviation = 7.7 dB). The three-frequency average air–bone gap ranged from 13–38 dB (mean = 23.3, standard deviation = 7.6) (Table 3). The estimated four-frequency air–bone gap (9) (air threshold mean of 0.5K, 1K, 2K, and 3K minus bone threshold mean of 0.5K, 1K, 2K, and the average of 2K and 4K; refer to Methods section) ranged from 12–34 dB

TABLE 2. *Audiometric data*

		Preoperative audiogram							Postoperative audiogram						
No.		250	500	1,000	2,000	3,000	4,000	8,000	250	500	1,000	2,000	3,000	4,000	8,000
1	AC	25	30	35	25	35	35	20	15	15	10	5	35	45	40
	BC	5	10	10	10		10		0	5	10	5		40	
2	AC	60	65	65	35	30	25	35	5	10	15	5	10	15	10
	BC	0	20	20	20		5		5	10	15	5		15	
3	AC	45	50	50	40	35	40	45	10	10	10	10	15	15	45
	BC	10	15	15	15		15		10	10	10	10		15	
4	AC	70	55	75	60	60	80	75	20	15	30	30	35	55	60
	BC	5	5	35	35		45		10	15	30	30		50	
5	AC	50	45	40	35	35	35	40	30	25	15	20	15	30	35
	BC	10	10	10	20		20		20	15	15	15		20	
6	AC	60	60	55	45	70	85	NR	15	15	25	20	45	55	NR
	BC	20	35	35	35		50		15	15	20	15		35	
7	AC	45	50	40	40	40	40	30	10	15	5	15	15	15	25
	BC	10	15	15	20		10		10	15	5	15		15	
8	AC	40	45	35	30	20	20	25	20	20	10	10	10	15	20
	BC	5	15	15	15		0		10	10	5	0		0	
9	AC	60	50	45	55	60	70	NR	30	30	30	35	60	65	NR
	BC	15	20	20	45		65		20	20	30	35		65	
10[a]	AC	40	45	35	35	50	45	60	10	15	20	35	35	40	60
	BC	10	10	25	35		25		10	10	20	30		35	
10[b]	AC								65	65	65	75	70	80	NR
	BC								0	5	20	25		30	
11	AC	45	65	65	55	50	55	80	10	15	25	25	35	40	60
	BC	10	35	35	45		35		10	15	25	25		40	
12	AC	70	65	70	85	65	75	NR	45	45	45	40	45	45	70
	BC	15	25	40	50		35		20	25	45	40		45	
13	AC	40	50	55	55	50	50	70	20	15	20	40	35	45	70
	BC	5	15	30	40		35		5	10	20	40		45	
14	AC	45	45	40	40	35	30	15	25	25	25	30	25	35	5
	BC	15	15	25	25		20		5	15	25	30		30	
15	AC	30	30	40	20	20	25	35	10	10	20	20	20	30	60
	BC	0	5	20	20		25		5	10	20	15		25	
16	AC	45	55	65	55	75	80	60	10	15	45	35	45	60	70
	BC	10	30	45	55		65		10	15	35	35		55	
17	AC	40	40	25	35	40	40	55	10	5	10	15	30	75	60
	BC	0	15	20	25		25		0	5	10	15		25	
18	AC	50	45	40	35	30	25	40	25	25	25	30	25	45	65
	BC	10	20	30	25		20		10	25	25	30		35	
19	AC	30	40	30	30	50	65	80	5	10	10	10	30	40	55
	BC	0	0	10	15		35		0	0	10	10		40	

AC, air conduction; BC, bone conduction; NR, no response.
[a]One month postoperative.
[b]Thirteen months postoperative.

TABLE 3. *Air–bone gap results*

ID no.	Preoperative (dB)	Postoperative (dB)	Change (pre – post) (dB)
1	20	3	17
2	35	0	35
3	32	0	32
4	38	0	38
5	27	5	22
6	18	3	15
7	26	0	26
8	22	8	14
9	22	4	18
10	15	3[a]	12[a]
		51[b]	−36[b]
11	24	0	24
12	35	6	29
13	25	2	23
14	20	3	17
15	15	2	13
16	15	3	12
17	13	0	13
18	15	0	15
19	25	3	22
Mean	23.3	2.4	20.9
SD	7.6	2.3	8.0

[a]One month.
[b]Thirteen months.

TABLE 4. *High tone bone conduction levels*

ID no.	Preoperative (dB)	Postoperative (dB)	Change (pre – post) (dB)
1	10	18	−8
2	15	12	3
3	15	12	3
4	38	37	1
5	17	17	0
6	40	23	17
7	15	12	3
8	10	2	8
9	43	43	0
10	28	28[a]	0[a]
		25[b]	3[b]
11	38	30	8
12	42	43	−1
13	35	35	0
14	23	28	−5
15	22	20	2
16	55	42	13
17	23	17	6
18	25	30	−5
19	20	20	0
Mean			2.4
SD			5.9

[a]One month.
[b]Thirteen months.

(mean = 21.6, standard deviation = 6.6). The footplate was reported as fixed in 13 cases, incompletely fixed in 4 cases, and unintentionally mobilized in 2 cases (Table 1).

Audiometric follow-up ranged from 1–66 months with a mean of 20.4 months. Follow-up of at least 12 months was achieved in 16 of 19 patients, and only 1 patient had <10 months' follow-up.

The air–bone gap was closed to <10 dB in all patients. The range for three-frequency postoperative air–bone gaps was 0–8 dB (mean = 2.4; standard deviation = 2.3; Table 3). With estimated four-frequency calculations, the range was -1–9 dB (mean = 3.1; standard deviation = 2.1). The change in air–bone gap (preoperative air–bone gap minus postoperative air–bone gap) for three-frequency calculations ranged from 12–38 dB (mean = 20.9; standard deviation = 8.0). For estimated four-frequency calculations, the change in air–bone gap ranged from 10–35 dB (mean = 18.9, standard deviation = 7.6). One patient had a large conductive hearing loss develop 13 months after surgery with an air–bone gap of 36 dB worse than preoperative levels (Table 3).

Overclosure or operative damage to hearing loss (preoperative minus postoperative bone conduction threshold average at 1K, 2K, and 4K Hz) (8) results ranged from 17 dB ("overclosure") to -8 dB ("operative damage"; mean = 2.4; standard deviation = 5.9; Table 4).

The preoperative conductive hearing loss was "unilateral" in 15 of the 19 cases. Five of the unilateral cases were patients who previously had undergone stapedotomies on the contralateral ear with good results.

One patient could not be reached for questioning. Of the 18 patients questioned, 10 (56%) described their hearing improvement as "excellent" and 7 (39%) as "good." The remaining patient described his hearing improvement as "fair" (Tables 1,5). Sixteen (89%) thought the surgery was "absolutely" worthwhile and 2 (11%) thought the surgery was "probably" worthwhile (Tables 1,6). These results include one patient (patient 10) in whom a large air–bone gap

TABLE 5. *Responses to question 1*[a]

	Improvement				
	Excellent	Good	Fair	No change	Worse
Unilateral loss[b]	7	6	1	0	0
Bilateral loss	3	1	0	0	0
Total	10	7	1	0	0

Values are no. of cases.
[a]"To what degree did your hearing improve from the surgery?"
[b]Includes five cases with prior successful stapedotomy in contralateral ear.

TABLE 6. *Responses to question 2*[a]

	Absolutely	Probably	Unsure	No
Unilateral loss[b]	13	1	0	0
Bilateral loss	3	1	0	0
Total	16	2	0	0

Values are no. of cases.

[a]"Do you think the surgery was worthwhile?" (See text for explanation.)

[b]Includes five cases with prior successful stapedotomy in contralateral ear.

TABLE 7. *Postoperative air–bone gap results*

	Range (dB)	Mean (dB)	SD (dB)
Fixed footplate	0–6[a]	2.2[a]	2.0
Incompletely fixed or mobilized footplate	0–8	2.8	3.0

There were no differences between groups (2-tailed Mann-Whitney test: $p = 0.76$).

[a]One patient with initial overclosure developed a 45 dB air–bone gap 13 months postoperatively.

developed after an initial good result. Because the initial hearing results and questionnaire responses are more informative regarding the evaluation of stapes surgery in patients with equivocal Rinne test results, these results were included. For completeness, the results after the patient's loss of hearing are presented with the data in Table 1.

To determine whether incomplete footplate fixation poses a risk to hearing results, patients with fixed footplates were compared to patients with incomplete fixation or unintentional mobilization. Postoperative air–bone gaps were used as the measure of conductive hearing results (Table 7), and the change in "high frequency bone conduction thresholds" (8) was used to assess the potential for inner ear injury (Table 8). There were no statistical differences between these two subgroups (two-tailed Mann–Whitney test: $p = 0.76$ for air–bone gap comparison; $p = 0.4$ for bone conduction threshold changes comparison). The use of the estimated four-frequency air–bone gap results did not appreciably alter the results (Mann–Whitney test: $p = 0.43$).

No differences were noted between patients with unilateral and bilateral conductive losses regarding subjective degree of hearing improvement or perception of how worthwhile the surgery was (Tables 5 and 6). With the exception of the above-mentioned conductive loss occurring 13 months after surgery, there were no complications.

DISCUSSION

A negative Rinne test result at 512-Hz has classically been used as a criterion in otosclerosis for selection of surgical candidates. In theory, if the tuning fork is not heard better by bone conduction than by air conduction, the potential for hearing improvement may be considered inadequate to make the surgery worthwhile. A positive or equivocal result with the 512-Hz tuning fork also may imply incomplete footplate fixation. Such patients have been believed to be at increased risk for footplate complications and associated inner ear injury during stapes surgery.

Our study of patients' responses to hearing and satisfaction questions does not support the use of the Rinne test as a predictor of subjective success in patients with equivocal preoperative Rinne test results. It is not the authors' claim that subjective hearing results should be a standard of evaluating otologic procedures. In fact, to our knowledge, no standard method of reporting subjective change exists. To study the hypothesis that a negative preoperative 512-Hz Rinne test is a prerequisite to patient appreciation of hearing improvement, an analysis of subjective results was required.

The Rinne test is not without value in detecting conductive hearing loss, but several studies question its quantitative accuracy (3–6). The range of audiometric 500-Hz air–bone gaps in our patients with equivocal Rinne test results is consistent with that in these studies.

Theoretical explanations for the variability in Rinne test results may include inconsistencies in the testing method between examiners regarding the distance and orientation of the tuning fork tines relative to the ear canal, the location of contact between the tuning fork stem and the skin over the mastoid, and the force with which the tuning fork is held against the patient. The force with which the tuning force is struck and the type of surface against which it is struck also may be sources of variability. These factors were minimized in our study by performance of the test, in all cases, by the senior author. Patient factors such as the thickness of the postauricular soft tissues, the attentiveness during testing, and the patient's understanding of the task may further contribute to the variability. The implication that equivocal Rinne test results indicate incomplete stapes fixation and increased risk of "footplate complications" was similarly not supported by this study.

CONCLUSION

On the basis of the results of this investigation (both objective and subjective), we conclude that a negative 512-Hz Rinne test result need not be an independent selection criterion for stapes surgery.

TABLE 8. *Change in "high frequency bone conduction thresholds"*

	Range (dB)	Mean (dB)	SD (dB)
Fixed footplate	−8 to 17	1.6	6.0
Incompletely fixed or mobilized footplate	−5 to 13	4.0	6.4

There were no differences between groups (2-tailed Mann-Whitney test: $p = 0.4$).

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