Assessment of patient satisfaction with various configurations of digital CROS and BiCROS hearing aids

Samuel L. Hill III, MD; Avron Marcus, MD; E. Nicholas B. Digges, MD; Nancy Gillman, MA; Herbert Silverstein, MD, FACS

Abstract
We conducted a study of 91 patients with severe-to-profound asymmetric hearing loss to assess their satisfaction with digital contralateral routing of signal (CROS) or bilateral contralateral routing of signal (BiCROS) hearing aids. Satisfaction was evaluated on the basis of the number of patients who elected to purchase their hearing aid following a free 30-day trial and on the results of a subsequent 8-question survey. We found that overall patient satisfaction was generally high. At the end of the 30-day trial, 66 of the 91 patients (72.5%) elected to keep their CROS or BiCROS device, a percentage that is far greater than the acceptance rates of 10 to 20% that had been previously reported with older models of the CROS and BiCROS devices. According to the survey responses, those who kept their devices gave them an overall rating of 3.4 on a scale of 1 (very dissatisfied) to 5 (very satisfied); those who returned their devices gave them an overall rating of 1.9.

Introduction
Traditionally, the medical community has not demanded the same level of aural rehabilitation for patients with unilateral or asymmetric hearing deficits as it has for patients with symmetric bilateral deficits. In fact, a still common recommendation for such patients is nothing more than to sit close to and turn the better-hearing ear toward the sound source. However, we do know that individuals with unilateral or asymmetric hearing loss can experience a wide range of hearing difficulties. The seriousness of these hearing deficits varies, depending on the nature and degree of the loss and individual work and social hearing demands.

Not all individuals who experience these hearing deficits complain about them or seek treatment, but those who do often report difficulty listening when speech originates on the side of the worse-hearing ear, difficulty understanding speech in a noisy environment, and difficulty in locating the source of sound. The unilateral listener usually has no difficulty communicating with only 1 person in a relatively quiet environment, but many listening situations occur in environments that include multiple individuals.

Several approaches to aural rehabilitation in patients with unilateral or asymmetric hearing loss have been suggested. Each strategy involves different methods of routing sound to the better ear. These approaches include transcranial sound transmission via high-output in-the-ear or behind-the-ear hearing aids, semi-implantable bone-anchored hearing aids, and conventional contralateral routing of signal (CROS) or bilateral contralateral routing of signal (BiCROS) hearing aids.

CROS and BiCROS devices traditionally have been used for patients with unilateral hearing loss in an attempt to restore the “head shadow effect” and improve sound localization. However, these devices have not gained widespread acceptance for numerous reasons, including performance factors such as ineffectiveness in high ambient noise and distortion. Among the theories that have been proposed to explain the poor performance are inappropriate fitting, poor adjustment, and technical inadequacies.

The performance of CROS and BiCROS devices may improve as a result of developments in digital signal processing. In this article, we describe our study of patient satisfaction with the new digital CROS and BiCROS hearing aid systems. Our goals were to determine whether technological advancements in digital signal processing have truly enhanced the efficacy of CROS and BiCROS devices and to identify any shortcomings that may remain.

Patients and methods
We conducted a case review of 104 patients at our institution who had severe-to-profound asymmetric hearing loss and poor speech discrimination scores (<40% in the worse
Thirteen patients were excluded because they did not meet eligibility criteria. The remaining group of 91 patients was made up of 43 men and 48 women, aged 41 to 89 years (mean: 70.6). The causes of their hearing loss included Menière’s disease, acoustic neuroma, autoimmune inner ear disease, temporal bone fracture, and noise exposure. All patients had undergone a full evaluation of their hearing loss, including audiometry, otoacoustic emission testing, electrocochleography, and brainstem-evoked response testing, depending on the individual’s underlying etiology.

Of the 91 patients, 9 were fitted with a corded CROS device and 82 with a BiCROS device (figure 1), either corded (n = 73) or cordless (n = 9). No cordless CROS device was used in this study. The selection of the specific type of hearing aid was based on audiometric data, configuration of hearing loss, availability, and patient preference.

One week after fitting, patients returned for a follow-up adjustment. Modifications were based on sound-field testing and patient input. A second follow-up was conducted at the end of a free 30-day trial, at which time patients chose to either purchase their hearing aid or return it without being charged for its use.

Two weeks after the end of the 30-day trial, we mailed a questionnaire to all patients, regardless of whether they chose to keep their CROS or BiCROS device. Four weeks later, we mailed follow-up questionnaires to those patients who had not responded to the first questionnaire. Two weeks later, we placed telephone calls to those who had still not responded.

The survey was made up of 8 questions (figure 2). Responses were quantified on a scale from 1 (very dissatisfied) to 5 (very satisfied).

Results

At the end of the 30-day trial, 66 patients (72.5%) elected to keep their hearing aid and 25 (27.5%) returned it (table 1). Acceptance rates were high for both the CROS (66.7%) and BiCROS (73.2%) devices. The overall acceptance rate for the corded models (76.8%) was high; the acceptance rate for the cordless model was low (33.3%), but only a small number of patients had received a cordless device.

Among the reasons cited by the 25 patients for returning their devices were (1) the new hearing aid was no better than their previous device, (2) the device was too complicated, (3) the device was too expensive, (4) use of the device was
ASSESSMENT OF PATIENT SATISFACTION WITH VARIOUS CONFIGURATIONS OF DIGITAL CROS AND BICROS HEARING AIDS

hindered by clinical circumstances such as otorrhea or otalgia (meaning that the patient was not a good candidate for the device), and (5) the cord was bothersome.

Completed questionnaires were received from 34 of the 66 patients who accepted their hearing aid (51.5%) and from 9 of the 25 patients who returned it (36.0%). Of the remaining 48 patients, we were unable to contact 29, and 19 declined to participate. Five of the 66 patients who had elected to purchase their hearing aid were not actually using it; taking this finding into consideration, the true acceptance rate falls from 72.5 to 67.0% (61/91).

The overall mean value for the responses to all 8 questions by all 43 respondents was 3.12 on the 5-point scale. The mean rating scores were 3.4 for those who kept their device (table 2) and 1.9 for those who did not (table 3). The highest overall mean value was 3.6 for the BiCROS corded device, and the lowest was 1.1 for both the CROS and the BiCROS cordless models.

Discussion
The original CROS hearing aid was described by Harford and Barry in 1965 as a prosthesis to assist hearing in patients who have one ear that is too impaired to be aided and the other that is normal or nearly normal. One of the effects of the CROS device is that it restores the head shadow effect. It has been demonstrated that significant decreases in sound pressure level occur when signals are presented from the poorer-hearing side of the skull. The amount of reduction in sound pressure level is frequency-dependent; the greatest decreases occur at high frequencies (shorter wavelengths)—that is, frequencies above 1,500 Hz by 7 to as much as 30 dB. Because consonants are the most informative speech elements and are characteristically carried in the high frequencies, speech understanding is significantly degraded in patients with significant reductions in sound pressure level. Speech discrimination is further impaired in patients with asymmetric hearing loss by ambient masking noise and the absence of binaural summation. Individuals with asymmetric hearing loss experience significant decreases in sound localization, as well as understanding in noise or with sound presented to the poorer side because of the head shadow effect. The head shadow effect is theoretically restored by placing a microphone in the poorer ear and routing sound to the better ear.

Table 1. Number (%) of patients who accepted and number (%) of patients who returned their hearing aid at the end of the 30-day trial

<table>
<thead>
<tr>
<th></th>
<th>Corded</th>
<th></th>
<th>Cordless</th>
<th></th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Kept</td>
<td>Returned</td>
<td>Total</td>
<td>Kept</td>
</tr>
<tr>
<td>CROS</td>
<td>9</td>
<td>6 (66.7)</td>
<td>3 (33.3)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BiCROS</td>
<td>73</td>
<td>57 (78.1)</td>
<td>16 (21.9)</td>
<td>9</td>
<td>3 (33.3)</td>
</tr>
<tr>
<td>All</td>
<td>82</td>
<td>63 (76.8)</td>
<td>19 (23.2)</td>
<td>9</td>
<td>3 (33.3)</td>
</tr>
</tbody>
</table>

* Five of these 66 patients said they were no longer using their hearing aid.

Table 2. Questionnaire responses (mean values) by 34 of 66 patients who kept their hearing aid*

<table>
<thead>
<tr>
<th></th>
<th>Experience enjoyable</th>
<th>Locate sound</th>
<th>Background noise</th>
<th>Hearing in car</th>
<th>Noise reduction</th>
<th>Spouse/family</th>
<th>General satisfaction</th>
<th>Recommend to others</th>
<th>Overall average</th>
</tr>
</thead>
<tbody>
<tr>
<td>CROS</td>
<td>3.0</td>
<td>3.3</td>
<td>3.0</td>
<td>3.8</td>
<td>3.3</td>
<td>3.3</td>
<td>2.8</td>
<td>3.0</td>
<td>3.2</td>
</tr>
<tr>
<td>BICROS corded</td>
<td>3.7</td>
<td>3.3</td>
<td>3.1</td>
<td>4.0</td>
<td>2.9</td>
<td>4.0</td>
<td>3.9</td>
<td>3.9</td>
<td>3.6</td>
</tr>
<tr>
<td>BICROS cordless</td>
<td>2.5</td>
<td>3.5</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>3.5</td>
<td>2.0</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>BICROS total</td>
<td>3.6</td>
<td>3.3</td>
<td>3.0</td>
<td>3.9</td>
<td>2.9</td>
<td>3.9</td>
<td>3.7</td>
<td>3.8</td>
<td>3.5</td>
</tr>
<tr>
<td>Overall average</td>
<td>3.4</td>
<td>3.3</td>
<td>3.0</td>
<td>3.8</td>
<td>3.0</td>
<td>3.8</td>
<td>3.4</td>
<td>3.5</td>
<td>3.4</td>
</tr>
</tbody>
</table>

* Response values are based on a scale from 1 (very dissatisfied) to 5 (very satisfied).
Modifications of the CROS system have included the introduction of dual microphones to mix and amplify signals from the poorer ear with input to the better ear.\textsuperscript{4,7} Important to this setup is the use of open ear molds in the better ear to attenuate low-frequency sounds and reduce occlusion effects in that ear. The acoustic benefit of open ear molds and the high-frequency emphasis produced have been shown to improve speech intelligibility.\textsuperscript{11} The additional benefit of permitting greater gain secondary to increased microphone and receiver distance has been postulated.\textsuperscript{4}

Vague preliminary selection criteria for CROS candidacy were originally defined by Harford and Dodds.\textsuperscript{4} Their criteria include (1) the presence of severe unilateral hearing loss with some accompanying loss in the better ear, although not enough to warrant an ordinary hearing aid; (2) a high demand on listening; and (3) a high level of patient motivation.\textsuperscript{4} Harford and Barry added that (1) a patient’s age at the onset of hearing loss is not a factor in the degree of success or failure of CROS aids, (2) mild-gain instruments should suffice for CROS, and (3) the most meaningful factor in helping a patient decide whether to commit to a CROS device is his or her experience while actually using one during regular daily activities.\textsuperscript{6} Additional research has been done in an attempt to better define the optimal CROS or BiCROS candidate and to improve methods of fitting these devices.\textsuperscript{12-15}

Despite system modifications, improvements in fitting methods, and some early reports\textsuperscript{13,15,16} describing the benefits of CROS and BiCROS hearing aids, their use has remained limited, partly because other reports\textsuperscript{12,14,17} and anecdotal accounts have detailed minimal benefits, numerous complaints, and low overall success rates. In addition, comparison studies of CROS and BiCROS with other methods of unilateral aural rehabilitation have found the former lacking.\textsuperscript{18-20} Common complaints include poor performance in high ambient noise and increased distortion. However, the relatively recent development of digital signal processing holds some promise for improving the CROS and BiCROS devices, although few studies have been performed. Although some problems have been positively identified in digital CROS, including inappropriate gain with subsequent good-ear masking, the lack of success is most likely attributable to a complex set of variables that includes poor patient motivation, unrealistic expectations, limited impairment, and other as yet unidentified factors.\textsuperscript{21}

Our study demonstrated that patient satisfaction with the new generation of digital CROS and BiCROS hearing aids was higher than that seen in previously reported studies. The acceptance rates in our study ranged from 33.3 to 78.1%, compared with only 10 to 20% for analog devices.\textsuperscript{20} Furthermore, our study demonstrated that the corded devices are more popular than cordless models, which is consistent with other reports in the literature.\textsuperscript{20}

In addition to the benefits of digital technology, the high level of acceptance of these hearing aids in our study can be attributed to appropriate candidate selection, proper fitting, and close follow-up. Therefore, we believe that CROS and BiCROS corded hearing aids should again be offered as a viable alternative for patients with asymmetric sensorineural hearing loss.

Acknowledgments
The authors thank Art Gagnon, BC-HIS, for alerting us to this technology, and Corinne North for helping with the data.

Table 3. Questionnaire response (mean values) by 9 of 25 patients who returned their hearing aid*