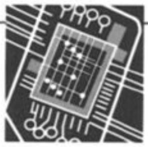
TECHNOLOGY

Real-ear gain provided by CIC, ITC and ITE Hearing Instruments

> Recently, there has been growing enthusiasm about the newest type of hearing aid on the market, the Completely-In-the-Canal (CIC) hearing instrument.[3,4,5,6] Among the reported benefits of CIC hearing instruments relative to other types of hearing instruments are reduced occlusion effect, reduced acoustic feedback oscillation problems and increased real ear acoustic gain, particularly in the high frequencies.[6,7]



By David Preves, PhD

The CIC instrument belongs to the category of deep canal hearing aid fittings which traditionally have been implemented by making the ear canal of the hearing instrument extend past the second bend of the wearer's ear canal.[3,8] Such deep placement of the receiver results in a smaller residual ear canal volume than that produced by hearing instruments with shorter ear canal lengths, which cause CIC hearing instruments to produce proportionally higher ear canal sound pressure levels. Bryant, Mueller and Northern,[2] reported 12 dB mean greater functional gain at 4000 Hz for eight subjects having ITE hearing instruments with a long earshell canal relative to that for ITE hearing instruments with shorter earshell canals.

Additionally, CIC instruments have a faceplate (and hence the hearing aid microphone inlet) recessed 1-2 mm below the ear canal aperture, deep within the ear canal.[3,4] Such deep placement of the microphone is thought to produce increased high frequency emphasis due to increased pinna and concha diffraction and increased ear canal resonance effects. This article attempts to further explore the causes of and extent of the increased gain benefit provided by CIC hearing instruments.

Method

David A. Preves, PhD, is vice president of research and development at Argosy Electronics, Eden Prairie, MN.

In order to determine the causes and amount of the overall increase in real ear aided gain and increased-high frequency emphasis provided by CIC instruments relative to that of ITE and ITC instruments, a study was conducted in which the following questions were addressed:

1 How much of the extra gain provided by CIC instruments is due to smaller residual ear canal volume?

2 How much of the extra gain provided by CIC instruments is due to the microphone inlet being further recessed into the ear canal?

3 How much more output SPL is produced in the real ear by CIC instruments than that produced by ITC and ITE instruments?

4 What is the difference between overall gain in the $2\ \text{cm}^3$ coupler and that in real ears produced by ITE, ITC and CIC hearing instruments?

To answer Question 1, two hearing instruments having faceplates with a deep microphone location were made for one ear of each of the five subjects participating in the study. One hearing instrument (an Argosy CAMEO CIC) had a long canal that extended beyond the second bend of the subject's ear canal, and the other had a shorter canal that extended only to the first bend of the subject's ear canal. These hearing instruments were used to determine the effect of CIC earshell canal length on the real ear aided sound pressure. One reason for examining this relationship is that some of the reported benefits of CIC hearing instruments, such as greater overall real ear aided gain, greater high frequency real ear aided gain and relief from the occlusion effect, are thought to be due to increased CIC earshell canal depth. The same receiver type (Knowles ES3140) and linear circuit with approximately 19 dB of HFA gain were used in each of these 10 hearing instruments and the receiver tubing outlets were positioned at the centers of the ear canals. The approximate earshell canal lengths (measured with a flexible ruler from the junction of the faceplate/earshell to the tip of the

SUBJECT	LONG CANAL (MM)	SHORT CANAL (MM)
AL	23	15
BJ	21	14
CS	23	16
TF	22	15
MW	23	16
MEAN: SD:	22.4 0.9	15.2 0.8

Table 1. *Approximate canal lengths of long canal and short canal hearing instruments.*

SUBJECT	LONG CANAL (dB SPL)	SHORT CANAL (dB SPL)	DIFFERENCE (dB)
AL	97.6	92.3	5.3
BJ	97.5	92.2	5.3
CS	95.1	88.9	6.2
TF	95.5	87.3	8.2
MW	98.0	90.9	7.1
			MEAN: 6.4 dB SD: 1.2 dB

Table 2. *Real ear RMS output SPL for long canal and short canal hearing instruments at fixed volume control settings.*

earshell) of the two instruments for each subject are shown in Table 1. The mean earshell canal length was 22.4 mm for the CIC instruments with long earshell canal and 15.2 mm for the instruments with the shorter earshell canal length. The instruments with the shorter canal length were designed to provide the typical location of the tip of an ITC earshell canal.

To answer Question 2, a full-concha ITE earshell, an ITC earshell and a CIC earshell were constructed for one ear of each of the five subjects. The same microphone type (Knowles EM 3046) was placed in the same location on the faceplate of the 15 earshells. These earshells had different faceplate depths to investigate the effect of microphone inlet position on the electrical signal provided from the microphone to the hearing aid amplifier. The approximate mean microphone inlet distances from the center of the ear canal apertures of the subjects were +10.5 mm, +4.3 mm and +1.0 mm, respectively for the ITE, ITC and CIC earshells. A more positive distance indicates a microphone inlet position more lateral to the ear canal aperture. Thus, the mean ITE microphone inlet position protruded out from the ears 6.2 mm further than the mean ITC microphone inlet position, which in turn protruded out 3.3 mm further than the mean CIC microphone inlet position. One reason for examining this relationship is that some of the benefits of CIC instruments, such as greater high frequency real ear gain and reduced acoustical feedback oscillation problems, are thought to be due to the deeply recessed microphone inlet on CIC instruments. The microphone signal was routed to an external amplifier to measure the change in microphone output with changing microphone depth in the five ear canals. Relative differences in sensitivity between the microphones were accounted for.

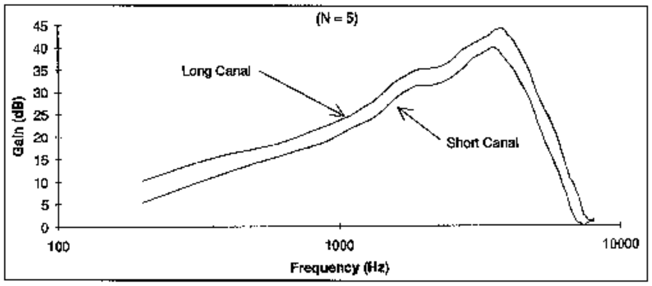


Fig. 1 *Means of real ear.frequency responses (REAR) in five subjects for the hearing instrumetns with recessed faceplates having long and short earshell canals as per Tables 1 and 2. Input: 60 dB SPL speech-shaped noise from Frye 6500 real ear probe microphone system.*

To answer Questions 3 and 4, data were gathered at another time for another set of complete ITE, ITC and CIC hearing instruments comparing real ear to 2 cm³ coupler overall rms output SPL. All of the instruments used the same type of microphone and receiver and the same linear circuit having approximately 19 dB HFA gain. While no attempt was made to keep the same amount of use gain as measured in the 2 cm³ coupler between ITE, ITC and CIC groups and subjects, the volume control trimmers were not moved between 2 cm³ coupler and real ear measurements for each subject. Also, no attempt was made to use the same subjects between ITE, ITC and CIC groups. However, the relative differences between 2 cm³ coupler output SPL and real ear output SPL should provide an indication of the differences in output SPL between CIC, ITE and ITC hearing instruments in real ears.

Data gathered on the above CIC, ITC and ITE instruments included noise output SPL, acoustic frequency response and acoustic input/electrical output with a 60 dB SPL speech-shaped noise input signal in accordance with ANSI S3.42-1992.[1] Acoustic data were obtained in the 2 cm³ coupler and in real ears using a Frye 6500 hearing aid analyzer/probe microphone system.

Results

In answer to Question 1, Table 2 shows the overall real ear rms noise output SPL obtained with the Frye 6500 probe microphone system in the five ear canals for the instruments with long and short earshell canals, respectively. On average, the 5 CIC instruments with longer earshell canals provided 6.4 dB greater overall real ear rms output SPL than that of the five instruments with shorter earshell canals that represented ITC hearing instruments. Using a 2-tailed t-test, this difference was significant at the .01 level. Since this result was obtained using approximately the same microphone inlet depth within the ear canals for both sets of hearing instruments, this benefit can be assumed to be caused solely by the difference in earshell canal length. Fig. 1 shows the means of the real ear aided frequency responses (REAR) obtained in the five ears for the long earshell canal and for the short earshell canal conditions. Although it appears that the difference between these two frequency response curves is about the same across the entire frequency range, there is actually about 6 dB difference in the high frequencies (e.g., at 4000 Hz and above) and only about 3-4 dB in the low and mid-frequencies. Thus, the increased earshell canal length of a CIC instrument provides greater overall output SPL with more high frequency boost as compared to an ITC instrument.

SUBJECT	DIFFERENCE (CIC-ITE) (dB)
AL	3.81
BJ	5.62
CS	2.37
TF	6.62
MW	3.49
	MEAN: 4.38 dB SD: 1.71 dB

Table 3. *Microphone placement effects (corrected for variability across Mics), CIC vs ITE earshells.*

In answer to Question 2, Table 3 shows that there is a 4.38 dB mean overall rms advantage by having a CIC microphone inlet position in comparison to an ITE microphone inlet position. This difference was significant with a t-test at the .05 level. Correspondingly, Table 4 shows that there is a 1.73 dB mean overall rms advantage having a CIC

SUBJECT	DIFFERENCE (CIC-ITC) (dB)
AL	2.28
BJ	3.39
CS	-1.76
TF	3.13
MW	1.63
	MEAN: 1.73 dB SD: 2.07 dB

Table 4. *Microphone placement effects (corrected for variability across mics), CIC vs ITC earshells.*

SUBJECT	DIFFERENCE (ITC-ITE) (dB)
AL	1.53
BJ	2.23
CS	4.13
TF	3.49
MW	1.86
	MEAN: 2.65 dB SD: 1.11 dB

Table 5. *Microphone placement effects (corrected for variability across mics), ITC vs ITE earshells.*

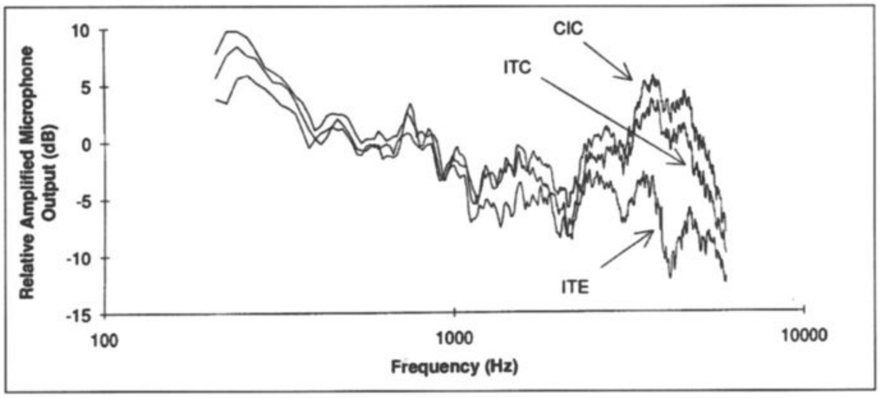


Fig. 2 *Means of amplified hearing instrument microphone output signal for ITE, ITC and CIC microphone inlet positions, each in five real ears. Input: 60 dB SPL speech-shaped noise from Frye 6500 real ear probe microphone system.*

microphone inlet in comparison to an ITC microphone inlet position. This difference between ITC and CIC microphone inlet positions was not significant at the .05 level with a t-test. Although not directly relevant to the experimental questions, Table 5 shows that there is a 2.65 dB overall rms advantage having a ITC microphone inlet position in comparison to an ITE microphone inlet position. This difference was significant with a t-test at the .05 level. Fig. 2 shows composite curves of the amplified microphone outputs, obtained by averaging the microphone outputs for all subjects for each of the three hearing instrument types–ITE, ITC and CIC. (Note that the speech-shaped spectrum of the noise input signal is contained in the microphone output spectrum.) It is evident from Fig. 2 that most of the overall rms differences in Tables 3, 4 and 5 occur in the high frequencies. Fig. 2 also indicates greater pinna and concha diffraction and ear canal resonance effects with the CIC microphone inlet position as compared to the ITE and ITC microphone inlet positions.

SUBJECT	2cc RMS SPL (dB)	REAL EAR RMS SPL (dB)	DIFFERENCE (dB)
CIC			
BJ	67.6	94.2	+26.6
AL	76.4	102.3	+25.9
MH	70.7	96.6	+25.9
TF	66.2	88.8	+22.6
			mean: +25.3 dB
ITC			
TF	75.3	90.2	+14.9
CS	75.3	92.0	+16.7
MW	72.8	92.2	+19.4
			mean: +17.0 dB
ITE			
TFR	79.8	93.0	13.2
CSR	79.1	88.1	9.0
BWR	79.8	87.4	7.6
JNR	78.5	92.5	14.0
			mean: +11.0 dB

Table 6. *2cc vs real ear output RMS SPL at fixed volume control positions for CIC, ITC and ITE hearing instruments (60 dB SPL input).*

For Questions 3 and 4, Table 6 shows the overall rms noise output SPL obtained for the CIC, ITC and ITE instruments in the real ears of their wearers versus that in the 2 cm^3 coupler. Although the subjects and coupler gains were not the same between the three groups, the relative values in the DIFFERENCE column should be valid. In answer to Question 4, the CIC, ITC and ITE instruments produced about 25, 17 and 11 dB greater mean noise output SPL, respectively, in the real ears than that produced in the 2 cm^3 coupler. Question 3 can be answered by taking the difference between these figures which is also required to normalize the coupler gain between subjects and groups. Thus, on average, the CIC instruments provided about 8 dB and 14 dB more real ear noise output SPL, respectively, than that provided by the ITC and ITE instruments.

Implications for designing CIC hearing instruments

The results of these tests are helpful in predicting the coupler gain that is required for a CIC hearing aid to match prescriptive fitting formulae targets such as those prescribed by NAL-R. From the results above, for a given audiogram, one would expect a CIC hearing instrument to require 14.3 dB less overall noise gain than an ITE hearing instrument and 8.3 dB less than an ITC instrument in the 2 cm^3 coupler.[1] Since much of the increase in output SPL provided by a CIC instrument is in the high frequencies (Fig. 2), proportionally less high frequency gain than overall gain in the 2 cm^3 coupler would be required to provide the required insertion gain for a given audiogram from a CIC instrument than from ITE and ITC instruments.

Conclusion

If CIC hearing instruments are constructed with faceplates deeply recessed so that their microphone inlets are at or below the ear canal aperture, and with long earshell canal lengths extending beyond the second bend, the overall real ear gain increase and increased high frequency output that CIC instruments are capable of providing will be realized. These benefits must be traded off with the issue of ease of insertion/removal which arises when providing such long earshell canal lengths. ◆

Acknowledgements

The author wishes to thank Chris Stevenson of Argosy Electronics for constructing the devices tested.

References

1. ANSI S3.42-1992. American National Standards Institute Standard Testing Hearing Aids With A Broad-Band Noise Signal.
2. Bryant M, Mueller G, Northern J: Minimal contact long canal ITE hearing instruments. *Hear Instrum* 1991; 42(1): 12-13.
3. Giller R: Completely in the Canal: A new style for a new clientele. *Hear Instrum* 1993; 44(4): 24-25.
4. Killion M: More on CICs. Letter to the Editor. *Hear Instrum* 1993; 44(10): 42.
5. Kochkin S: Optimizing the emerging market for completely-in-the-canal instruments. *Hear J* 1994; 47(6): 25-34.
6. Staab W: Precipitous, high frequency hearing losses: a new solution. *Hear Instrum* 1993; 44(4):20-22.
7. Staab W: The peritympanic instrument: fitting rationale and test results. *Hear J* 1992; 45(10):21-26.
8. Staab W and Finlay B: A fitting rationale for deep fitting canal hearing instruments. *Hear Instrum* 1991; 42(1): 6-10.