If you were asked to name the most significant developments in hearing aids over the last fifty years, which ones would you consider?

Digital signal processing? The custom in-the-ear (ITE)/in-the-canal (ITC) family? The directional microphone? First fit algorithms? Technologies for feedback control? They are all very worthy of inclusion, but there are those who would place the introduction of CROS amplification very near the top of that list. In point of fact, the CROS concept, introduced over fifty years ago, was the impetus for a revolution in the thinking of hearing care professionals of the day, and it spawned any number of understandings over the next decades that remain an influence in our modern approach to fitting.

Recall that CROS is an acronym for **Contralateral Routing of Signals**, a hearing aid system first recommended (and still fitted today) for unilateral hearing losses where the patient’s hearing is good on one side and a loss is on the other. Originally conceived for use with eyeglass aids, a microphone in the temple of the unaidable side picked up the signal that was transmitted by a thin wire/cord connected to the circuitry and receiver in the other temple. The amplified sound was delivered by tubing to an open ear, obviating the use of standard earmolds. Later, the industry developed wireless CROS instruments that did away with the need to use wires and cords to connect each side.

In 1970, Al Dunlavy, a hearing care professional in Manhattan, wrote an article for *Audecibel*, a publication of the National Hearing Aid Society, titled “CROS: The New Miracle Worker.” (Dunlavy, 1970). Why would he call CROS, of all things, a miracle? And was it really? This article deals with a specific and unique application of the CROS aid that was never originally intended but that eventually became its most significant form of usage — i.e., a solution to the problem of feedback.

Until the advent of CROS, problems with feedback dogged the industry. Today, open canal fittings are routine and feedback issues are seldom a concern. Starkey’s feedback cancellation algorithm makes bilateral high frequency fittings a walk in the park. One can literally grab a couple of unoccluded ear buds from off the shelf and fit them without giving a thought to the issues faced years ago.
The Harvard Report on Hearing Aids

To get a full appreciation of the impact of CROS on the practices of the day, we need to go all the way back to 1947, about the time audiology began. That year a famous research monograph on hearing aids was published, referred to as the Harvard Report (Davis et al., 1947). At the time, the Psycho-Acoustics Laboratory at Harvard University was the single most influential research center in the United States regarding auditory and acoustic matters. The report bore the names of some of the true pioneers of psychoacoustics and, as such, was received with the highest respect. The report recommended that a flat or six dB per octave slope frequency response was adequate for the majority of patients who needed a hearing aid, and it severely criticized other methods of fitting, implying they were a waste of time.

The Harvard Report recommendations led the early audiology world astray for years. The Report was treated with some reverence and was taught accordingly. But fitting hearing aids with a flat response or a six dB per octave response on patients with sensorineural losses led to many dissatisfied patients with poorly performing hearing aids. It seemed heretical to question the puzzling recommendations of these prestigious authors, so professionals just quietly ignored them and ended up making their own decisions about which frequency response to fit. Some of the hearing aid companies also questioned the Report and continued to supply aids with responses that emphasized frequency ranges where the loss was greatest (Watson & Tolan, 1949).

A witch’s brew of selection methods permeated the hearing aid world for the next decades. Included were the Carhart Method (discussed later), selective amplification, prescriptive formulas, master hearing aids and suprathreshold sound pressure testing. Few, if any, professionals in the decades between 1950 and 1980 had a clear idea, or even an inkling, of how to choose the most appropriate frequency-gain response. Lybarger’s half-gain rule, which became the starting point for some of today’s prescriptive fitting algorithms, was generally known only to a select few and hadn’t spread enough to influence the rest of the hearing aid world (Lybarger, 1944 & 1963).

Hearing Aid Evaluations in Clinics

At about the time of the Harvard Report, Raymond Carhart, generally considered the “father of audiology,” published procedures for selecting the most appropriate hearing aid (Carhart, 1946 & 1950). This method gained much ascendancy in the university clinics. Aids were pre-selected from clinic stock for inclusion according to the best judgment of the professional. As a result, the selected aids varied widely according to the personal preference of the professional. When body aids were being evaluated, they were placed on a baffle board alongside the patient; sometimes with custom and sometimes with stock molds, sometimes with venting and sometimes without venting. Head worn aids were also connected to stock and sometimes to custom molds with and without venting. Aided and unaided tests including functional gain, discomfort, and word recognition in noise and quiet were performed. It’s hard to imagine today, but conventional wisdom held that on average, aided word understanding scores were not expected to exceed the unaided score, which served as a target. The best performing aids were those that provided aided scores approximating the unaided score obtained under earphones. The patient was then referred to a hearing care professional for the purchase. This method had some face validity, having been developed during WWII in veteran’s rehabilitation clinics. Eventually, however, studies showed it to be completely unreliable and non-predictive (McConnell et al., 1960; Shore et al., 1960; Resnick & Becker, 1963).

Further problems ensued when early behind-the-ear (BTE) and eyeglass aids were first introduced in the 1950s. Better bandwidth was theoretically possible with head worn aids, but the transducers...
were positioned much closer to each other than in body aids, and manufacturers had a difficult time isolating one from the other. The result was a high incidence of internal and external feedback. One could use full-shell earmolds with minimal venting in order to eliminate external feedback, but that exacerbated the occlusion effect for some patients.

It is no wonder that hearing aid fitting became one of the least desirable aspects of audiology during those years. Few students opted for making hearing aids the major focus of their studies. In fact, it was regarded as somewhat déclassé if one did, and pity the brave instructor who taught amplification, for reliable facts were few and far between. Professionals were fitting rather large aids with little or no understanding of earmold acoustics on patients who, then as now, invariably presented with losses having a high frequency component. Plus, most head worn aids in the 1950s and 1960s had very limited flexibility, feedback issues, short battery life, and inadequate gain, output and response characteristics.

The Beginning of Wisdom

Fully five years prior to the Harvard Report mentioned above, Earl Harford, Ph.D., a professor at Northwestern University, began to document the advantage of the CROS concept and reported it to the scientific community. He and his colleagues published a series of studies in the professional journals exploring its potential and benefits (Harford, 1966, 1967, 1968; Harford & Barry, 1965; Harford & Dodds, 1974; Dodds & Harford, 1968). Almost immediately, professionals recognized that CROS was not just a solution for unilateral hearing loss, but rather, because the microphone and receiver were on separate sides, it was possible to provide high gain, high frequency amplification without encountering feedback for patients with bilateral high frequency losses. Since nearly all fittings in those days were monaural anyway, every patient who presented with a bilateral sloping high frequency loss was a candidate and was assured of a nearly perfect fitting in at least one ear. It was finally possible to deliver the satisfaction that the hearing aid ads promised.

In one fell swoop, this unique CROS application dealt with a number of issues. Papers began to appear in the audiological literature showing that aided discrimination scores actually did improve markedly with CROS fittings compared to scores that had been obtained under earphones (McClellan, 1967; Green, 1968; Hodgson & Murdock, 1970; Jetty & Rintelmann, 1970). This was a surprise to many, for although it was known that test scores varied as test conditions changed (talker, level, transducers, test stimuli, etc.), for some reason that had never fully registered in the case of hearing aid fittings. The improvement in scores was a result of the following:

1. The high frequencies received markedly greater amplification than had been possible heretofore.
2. The high frequency amplification bandwidth was significantly more extended than was previously achievable.
3. Reduced upward spread of masking effects was due to the absence of amplification in the low frequencies.
4. As a bonus, the occlusion effect was virtually eliminated.

These results set in motion countless research studies over the years dealing with the benefits and usefulness of high frequency amplification and its contribution to word recognition in both children and adults. It also produced many studies dealing with the effect of the earmold/coupling on the frequency response.
Achieving Miracles

It is instructive to review the steps of hearing care professionals who were fitting CROS hearing aids prior to the introduction of wireless CROS. First, the patient had to be wearing zyl (special plastic) eyeglasses or was persuaded to purchase a pair. If the patient did not wear glasses, he or she was asked to get a pair with plain glass lenses. The frames had to have so-called “standard hinges” because the graduated temple terminations furnished with the eyeglass hearing aids were only available with this type of hinge. Then a small circular motor-tool saw blade was used to cut a trench from hinge to hinge in the back of the frame. A very thin plastic cable containing two or three extremely fine wires was placed in the trench and covered over with a plastic sealant. After it had dried, the inside cover of each temple was removed, and the fine wires were soldered to the microphone on one side and to the circuitry and receiver on the other. The temple covers were then re-glued or screwed back into place. The eyeglass temples and frame were heated, bent and adjusted so that the patient was comfortable with the glasses. A pipe cleaner that had been shaved down was inserted into a length of earmold tubing and bent to the right shape for secure placement in the ear canal. The tubing was then heated with a blower until it set. If needed, the response could be manipulated somewhat by changing the depth of the tubing in the ear canal, or by using tubing with different dimensions.

Why would the professionals go through such a complicated, lengthy and convoluted process? The answer is that they never had so many grinning, enthusiastic, happy customers. Handholding just about disappeared if the patients were fitted with CROS; most old and new customers experienced success right out of the box. Even with all the rigamarole that attended CROS installation and fitting, countless professionals routinely chose to recommend and fit them. To them, fittings without feedback problems were indeed miracles. In the early 1970s, the records show that in some years CROS fittings accounted for nearly 20 percent of all head worn aids. Harford and Dodds (1974) suggested that by 1972 CROS fittings had probably reached close to 40 percent of all recommendations in university audiology clinics.
References


