The outer ear canal is made up of a tube that is closed at the eardrum end (medial) and open at the outer part (lateral). We call such a tube (open at one end and closed at the other), a quarter-wavelength resonator.

Such resonators are found everywhere: First resonance in the behind-the-ear (BTE) hearing aid response, the resonances of a trumpet, clarinet, and even our vocal tract uttering the sound [a] as in “father.” The frequency at which such a resonance occurs is the speed of sound (we will assume it to be exactly 340 m/sec or 340,000 mm/sec, even though it actually is slightly slower) divided by four times the length of the tube, or \( F = \frac{v}{4L} \).

There are also higher modes of resonances at three, five, and seven times the main frequency. For example, in a BTE hearing aid tubing, the primary resonance on a specification sheet (or in the real ear) is at about 1000 Hz. There are also odd-numbered resonances at 3000 Hz (three x 1000 Hz), 5000 Hz (five x 1000 Hz), 7000 Hz (seven x 1000 Hz), and so on, which are quarter-wavelength-related: odd-numbered multiples of the lower frequency (see Figure 1). This pattern is characteristic of all quarter-wavelength resonances, and all quarter-wavelength resonances come from a tube that is closed at one end and open at the other.

In the early 1970s, KEMAR (Knowles Electronics Manikin for Acoustic Research) was constructed to emulate the average head and upper torso, including the average ear canal. KEMAR has a removable outer ear pinna and, instead of an eardrum, it uses a small half-inch microphone so that accurate measurements can be taken and recorded at the level of the “eardrum substitute.”

KEMAR typically uses a coupler or ear canal called a Zwislocki coupler. This is a metal cylinder 21.5 mm long that has, depending on the type, two or four side-branch resonators. This combination of ear canal length (21.5 mm) and half-inch microphone yields a resonance of 2700-3000 Hz, just like the adult human ear. However, the adult ear canal is typically 6.5 mm longer than KEMAR’s 21.5 mm, yet both resonate at 2700-3000 Hz as their first quarter-wavelength resonance.

The trick that Burkhard and Sachs used in 1973 was to give the diaphragm of the microphone a compliance that adds some “acoustic length” to the 21.5-mm tube, essentially causing it to behave as if it were 31 mm long. Even the real human ear isn’t that long. It averages 28 mm, and the normally compliant human eardrum adds a few more millimeters of acoustic length to the measured length. The ear canal is a quarter-wavelength resonator and, like the tubing resonances in a BTE hearing aid, is given by the equation, \( F = \frac{v}{4L} \) (\( F = \frac{340,000 \text{ mm/sec}}{4 \times 31 \text{ mm}} = 2700 \text{ Hz} \)).

KEMAR just needs to make a larger correction, since half-inch microphones have significantly more compliance than typical eardrums. Some people with very flaccid tympanic membranes (type AD tympanograms) have outer ear canal resonances on the order of 2500 or 2600 Hz, since they function as if they were slightly longer tubes (i.e., have more “acoustic length”).

So far, this description of the etiology of the REUG could come from a first-year audiology textbook and contains nothing new. The first resonance, together with a second resonance at about 5500 Hz, makes up the REUG or real-ear unaided gain. The REUG is what people with normal hearing typically hear through when they perceive speech and music. For hearing aid wearers listening in the “real world” (or in sound field audiometry), the REUG typically needs to be subtracted from the REAG (real-ear aided gain) to get the real, useful, or insertion gain. Real-ear measurement systems have been used since the early 1980s to accomplish this and are a mainstay for those who work.
The etiology of the REUG and of Shaw, formulas of both the quar-
appre-
KEMAR response with and without the outer pinna removed showing the

Real-ear measurements (REM) were taken at 0° azimuth and 0° altitude using a swept warble signal at 70 dB SPL. This is the exact opposite of what Shaw did 30 years ago when he removed the ear canal tube from the experiment by plugging it at the meatal opening.²

Figure 4 shows one response (seen in 13 of the 30 subjects) with the concha bowl completely occluded with earmold impression material showing no appreciable destruction of the so called “con-
cha-related volume resonance.” There was a slight decrease in the frequency of both the 2700-Hz and 5500-Hz wavelength resonances. As in Figure 2, this occurs because the earmold impression material adds several millimeters of length to the ear canal. (When the pinna was removed from KEMAR in Figure 2, this extra length was removed from the system so the KEMAR ear canal resonance was slightly higher in frequency).

In the other 17 subjects (56%), there was an appreciable degradation of the 5500-Hz “concha-related” resonance. Possibly in these subjects, concha volume was significant enough to be a measurable (or dominant) factor. It is also possible that their ear canals were more cylindrical than the typical human ear canal. The 17 subjects who demonstrated a significant loss of sound energy in the 5500-Hz region are consistent with previous data such as those of Shaw; and in these cases, this resonance may indeed be primarily concha related.

The results shown in Figure 4 demonstrate that at least for some people (13/30 subjects), the “concha-related” 5500-Hz resonance is not solely related to their concha volume, but related also to their ear canal length and to having an anatomically conical ear canal, which narrows gradually from the lateral meatal opening to the medial tympanic membrane. (For other people, the 5500-Hz resonance may be solely related to their concha volume.)

If this is indeed the case, then arguments made by some hearing aid manufacturers and dispensers that not occluding the concha has the advantage of allowing more high-frequency sound pressure to be received at the hearing aid microphone (at 5500 Hz) may not be true in all people. Such arguments are often used to support the use of completely-in-the-canal, canal, and mini-canal hearing aids. While these styles of hearing aids do have many advantages, both acoustic and cosmetic, for some people, preserving the concha resonance may not be one of them.

Marshall Chasin, AuD, MSc, AuD(C), is an audiologist at Musicians’ Clinics of Canada. Dr. Chasin may be contacted at Musicians’ Clinics of Canada, #340–340 College St., Toronto, Ontario, Canada, M5T 3A9; 416/96-MUSIC; or Marshall.Chasin@rogers.com.

REFERENCES