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Review

The contributions of William F. House to the field of implantable auditory devices

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ABSTRACT

William F. House was a pioneer in the evolving field of cochlear implants and auditory brainstem implants. Because of his vision, innovation and perseverance, the way was paved for future clinicians and researchers to carry on the work and advance a field that has been dedicated to serving adults and children with severe to profound hearing loss. Several of William House's contributions are highlighted in this prestigious volume to honor the recipients of the 2013 Lasker-Debakey Clinical Medical Research Award. Discussed are the early inventive years, clinical trials with the single-channel cochlear implant, the team approach, pediatric cochlear implantation, and the auditory brainstem implant. Readers may be surprised to learn that those early contributions continue to have relevance today.

This article is part of a Special Issue entitled <Lasker Award>.

William F. House, D.D.S., M.D., the father of Neurotology, died on December 7, 2012 at the age of 89 years. To those of us fortunate enough to have worked alongside Dr. House during the early days of implantable auditory devices, we may now look back and contemplate the ways in which our careers have been shaped by the experience. To us he will always be remembered fondly as "Dr. Bill" (Fig. 1).

I have been asked to pay tribute to the memory of William House by highlighting his contributions to the early development of implantable auditory devices in this prestigious volume to honor the 2013 Lasker-DeBakey Clinical Medical Research Award recipients—Drs. Graeme Clark, Ingeborg Hochmair, and Blake Wilson. Had William House still been with us, he would have applauded their accomplishments. We would be remiss, however, in not recognizing the accomplishments of William House for his development and early trials of both the cochlear implant (CI) and the auditory brainstem implant (ABI). Each of us engaged in this work today remains indebted to him.

Dr. House received many accolades throughout his illustrious career, followed by fond remembrances after his death. My goal here is to refresh readers' memories about William House's remarkable accomplishments during the early era of implantable auditory devices. I was exceptionally fortunate to have worked with William House during that period, having joined the CI team in 1976 as a newly minted audiologist. This early work was first carried out at the Hearing Rehabilitation and Research Center, an affiliate of the Ear Research Institute in Los Angeles. The two centers eventually merged to become the House Ear Institute.

In this paper I highlight the important events and achievements that occurred during the early development of the CI and ABI at the House Ear Institute, and touch upon their relevance today. Beginning with the early inventive years, the topics that follow include the first CI clinical trials, the team approach, pediatric cochlear implantation, and the ABI. I suspect that those not conversant with the literature that details the contributions and innovations of William House to this field will be pleasantly surprised.

1. Origins

William House first became interested in electrical stimulation of the auditory nerve as far back as 1958 (the second year of his medical practice), when a patient brought him a newspaper article reporting that a deaf adult responded to sound after receiving direct stimulation of the auditory nerve (House, 2011). The investigators were Andre Djourno and Charles Eyries from Paris, France, and the surgery they performed was in 1957 (see Eisen,

List of abbreviations: ABI, auditory brainstem implant; CAP, Categories of Auditory Performance; CDaCI, Childhood Development after Cochlear Implantation; CI, cochlear implant; FDA, Food and Drug Administration; Hz, hertz; kHz, kilohertz; NF2, Neurofibromatosis Type 2; NIDCD, National Institute on Deafness and Other Communication Disorders; NIH, National Institutes of Health

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Fig. 1. Photograph of William F. House, D.D.S., M.D. (from the House Ear Institute archives).

2003). Dr. House soon became actively involved in developing his own CI, which saw the first two adult patients implanted with a prototype in 1961, one of whom was implanted with a multiple-electrode device. The first "take-home" wearable device, a single-electrode CI, became available in 1972 (House and Urban, 1973; Danley and Fretz, 1982). Dr. House's original motivation for instigating this work was based on a deep desire to help children with profound hearing loss. In his memoir he writes.

> *"… I had seen deaf children with some residual hearing who could hear a degraded signal with a hearing aid and could learn lipreading. It seemed possible that if an implant could give totally deaf children some hearing, they could learn lipreading, be successful in an oral school, understand the English language and learn to read"* (House, 2011, p. 67).

Cochlear implantation of the first humans in the United States became a source of heated debate between the early CI surgeons and their peers in basic science about the ultimate value and potential risks of human experimentation (House and Berliner, 1991; Levitt, 2008). Even the National Institutes of Health (NIH) imposed itself into the dispute by issuing a request for proposals to conduct an independent study on patient outcomes with the first wearable CIs. The University of Pittsburgh was selected as the site to carry out this study. The eventual results were published in a supplement (Bilger et al., 1977), which came to be known as "The Pittsburgh report". Thirteen patients from two sites in California, the House Ear Institute in Los Angeles ($n = 11$) and the University of California, San Francisco ($n = 2$), traveled to Pittsburgh to be assessed on a number of test protocols. To the surprise of many the results of the study were generally positive, reflecting findings similar to those that the early clinicians had been reporting: 1) detection thresholds were improved across a broad frequency range with the implant activated, and 2) lipreading and voice monitoring were improved with use of the implant, as was quality of life. There also were two negative findings from the Pittsburgh study; noise was bothersome and postural instability was increased on some of the balance test conditions.

This finding of postural instability surprised the Los Angeles group because balance had not been problematic for their CI patients. In response to this negative finding, Dr. House and his team conducted a study to investigate potential adverse vestibular effects. Surprisingly, the results from the House vestibular study were found to be quite the opposite of the Pittsburgh findings. It was discovered that postural stability actually *improved* with electrical stimulation on some test conditions (Eisenberg et al., 1982). This positive finding was later verified in a study by Buchman and his colleagues (Buchman et al., 2004).

The Pittsburgh study was to become a turning point in the evolution of CI technology. The generally positive findings gave the early investigators a green light to move forward in human cochlear implantation. As a consequence, auditory scientists began to work hand in hand with clinicians in a synergistic relationship to study performance outcomes. Engineers were inspired to develop new electrode designs and advanced speech processors. Today clinical and research studies on the CI enjoy a strong presence in journals dedicated to hearing research, otology, audiology, speech-language pathology, and deaf education. We have Dr. House and the other pioneers to thank for their perseverance and fortitude to meet those early challenges and to not be deterred by them.

2. Clinical trials and the team approach

The single-channel CI was the first auditory implantable device to undergo a multicenter clinical trial in adults with official oversight from the United States Food and Drug Administration (FDA). Manufactured by the 3 M Company in 1982 and based on the 1972 single-electrode processing algorithm (Danley and Fretz, 1982), the single-channel device became known as the 3 M House CI (Fig. 2). The processing scheme was fairly simplistic; the incoming stimulus was band-pass filtered (340–2700 Hz) which amplitude modulated a 16-kHz sinusoidal carrier wave (Fretz and Fravel, 1985). Following the clinical trial, an advisory panel of experts convened by the FDA reviewed the adult data to determine safety and efficacy. The data confirmed that the CI was feasible in adults and that the procedures could be carried out safely in different clinical settings (Berliner and House, 1982). In November, 1984, the 3 M House CI became the first CI to receive marketing approval by the FDA. Formal approval by a regulatory agency represented another important milestone in the evolution of the CI.

The design and implementation of multicenter clinical trials necessitated the formation of clinical teams. Thus, another major contribution from the early CI trials was the establishment of the multidisciplinary team. During the original development of the CI,

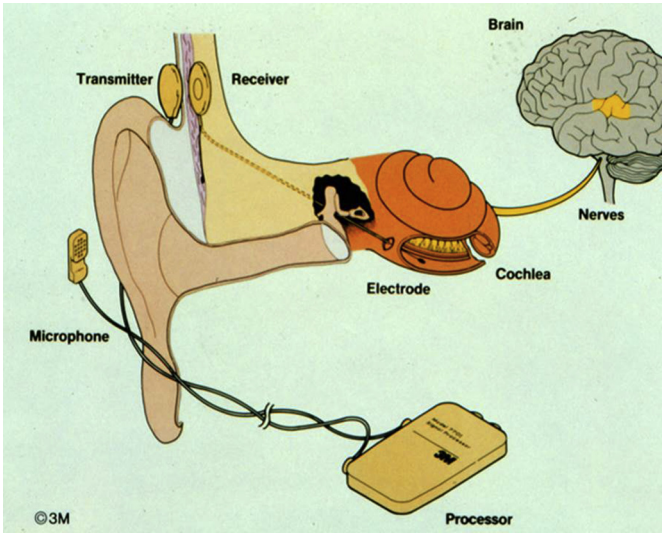

Fig. 2. Schematic of the 3 M House cochlear implant system showing both internal and external components (circa 1982, from the House Ear Institute archives).