Cochlear Implants: Yesterday, Today, and Tomorrow

An Honors Thesis (HONRS 499)

by

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Abstract

The cochlear implant is a modern medical marvel. Since its invention, the cochlear implant has given the gift of hearing to thousands of people with hearing impairments. Most people could never imagine life without sound, and thanks to the cochlear implant, far fewer people will ever have to experience it. This thesis gives an in-depth glance into this amazing device, providing a greater understanding of the significant impact it has upon society. The first part of the thesis explains the cochlear implant's history, the professionals who pioneered the device, the early models of the cochlear implant, as well as the limitations of those models, giving one a better understanding of the difficulty early professionals endured in an effort to make sound available to those who had never experienced it. The next section of the thesis provides a detailed view of how the device works, the candidacy process, the surgery, the cochlear implant team, orientation to the implant, the products available today, the concept of bilateral implants, the cost of ownership, current attitudes toward the implant, and personal stories about life with an implant, helping to provide a sense of what the device means to today's society. The last part of this thesis offers a glimpse into the future of the cochlear implant, looking at where the technology is headed and inspiring hope that, one day, all people will be able to achieve normal hearing and hearing impairments will be a flaw of the past. Finally, a reminder of how this fits into my life and career will help me to use what I have learned through the research to attain overall competence in my work as a professional speech-pathologist.
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### References
Yesterday

History

Most people view cochlear implants as a fairly modern development of technology. Few people realize, however, that its most ancient roots come from Pythagoras, a Greek philosopher who lived from about 570-498 B.C. Pythagoras first realized that sound was actually the result of vibrations in the air. Later, in 175 A.D., Claudius Galen, a Greek physician, discovered that the sensation of sound was transmitted to the brain by nerves. By 1543, scientists began studying the middle and inner ear more closely and began to understand how this tiny part of the body functioned (Finn, 2009).

Though much of the ancient history traces back to the Greeks, it was a Belgian anatomist, Andreas Vesalius, who discovered two of the three ossicles, the bones in the middle ear, that pass sound from the eardrum to the cochlea (Finn, 2009). The two bones he discovered were the malleus, also known as the "hammer," and the incus, known as the "anvil." It was not until 1561 that an Italian professor, Gabriello Fallopio, learned about the third ossicle, the stapes or "stirrup." Fallopio also discovered the cochlea, a tiny, hollow, snail-shaped bone located in the inner ear. He surmised that the cochlea was filled with air, although scientists have since realized that it is full of liquid (Finn, 2009).

In 1851, Alfonso Corti of Italy used a microscope to examine the cochlea and provide more detail about its composition. He discovered stereocilia, the organelles of the hair cell which move as sound waves enter the ear. Next, he discovered a structure which he named the "Organ of Corti." This organ is a structure that communicates with the brain when sound has taken place and determines the frequency of that sound (Finn, 2009). Later, a German named Hermann von Helmholtz theorized that it was actually fibers on the basilar membrane, another structure inside the cochlea resting beneath the organ of Corti, that vibrate to different frequencies of sound. Scientists have since verified that von Helmholtz was correct in his assumption that different parts of the organ of Corti do respond to
different tones. More specifically, the sections farther from the ossicles pick up the lower frequencies and sections closer to the ossicles pick up the higher frequencies (Finn, 2009).

As the twentieth century emerged, technology began to emerge as well. A Hungarian physicist, Georg von Bekesy, built models of the cochlea large enough to easily study its structure. His model consisted of a straight tube of glass, representing the cochlea in its “unrolled” form, with a piece of rubber through the middle to represent the basilar membrane. Using water to represent the fluid in the ears, von Bekesy created vibrations and observed how they traveled through the cochlea. To confirm that his models were accurate, von Bekesy obtained cadaver cochlea to observe the same effect. When he was able to study a real cochlea, he discovered another membrane that laid on top of the hair cells in the cochlea. This structure became known as the tectorial membrane. Von Bekesy realized that the two membranes, basilar and tectorial, provided a means for perceiving different tones along different areas of the organ of Corti. Von Bekesy won the Nobel Prize in Physiology or Medicine in 1961 for his discoveries related to the sense of hearing, and more specifically, the cochlea (Finn, 2009).

Meanwhile, researchers discovered that the organ of Corti and the auditory nerve helped to sort the sounds received by the auditory system into twenty-four different channels, each with a predictable tone (Finn, 2009). This system is called, “tonotopic organization.” Although researchers were aware of all these channels, they believed that only six or seven channels would provide sufficient sound quality because that was the number of channels used to broadcast speech via telephone. In 1966, one physician in particular, F. Blair Simmons, made an attempt to implant six different electrodes into the cochlea, each aimed to stimulate nerves tonotopically. His results supported the idea of localizing the stimulation to correspond with different frequencies (Cooper & Craddock, 2006). Many physicians were afraid to implant multiple electrodes because they thought it would obliterate ganglion cells, which are important in transmitting the sound signal from hair cells to the brain (Finn, 2009). Physicians were more inclined to attempt multiple electrode implants after animal experiments demonstrated that the
ganglion cells actually benefitted from the stimulation.

In this same period of history, physicians defined two basic types of hearing loss: conductive and sensorineural. A conductive hearing loss is due to damage of the eardrum, ossicles, or any structure that passes the sound waves to the cochlea. Conductive losses are often the result of excess fluid or infection in the middle ear (otitis media) or ear canal (external otitis), the accumulation or compaction of earwax, foreign materials in the ear, or deformations or abnormalities of the outer ear, ear canal, or middle ear ("Type, Degree," 2010). A conductive hearing loss results in the perception of softer sounds and can be easily remedied with simple hearing aids or a surgery to repair the damage (Finn, 2009). A sensorineural hearing loss affects the inner ear, most often the cochlea or neural pathways, rather than the outer or middle ear. In addition to reduced sound level, a sensorineural hearing loss also results in a lack of speech understanding and clarity. Unlike conductive hearing losses, sensorineural losses cannot be corrected with hearing aids or surgery. Such a loss can be attributed to many causes, some of which are; genetics, ototoxic drugs (those affecting the ears), some diseases, or complications from birth ("Type, Degree," 2010). Because conductive hearing losses are easily corrected using other methods, cochlear implants are used to correct, or at least improve, sensorineural hearing losses.

Once people understood the process of hearing and how the ear functioned, they began to develop ways to improve poor hearing and speech comprehension. Beginning in the nineteenth century and extending into the twentieth century, amplification went through five basic stages (Fay, Popper, & Zeng, 2004). The first stage began with cupping one’s hand around the ear and then evolved into using acoustic resonators such as ear trumpets to amplify the sound. When telephone technology became more dominant, some aspects of that technology were incorporated into the acoustic resonator, leading to the emergence of the second stage. At this stage in the evolution of amplification, a carbon microphone was used to provide electrical amplification. Problems with sound distortion and excessive noise from the microphone occurred with this method. This transitioned into the third stage which
involved vacuum tubes. This amplification was an improvement over carbon microphones. As transistors replaced vacuum tubes, the fourth stage began. Due to their smaller size, transistors were used in amplification devices worn on the head. The fifth and final stage in the development of amplification continues today. Digital technology has led to amplification instruments that function outside of frequency-dependent devices (Fay et al., 2004). Features such as reduction of noise, cancellation of feedback, directional processing, and environmental adaptation are now possible. Given how far simple amplification has progressed, the hopes that cochlear implants will progress similarly are high.

Looking specifically at the history of cochlear implants, the first attempt to use electricity to stimulate auditory sensation occurred around 1800. An Italian by the name of Count Alessandro Volta, “inserted metal rods in his ear canals and connected them to an electric circuit” (Christiansen & Leigh, 2002, p. 15). Not only did Volta realize that auditory senses could be affected by electric stimulation, he also revealed that electric stimulation also affected the visual, olfactory, and touch senses as well (Fay et al., 2004). As a follow-up to Volta’s experiment, S.S. Stevens conducted a series of studies that reexamined Volta’s electric stimulation (Fay et al.). He determined that three mechanisms were responsible for this electrophonic perception. The first mechanism was the vibration of the hair cells caused by electric stimulation. This is what people perceive as a tone and is referred to as the electromechanical effect. The next mechanism is the conversion of the electric signal to an acoustical signal by the tympanic membrane, or the eardrum. The last mechanism is the direct activation of the auditory nerve. Shortly after Stevens’ studies, researchers developed animal models of electric hearing to help compare the neural activity and patterns in the inner ear to acoustic and electric stimulation (Fay et al).

In 1950, Lundberg tried directly stimulating the auditory nerve with electricity, but the result was only noise instead of desired, distinguishable sounds (Cooper & Craddock, 2006). In Paris in 1957,
Charles Eyries and A. Djourno made a more specific attempt to stimulate the auditory nerve in the cochlea. This allowed the patient to hear a few sounds, but only for a short period of time (Christiansen & Leigh, 2002).

Shortly after these experiments, scientists in the United States gained recognition for their own work in the field. William House and James Doyle performed trial implantations on volunteers. They tested a multichannel implant with five different frequencies in an attempt to provide speech discrimination, and they also tested a single channel implant. Their patients developed problems with the insulating material of the implants, however, and the implants had to be removed (Christiansen & Leigh, 2002). From 1965-1970, House joined researcher Jack Urban to focus on the single channel implant, and together, they designed a workable, wearable implant ("Cochlear Implant Timeline," 2010). In 1972, House was responsible for building the first signal processor that could be worn by the patient ("Cochlear Implant Timeline," 2010). Doyle went on to experiment with multiple electrode implants, making his first attempt in 1964. His patient was able to distinguish some pitch and rhythm, but could not recognize speech (Cooper & Craddock, 2006).

In the mid-1960's, Australian investigator Graeme Clark, inspired by his deaf father, tried to create a "bionic ear" (Christiansen & Leigh, 2002). He gave speeches to organizations such as the Lions Club and the Rotary Club for donations and even participated in telethons to pay for his research because his request for funds was denied by Australia's National Health and Medical Research Council. Clark's most significant contribution toward developing the cochlear implant was in determining the best type of wire to thread through the cochlea. He did this using a shell and a blade of grass as his model.

One enormous problem with cochlear implants at this stage of their development was that sound was distorted to the point where interpretation was extremely difficult. Researcher Blake Wilson observed that this was caused by the fluid in the cochlea spreading the stimulation from one electrode
to nerve fibers it was not intended to reach. This trend is referred to as "cross talk." He helped to reduce this problem through a technique called "interleaving," or stimulating the electrodes sequentially rather than all at once. This procedure vastly improved the satisfaction of people who used cochlear implants (Finn, 2009).

One important milestone in the developmental history of cochlear implants was the Bilger Report of 1977. This report was conducted by Robert Bilger of the University of Pittsburgh and was sponsored by the National Institutes of Health (NIH). This report was, "one of the first efforts to independently evaluate the efficacy of cochlear implants," and it, "was based on a study of thirteen adult subjects, all of whom were using some type of single-channel implant" (Christiansen & Leigh, 2002, p. 22). The results of this study suggested that, although background noise was an issue, patients heard sounds of different frequencies, identified sounds in their environment, and demonstrated improvements in speech reading and lip reading. These results were acknowledged in the Bilger Report and, "provided substantial scientific evidence for benefits of cochlear implants and gave credibility to emerging technology" (Christiansen & Leigh, 2002, p. 23). This was the breakthrough researchers had been waiting for and gave rise to a wider acceptance of the technology, allowing the pursuit of further advancements in cochlear implants. Because the publication of this report gave credence to the cutting edge technology of the cochlear implant, people began to accept the idea of implanting children. That same year, in France, a ten year old and a fourteen year old became the first children to receive cochlear implants (Christiansen & Leigh, 2002).

By the 1980's, cochlear implants had become an industry. Clinical trials in both adults and children increased dramatically, the first Cochlear Implant Consensus Conference and many other professional meetings took place to monitor implant effectiveness, and cochlear implants began to be commercially manufactured (Christiansen & Leigh, 2002). In 1980, physicians in the United States performed the first implant surgery on a child. This took place at the establishment founded by William
House, the House Ear Institute. The U.S. Food and Drug Administration (FDA) first approved House’s 3M/House implant model in 1984, and then approved Graeme Clark’s Nucleus 22 in 1985 (Christiansen & Leigh, 2002). Although the FDA’s approvals were only for adults, it took only a few years before the Nucleus device was also approved for children.

In 1988, The Consensus Development Conference was held to address issues such as candidacy, advantages and disadvantages of implants, pre/post implant assessments, habilitation and rehabilitation procedures, and future research. The conference was sponsored by NIH to make concrete specifications in regards to the areas addressed at the conference. They again sponsored a follow-up conference in 1995 to focus on the implantation process and the successes of various age groups (Christiansen & Leigh, 2002).

By the 1990’s, three main companies were commercially manufacturing cochlear implants. Those companies were; Advanced Bionics, Med-El, and MXM (Cooper & Craddock, 2006). The United States still approves of the use of cochlear implants from Advanced Bionics and Med-El. The third approved company, however, is now Cochlear Limited. By the year 2000, the sixth International Cochlear Implant Conference was held in Miami, Florida. By this point, surgeons were implanting children as young as twelve months and the FDA had begun clinical trials for children who still had a considerable amount of residual hearing.

**Noted Professionals: Dr. William House**

Little is known of William House’s childhood, except that he was born in Kansas City, Missouri. In 1941, House began his first year at Whittier College in California studying pre-dentistry, but shortly after he had begun, Pearl Harbor was attacked. At that point, he tried to join the Navy, but was sent back to school and, instead, enlisted in the reserves. He went back to school and received his Doctor of Dental Surgery (D.D.S) from the University of California in San Francisco in 1945. While he was in dental school, House was called to active duty and was stationed in Bremerton, Washington to finish his degree
at a dental clinic there. He remained on duty in the Navy for three years after he finished his D.D.S, and after he left the Navy in 1948, he pursued an interest in medicine (House, 2004).

During his medical residency in Otolaryngology, medicine of the ears, nose and throat, at Los Angeles County General Hospital, House began to concentrate his interest on problems related to the ear. House became the first American otologist by creating his own branch of medicine dealing with the ear: otology. He began to consider the potential effects of cochlear implants when Eddie Johnson, Chief of Audiology at the Otologic Medical Group, introduced House to the John Tracy Clinic, the place Johnson brought his daughter who was deaf. In reference to that clinic, House said, “I found it very difficult to tell the parents, 'There’s not much we can do. Why don’t you get some hearing aids and we’ll refer you down to the John Tracy Clinic.' Many of the patients ultimately ended up with manual communication, sign language” (House, 2004, p. 1). After hearing that Dijourno and Eyries successfully used electrical stimulation to provide sound to patients, House was motivated to persevere in his work to give sound to the deaf. House says, “I thought it was a tremendous idea. Why can’t we learn to do it?” (House, 2004, p. 1). In 1959, he teamed up with engineer James Doyle to construct a cochlear implant, which he then tested in deaf volunteers in 1961. The patients did report hearing sound, but unfortunately, House was forced to remove the devices due to irritation in the ear from the materials used in making the devices. Dr. House received no credit when Doyle finally patented their creation in 1969 (“Our Founder”, 2010).

Once researchers learned enough about the compatibility of certain materials with the body, Dr. House sought another partner. He found Jack Urban, an electrical engineer, and they worked together to design better cochlear implants. By 1969, House and Urban had finally created a cochlear implant that was realistically useful. By 1973, Dr. House had eleven patients who had received and continued to use cochlear implants. These patients became some of the subjects studied in the Bilger Report of 1977.
Dr. House founded AllHear, Inc. in 1991 and continues his work by endeavoring to make cochlear implants more affordable ("Our Founder," 2010).

**Noted Professionals: Professor Graeme Clark**

Graeme Clark was inspired to work with people who were deaf from a young age. He was born in 1934 in Australia and, while still young, his father became deaf (Anderson, 2007). As a child, Clark harbored a passion for creativity, exploration, and experimentation. A friend of his father’s helped him learn to be a nose and plastic surgeon. As Clark describes the moment of his decision to further investigate cochlear implants, he says, “I had been frustrated in my practice at seeing profoundly deaf people come and realizing that I couldn’t tell them we could do anything for them. But then I got this inspiration to go and do work by electrically stimulating their hearing when I read this article by an American surgeon - Simmons” (Clark, 2004, p. 1).

Some give credit for the invention of the cochlear implant to Graeme Clark, but Clark says, “Well, there’s no one original idea...there’s been so many different things to bring together to create a bionic ear” (Clark, 2004, p.1). Whether it was his own creation, or a combination of efforts, Clark became a popular name in regard to implantation for the deaf. He lead the way in the development of the multi-channel implant, which also became known as the bionic ear. The bionic ear was the first clinically successful device to bring not only sound, but also speech understanding to the deaf. This was a monumental advancement in the cochlear implant industry as Cochlear Limited began the manufacturing of this device ("About Graeme Clark," 2010). In 1978, he was the first to perform the bionic ear implantation, with Mr. Rod Saunders as the first bionic ear patient (Anderson, 2007). He then participated as the chief surgeon in the first multiple channel electrode device implanted in a child in 1986. Recalling his experience with Saunders, Clark said, “When he heard speech, I knew that all our hard work had been successful. It was one of the most wonderful experiences of my life. I was so
overcome, I went into the next-door laboratory and did what's not very Australian—I burst into tears of joy" (Clark, 2004, p. 1).

Once Clark’s goal of providing speech understanding to the deaf had been achieved, he began to look for another problem to solve. He decided that he wanted to work toward helping children who were born deaf acquire spoken language. He researched this topic extensively and because of his success, the FDA approved his bionic ear device in 1990, deeming it safe and effective for children two years of age and older ("About Graeme Clark", 2010). Clark continues to challenge himself by setting lofty goals. Currently, he is attempting to use proteins from the brain to restore the hearing nerve and inner ear. If he succeeds, the bionic ear will no longer be necessary, as deafness and hearing loss will be completely preventable (Anderson, 2007).

**Noted Professionals: Alessandro Volta**

Alessandro Volta was born into nobility in 1745 in Lombardy, Italy. His family thought him to be mentally retarded because he did not speak until he was four years old. When he was seven, however, he began to demonstrate that he was actually more advanced than other children his age. His father died when Volta was a young child, and when he was fourteen, he decided he wanted to be a physicist. He particularly enjoyed experimenting with electricity. In 1775, he invented a machine called the electrophorus which used electrostatic induction to produce an electrostatic charge. He even received the Copley Medal of the Royal Society in 1791 for his work with electricity (Weinberg, 2000).

The invention for which Volta is most known is that of the electric battery. His first version of the battery was a device called a voltaic pile, which was no more than a pile of zinc and silver discs with a piece of cardboard soaked in saltwater placed between the two piles. A wire connected the zinc to the silver and generated sparks. Volta created this device in 1800, making huge progress in the area of science, as it was the first appliance that could sustain an electric current. Volta also figured out how to
monitor the intensity of the current by changing the number of elements used in the pile (Weinberg, 2000). It was shortly after this development that Volta tried to create auditory sensation using electricity, creating the spark necessary for incredible advancements in what ultimately became the cochlear implant.

In 1810, Napoleon honored Volta for his achievements in the field of electricity by designating him a count. The works written by Volta while he experimented and researched were published in 1816 in Florence. Count Alessandro Giuseppe Antonio Anastasia Volta died in 1827. As a final tribute to the extensive progress he made, the electrical unit of measurement, the volt, was named after him in 1881 (Ament, 2005).

Noted Professionals: Richard T. Miyamoto

In regard to noted professionals today in the Midwest, Dr. Richard T. Miyamoto is one held in high esteem. Miyamoto began his higher education by majoring in Chemistry at Wheaton College in Illinois and he received a Bachelor's Degree from Wheaton College in 1966. He then earned a Medical Degree from the University of Michigan in 1970 (DeVault, 2010). He spent two years completing general surgery training at Butterworth Hospital in Grand Rapids Michigan. During his time there, Butterworth Hospital was affiliated with Indiana University (IU), which is how he ended up at IU for his residency in otolaryngology. After taking three years to complete that residency, he decided to join the Air Force for two years. From 1977 to 1978, Miyamoto participated in a fellowship at the House Ear Institute in California. Finally, Miyamoto came back to IU as a professor (Miyamoto, 2003). There, he helped establish the Indiana University Cochlear Implant Program. He performed his first implant surgery in 1979, before much was known about the long term effects these devices would have on patients. Miyamoto recognized the potential of the cochlear implant and played an active role in its development and improvement. He was even a spokesperson to the Food and Drug Administration (FDA) when they
demanded clinical trials to provide evidence that the new device was actually beneficial to patients ("Profile," 2010).

Currently, Dr. Miyamoto is president of both the Association of Academic Departments of Otolaryngology-Head and Neck Surgery and the Centurions of the Deafness Research Foundation. He serves as Director of the American Board of Otolaryngology and is also a member of many other professional groups. Dr. Miyamoto is currently involved in professional research studies involving speech perception, speech production, and language in children with cochlear implants (De Vault, 2010). Clearly, Dr. Miyamoto has valuable expertise regarding otolaryngology, and particularly cochlear implants. Most likely, he will continue to provide a great service to the community for years to come.

**Past Versions of the Cochlear Implant**

When cochlear implants were still in the experimental stage of their development, developers used two different approaches; single-electrode and multi-electrode. The first official implant design which obtained some sort of success for its clients was of the single-electrode approach. The first device was known as the House/3M. Designed in the early 1970's by Dr. William House in Los Angeles, California, the House/3M was extremely basic in comparison to today's standards. It had a processor, transmitter/receiver, and the single electrode (Loizou, 1998). This early version of the cochlear implant did not provide the benefits that we associate with today's cochlear implants. The quality of sound was so poor that the recipient did not have the ability to distinguish speech sounds, but they were able to perceive environmental sounds (Clark & Grayden, 2005).

Not too long after the House/3M came out, the Chorimac device was developed in Paris, France. Initially, it consisted of eight channels, but later improvements in 1982 added four more channels and it became the Chorimac-12 (Clark, 2003). As opposed to the House/3M, these two models of cochlear implants did allow patients to recognize some speech sounds. Between the releases of the two
Chorimac models, an Australian device was released that consisted of ten electrode channels. This was developed at the University of Melbourne and was noted for its use in helping recipients improve not only speech recognition, but also speech reading ability (Clark & Grayden, 2005).

Throughout the 1980’s a number of different models were produced in countries around the world. The University of Louvaine, in Belgium, developed a system called the LAURA, which used eight electrodes. The University of Utah produced a four channel system called Symbion Ineraid (Clark & Grayden, 2005). In 1981, Cochlear Corporation in Australia developed the Nucleus-22. As its name suggests, it had 22 electrodes and was an improvement upon the twelve electrode design of the Chorimac-12. In 1985, this became the first device to be implanted in a child and received approval from the FDA in 1990. This device quickly evolved into the Mini 22, which was smaller and used a magnet to attach the transmitting coil to the device, thus eliminating the need for a bulky headset. Then, the Nucleus 24 replaced the Mini 22. This device featured two electrodes outside of the cochlea in addition to the 22 inside the cochlea (Roland & Waltzman, 2006).

Multiple countries competed with each other for the best and most effective cochlear implant design. In the 1990’s, Advanced Bionics, Med-EI, and MXM were three companies which stood out in the cochlear implant business (Cooper & Craddock, 2006). Today, those companies are: Advanced Bionics, Med-EI, and Cochlear Americas/Cochlear Corporation. These companies continue to create improved models which will be discussed in a later section of this document.

Technical Limitations

The early cochlear implants possessed a variety of technical limitations. The area of electronics is constantly progressing and improving. The early cochlear implant pioneers did not have access to the electronic technology that professionals have today, and the cochlear implants were therefore limited to a more primitive technology. As mentioned briefly in the history section, some of the early models of
cochlear implants presented issues in regards to tissue tolerance. This problem limited the types of patients who were able to receive the implants without having difficulties with skin irritation. Long term effects of electric stimulation also limited the progress of the cochlear implant. Many people feared them because they did not believe the stimulation to be completely safe. Finally, auditory learning with the early models of cochlear implants was not as effective as initially expected. The quality of speech sounds was poor and the benefits were extremely limited in comparison with the benefits people reap from cochlear implants today (Fay, Popper, & Zeng, 2004).

Initial Reactions

When the cochlear implant was still a new product, people had mixed reactions regarding the device. Most patients were extremely enthusiastic about the device, but professionals were skeptical and remained cautious. The media portrayed cochlear implants in a positive light, but professionals wanted to see official data before they would agree that the device provided benefits (Tucker, 2009). A different, and surprising, reaction came from the neurophysiologists. They felt that less specialized professionals were encroaching on their territory and that the cochlear implant was, "a misguided attempt by surgeons--who knew little or nothing about auditory neuroscience--to stimulate nerves that were already dead" (Christiansen & Leigh, 2002, p. 17).

Unfortunately, the negative attitude did not end with medical doctors and surgeons. The cochlear implant was initially rejected by psychologists and ear, nose, throat (ENT) specialists as well. The psychologists, did not understand how the device could work from a structural perspective. They believed the structures of the ear to be much too small for any type of implant to generate success. The ENTs had been thoroughly convinced and taught that absolutely nothing should ever be placed in the inner ear, and feared the device would damage the cochlea (Christiansen & Leigh, 2002).

In addition to the physical dilemmas that scientists faced, some also viewed the cochlear implant debate through a moral perspective. A pediatric otolaryngologist voiced his opinion to Dr.
House that, "There is no moral justification for an invasive electrode for children...[the cochlear implant is] a costly, cruel incentive, designed to appeal to conscientious parents who may seek any means that will enable their children to hear" (Christiansen & Leigh, 2002, p. 20). Because of such negative reactions from the scientific community at large, the development and improvement of the cochlear implant became extremely difficult to fund.

The Deaf Community had their own opinion regarding cochlear implants. Although theirs was not much more positive than that from the scientific community, it came from a slightly different perspective. The reason members of the Deaf Community did not appreciate cochlear implants was because of the negative stigma attached to the concept of deafness by the promotion of cochlear implants (Christiansen & Leigh, 2002). They also believed that the promotions of cochlear implants drastically minimized or glossed over some of the major health risks involved in implantation.

Eventually, as professionals created improvements to the device, more and more people began to approve of it. Approval from the FDA and other trustworthy groups also boosted support for the cochlear implant. More information about cochlear implants has become readily available, which has helped to eliminate any unknowns that caused hesitation for so many people. Opinions of the cochlear implant have changed over time, and a later section will discuss how people view the device now.

**Today**

**Statistics**

- In the United States, about 28 million people have a hearing impairment ("Statistics," 2010).
- In the United States, there are at least one million children who are either deaf or hearing impaired ("Facts and Figures," 2006).
• 90% of the babies born with hearing loss are born to hearing parents ("Facts and Figures," 2006).

• 60% of hearing loss is genetic ("Statistics," 2010).

• Of the children who qualify for a cochlear implant, less than 50% actually receive one ("Facts and Figures," 2006).

• More than half of the children who receive cochlear implants are implanted by five years old or younger ("Cochlear Implant Statistics," 2008).

• World-wide, a total of 120,000 people have received cochlear implants, as of 2007 ("Cochlear Implant Statistics," 2008).

How it Works

For a person unacquainted with cochlear implants, describing how the device works can become fairly complicated. To begin understanding cochlear implants, one must first understand how a normally functioning ear works. The ear is typically divided into three sections: the outer ear, the middle ear, and the inner ear. The outer ear contains the pinna, the section which protrudes from the head and which most people associate as the ear, and the ear canal. The first step in the process of hearing involves the pinna funneling sound waves into the ear canal. Then, the waves travel to the middle ear, which contains three parts: the eardrum, the ossicles, or bones of the middle ear, and the middle ear space. The sound waves bump into the eardrum, causing it to vibrate. Its vibration then causes the vibration of the ossicles. Finally, the waves reach the inner ear which contains the cochlea and the organs of balance. When the smallest of the ossicles, the stapes, begins to vibrate, it hits the cochlea. The liquid in the cochlea begins to move, thus activating thousands of tiny hair cells that line the inside of the cochlea. The hair cells convert the vibration into electrical pulses. Nerve fibers then carry the pulses to the brain, which interprets them as sound. Cochlear implants are used in people whose hair cells are not
stimulated by the movement of the fluid, and therefore, fail to produce the electrical pulses that are sent to the brain and interpreted as sound. The implant supplies a means for the message to reach the brain by creating electrical pulses from an outside source ("What is a Cochlear Implant," 2010).

The implant contains both external and internal components. The external components consist of the microphone, the speech processor, and the transmitter. The internal components consist of the receiver and stimulator as well as the electrodes, of which there could be up to twenty-four. The operation of a functioning implant begins with the collection of sound by the microphone. Then, the sound moves from the microphone to the speech processor via cable. The speech processor sorts and digitizes the sound into a code of electrical signals, which then travel to the transmitting coil. At this point, the sound moves to the internal components of the cochlear implant via the skin by means of FM radio signal, at which point it reaches the receiver/stimulator. The sound is then distributed to the proper electrodes, each of which then stimulates the auditory nerve fibers in the cochlea. The nerve fibers alert the brain as to how the signals need to be interpreted ("What is a Cochlear Implant," 2010).

The structures of cochlear implants vary slightly, depending on the design, style, and manufacturer. The microphone, while usually positioned on the unit that sits behind the ear, can also be placed on the speech processor, or even worn separately as a clip on clothing. One feature that is critical to the quality of a cochlear implant microphone is the range of frequencies to which it responds. It is not only important that the microphone respond to a broad range of frequencies so that the wearer can hear as many speech and environmental sounds as possible, but also that the microphone not respond to low-frequency vibrations caused by head movements, clothing, or physical activities such as walking. Now, with the prospect of bilateral cochlear implants, the use of two microphones may become the new standard (Fay et al., 2004).

In older models of the cochlear implant, the speech processor looks like a small box that must be held in a pocket or otherwise attached to the clothing. These are known as body worn processors.
With newer technology, some cochlear implants place the speech processor on the unit that sits behind the ear. These are known as head-level processors. For a relatable size comparison, the head-level processors run on hearing aid batteries, whereas the body worn processors require two double A batteries. It is important that the batteries are able to last between twelve to sixteen hours; enough time for the wearer to use the device morning to night without having to replace or recharge the batteries. The head-level processors, made possible by advancements in technology, are becoming much more popular than the body worn processors because they are much less obtrusive and more cosmetically appealing. Given the enormous progress being made in the design of cochlear implants, it is not unrealistic to expect to see fully implantable systems in the near future (Fay et al., 2004).

The transmitter connects the speech processor to the internal components of the cochlear implant. It looks like a wire that comes out of the processor with a magnet on the opposite end. The magnet helps the wearer to align the speech processor with the internal components of the implant, as another magnet is placed under the skin where the internal parts are located (O'Reily, 2008).

The receiver/stimulator is the first basic section of the internal part of the cochlear implant. It is the internal component that contains the second magnet, which keeps it aligned with the speech processor. The receiver/stimulator is like the fuse box that controls both the electronic circuits and the number of electrical signals/pulses that reach the auditory nerve. It has a small antenna that can receive the signals sent by the speech processor through the skin ("What is a Cochlear Implant," 2010).

The final, but arguably most important element of the cochlear implant is the electrode array. This is the part that is threaded through the cochlea and it consists of both the electrodes and the electrode carrier. The array is placed as close to the location of neural activation as possible, usually close to the cells of spiral ganglion neurons which are responsible for the delivery of the sound signal to the brain (Bonham, Hetherington, Leake, Rebscher, Wardrop, & Whinney, 2008). As discussed in the history section of this document, the primitive cochlear implants contained a single electrode. As
researchers experimented with multiple electrodes, however, they found that the more electrodes used in an implant, the better the patient could hear and understand sounds. They also realized that electrodes on different areas of the cochlea corresponded to different frequencies, or tones, of sound. The higher frequencies correspond to areas toward the base of the cochlea, whereas the lower frequencies correspond to areas toward the apex of the cochlea. Despite which frequency responds, it is this electrode array that is responsible for the last step of the implant’s function: relaying the signal to the brain.

Researchers are diligently working to improve upon each of the components of the cochlear implant. It is important to have a general understanding of the performance of a cochlear implant as well as a quick overview of the individual components in order to fully appreciate the advancements currently being made by researchers. Studies regarding such advancements will be discussed later in this document.

Candidacy

Not every person with a hearing loss is eligible to receive a cochlear implant. In fact, the requirements for candidacy consideration are somewhat stringent. Most professionals agree that the conditions for candidacy vary upon age and are lumped into two basic categories: adults and children. According to the American Speech-Language-Hearing Association (ASHA), adults should have a hearing loss in both ears and the degree of hearing loss must be severe to profound. Adults considering cochlear implantation should also have had hearing aid trials which determined that their benefit from other amplification was minimal. No adult requesting cochlear implants should have any medical or health issues that would increase the risk of complications during surgery. Adults wanting a cochlear implant should desire to learn to communicate through listening, speaking, and speechreading, and be prepared to work hard in order to attain that goal. For this reason, adults who lose their hearing after they have developed speech and language skills make better candidates for cochlear implantation
Because the circumstances of a child considering a cochlear implant and an adult considering a cochlear implant could vary significantly, ASHA provides separate guidelines for child candidacy. As with adults, children should also have a hearing loss in both ears; however, the degree of hearing loss in children must be profound. Parents and professionals working with children who may become candidates for cochlear implants should determine that hearing aids do not benefit the child in any way. Surgery performed on children leads to a higher risk of complications, so the child receiving the cochlear implant should be as healthy as possible with no additional medical conditions. Often, when children undergo any type of medical process, the parents receive the instructions and make the decisions. With cochlear implants, however, it is important that the child is involved as much as possible with the implantation process because he or she will ultimately live with and maintain the device. The child should also possess a clear understanding of what to expect with the implant, and the parents and professionals should make sure those expectations are realistic. The child must be willing to participate in a habilitation or rehabilitation process. Otherwise, the child may never learn to reap all the advantages the device offers. A final but most critical requirement for a child cochlear implant candidate is support from his or her educators to reinforce auditory skills ("Cochlear Implants," 2010).

The guidelines stated above may vary depending on the professional consulted. Some may require additional testing to determine how much language a person can recognize and comprehend in an ideal listening situation (quiet, close to speaker, etc.) using amplification. A common requirement of some professionals is that a person eligible for cochlear implants would only recognize thirty percent or less of the sentences tested (Arndt & Vonlanthen, 2007). Another test a potential candidate may undergo is an evaluation of the structures of the middle and inner ear. This may involve a computerized tomography (CT) scan or a magnetic resonance imaging (MRI) scan to determine whether any bone growth has occurred that would hinder implantation (Kaneshiro, 2010). An opinion held by many
professionals is that the younger a person is when he or she receives a cochlear implant, the better they will respond to the device. The best time for implantation is before the age of six months because the child will have the best chance of acquiring language at the rate of children with normal hearing. On the other extreme, adults who have not had success with hearing aids will most likely not be as successful with a cochlear implant because they have not had a decent basis for spoken language (Tucker, 2009). Some professionals are even beginning to recommend that children who already receive some benefit from hearing aids may also be candidates for cochlear implants because they could access more sound more easily, rather than straining to access little sound (Tucker, 2009).

Not only do the guidelines for candidacy change due to discrepancies between individual professionals, but they also change due to newer technology which enables more groups of people to receive benefits from implantation. One example of the guidelines changing due to developing technology is the 2004 Food and Drug Administration (FDA) approval of, "cochlear implantation in children aged 12-23 months with profound hearing loss, and in children ages 2 years or older with severe to profound hearing loss" (Firszt, Holt, Hood, & Kirk, 2006, p.1), rather than limiting implants only to children with profound losses. Another current illustration of technical advancement is the prospect of bilateral implantation, which is when a patient receives a cochlear implant in each ear. Professionals are working to determine the candidacy requirements for people considering the implantation of the second ear. Although no specific guidelines have yet been stated, one important aspect which will be tested on patients considering this procedure is how well the patient can recognize and understand speech in situations and conditions that the patients deals with on a daily basis. The testing would determine how the patient currently deals with background noise, multiple speakers, and interference with the device, and would assess whether the patient could benefit from a second cochlear implant (Firszt et al., 2006).

The characteristics that make a suitable cochlear implant candidate will continue to fluctuate
and change as professionals conduct more studies and develop better technologies. Despite the great amount of changes expected, becoming a cochlear implant candidate is becoming easier rather than more difficult. More and more people are able to meet the requirements necessary and are receiving implants which help create a better way of life for them.

**The Surgery**

Because so much preparation is required before a candidate can actually receive his or her implant, and because so much time is spent in rehabilitation after the surgery, the actual process of inserting a cochlear implant into a patient can seem fairly quick. The surgery itself usually lasts about two hours, although if complications arise or a patient has certain abnormalities of the cochlea, it can last much longer. The patient will undergo general anesthesia for the duration of the surgery ("Cochlear Implant Surgery," 2009).

In preparation for the surgery, a nurse will shave a small section of the scalp behind the ear where the incision will be made. Then, that part of the scalp is thoroughly cleaned. After the scalp is prepared, a nurse will begin to attach cables and patches to the patient, which allow the surgeon and surgical assistants to monitor the patient's vital signs. Someone will then place a mask over the patient's mouth and nose as well as an intravenous (I.V.) line in the patient's arm. Through these devices, the patient receives oxygen, anesthesia, and other drugs that may be necessary for the patient during the surgery ("Medical Devices," 2009).

The surgeon begins by drilling a hole to the inner ear via the mastoid bone, the hard bump that can be felt behind the ear. He then threads the electrode array through the cochlea. Using a small pocket that was created in the mastoid bone, the surgeon fastens the receiver in place and stitches the incision together. Finally, the surgeon will cover the area with a large dressing. Often times the patient is required to stay in the hospital overnight for observational purposes. (Kaneshiro, 2009).
After waking up from the surgery, the patient is likely to feel soreness over the ear that received the implant. The patient may also feel dizzy, nauseous, and even disoriented for a short amount of time. The breathing tube used to administer the anesthesia may also leave the patient with a sore throat.

Taking care of the wound is extremely important in order to prevent infections from developing. The bandage must be changed and the area around the incision must be washed regularly. Sometimes, the patient may have to return to have the stitches removed, but due to medical advancements, most doctors will use stitches that dissolve on their own, thus eliminating the need for an extra visit to the hospital. Although many patients are able to return to daily activities within the first week of recovery, it may take up to several weeks for complete recovery. Once the patient has completely recovered, the external portion of the implant is attached and the tuning process can begin ("Medical Devices," 2009).

A variety of complications can occur throughout the surgery. Minor complications that are fairly common include the breakdown of skin over the implanted device, infection of the incision, and the device falling out. More serious complications that are less likely to occur include damage to the nerve responsible for motor movements of the face, leakage of cerebrospinal, or brain, fluid, meningitis, dizziness, or even the device failing to work correctly (Kaneshiro, 2009).

**Cochlear Implant Team**

Undergoing a cochlear implant requires copious amounts of preparation from everyone involved. Some people may believe that a person merely has to acquire an implant via surgery before they can hear. On the contrary, the process involves a whole team of people who work together to help an individual succeed throughout the entire cochlear implantation process. A team can involve as many as nine different types of professionals, including: the surgeon, audiologist, hearing therapist, psychologist, nurse, teacher of the deaf, speech-language pathologist, coordinators, and administrative support. Perhaps because of the vast number of people who become a part of this process, "the cochlear implant team is one of the most successful multi/inter-disciplinary collaborations in the
healthcare systems of the modern world" (Cooper & Craddock, 2006, p. 70).

According to Cooper and Craddock (2006), an effective cochlear implant team has a clearly defined purpose and shares similar values. Its leadership, management, and communication are consistently present, resulting in high quality performance. A cochlear implant team should act effectively and efficiently with a well-defined chain of responsibility. It should also make others outside of the team, such as the patient or family members, feel as though they are able to understand what is happening and that they can trust the team. In general, "the role of the cochlear implant team is to determine candidacy for cochlear implantation, to help prospective recipients make informed decisions about cochlear implant surgery and device options, to provide necessary medical care, to carry out the surgical implantation, and to provide post-implant device setting and monitoring" ("Working Group," 2004, p. 1). While maintaining these aspects of team membership, the individual professionals also have many more of their own responsibilities.

The surgeon is responsible for actually placing the device into the patient. Although the surgeon is one of the most vital members of the team, he or she also spends the least amount of time with the patient. Because of the limited amount of time with the patient, it becomes extremely important that the surgeon is accessible to other members of the cochlear implant team for questions or concerns raised by any person involved in the implant process. The surgeon is responsible for the surgery itself as well as following up with the patient on the medical aspects pertaining to recovery. Most surgeons are Ear Nose Throat (ENT) doctors who specialize in otology. In the most effective cochlear implant teams, the surgeon is involved both in the medical assessment of the patient as well as the outcome of the surgery (Cooper & Craddock, 2006).

Another vital member of the cochlear implant team is the audiologist. This member has the most contact with the patient throughout the implantation process. The audiologist administers testing and ensures that the patient will make an adequate candidate. Additionally, the audiologist should make
sure the patient knows what to expect and, after the surgery, helps the patient program, tune, and maintain the implant device. The audiologist is often responsible for understanding how to troubleshoot and correct any technical issues that may arise (Cooper & Craddock, 2006).

Although the surgeon and the audiologist are the two most critical team members, other professionals can make important contributions to the team. Many cochlear implant teams include a hearing therapist and a psychologist. The hearing therapist explores any needs the patient may have in regards to home life, work life, or even emotional needs. This person helps motivate the patient, assists in dealing with disappointments or dissatisfaction, and helps them to cope with stress. The psychologist performs the assessment of a patient’s, or a potential patient’s, emotional or psychological condition. This information can be helpful to the team by providing valuable insight as to whether a person has the necessary capabilities to deal with a process as intense as cochlear implantation (Cooper & Craddock, 2006).

A nurse could participate as another member of a cochlear implant team. Nurses are important members because they can relate to the patient and family in a unique way. Family members often feel more comfortable asking the nurse questions pertaining to the procedure because they believe that the doctor or surgeon is too busy or may think the question is insignificant. The nurse then becomes a link of communication between the surgeon and the patient. The nurse is also able to conduct routine health checks, which are important in tracking the medical status of the patient before and after surgery (Cooper & Craddock, 2006).

Often, usually in the case of children, a teacher of the deaf becomes a member of the team. This person would assess the educational needs of the young patient and help the family to choose the right educational environment for their child. If a teacher of the deaf is not a part of the team, this responsibility may fall upon the speech-language pathologist (SLP). The SLP is another integral member of the cochlear implant team. This person provides the patient and family with information on returning
the patient's communication skills as close to normal as possible. This often involves individual therapy with the recovering patient. The focus of therapy in children would likely be speech and language development. In adults, however, the focus of therapy would be on developing general language skills. The involvement of the SLP is important both before and after the implantation (Cooper & Craddock, 2006).

Finally, coordinators and administrative support may sometimes be involved as part of the cochlear implant team. A coordinator is extremely helpful to the team because this person can ensure clear communication between the rest of the members. This person is involved throughout the entire process, including the referral, the evaluation and selection of the patient, the surgery, and the rehabilitation process. The coordinator is a point of stability within the team, holding it together and making sure that the quality standards of clinical practice are met. The administrative support works with the coordinator to keep the process running smoothly. The administrative support's largest responsibility, however, is to make sure that the funding and supplies required for the cochlear implantation are present (Cooper & Craddock, 2006).

Not every cochlear implant team involves all of the professionals previously mentioned. It is clear, however, that each professional involved plays an essential role in the implantation process. With so many different team members, communication between all these individuals becomes a necessity. Every member of the cochlear implant team must share common goals and agendas. When all runs correctly, this team can provide their patient with a higher quality of life; an invaluable gift.

**Orientation/Therapy**

After a person receives a cochlear implant, they still have a long journey ahead of them before they are able to use the implant effectively. Beginning with a 4-6 week healing period following surgery and including therapy needed for recovery from any complications associated with the surgery, the
process involves orientation to the implant, programming and activating the electrodes, and finally habilitation or rehabilitation. Even with the help of multiple professionals, it can take years for a person to maximize the use of his or her implant. Family members, educators, and the patients themselves play the most critical role in the (re)habilitation process. Other professionals, however, are necessary to help guide the patient through the process. First, physical therapists, or other specialists may be needed to help correct any complications resulting from the surgery. Although complications are not uncommon, not every patient who receives a cochlear implant will need these types of services. The most common professionals involved in this process are the audiologist, who activates and continues to reprogram the patient's implant, and the speech pathologist, who evaluates, assesses, and helps improve the patient's communication skills using aural rehabilitation and/or speech and language therapy.

If any side effects from the cochlear implant surgery should occur, those need to be addressed immediately, even before the patient begins to use his/her implant. Symptoms such as numbness or stiffness around the wound are common and clear up on their own. Other side effects, such as facial drooping, paralysis, tinnitus (ringing in the ears), or dizziness may require physical or occupational therapy (Uddin, 2010). One example of a service physical or occupational therapists can provide for cochlear implant recipients who experience postsurgical problems is Vestibular Rehabilitation Therapy (VRT). This is a technique use to treat inner ear deficits, such as the dizziness which may occur due to the cochlear implant surgery. As its name implies, VRT targets the vestibular system, which controls the body's sense of balance and spatial orientation. VRT involves completing a set of exercises, determined by the physical or occupational therapist. The exercises are specific to the head, body, and eyes, and are used to, "retrain the brain to recognize and process signals from the vestibular system and coordinate them with information from vision" ("VRT," 2010, p.1). Through VRT, the body eventually learns to compensate for the deficits of the vestibular system and the patient stops feeling so dizzy.

The first step a patient needs to take after recovering from cochlear implant surgery is to meet
with an audiologist to have the speech processor, which is the external component of the implant, fit to their internal component. Activation usually takes about six hours or more and is completed over the course of two or three days ("System," 2010). The activation is drawn out over the course of a few days because the task is extremely exhausting for the patient and his/her family. Especially in the case of people who are deaf, the brain becomes overwhelmed with the auditory stimulation with which it is bombarded once the cochlear implant is working. Bonnie Tucker describes her experience with activation in her book, *Cochlear Implants: A Handbook*, as follows, "Just the pinpricks of sound were overwhelming. I had a headache accompanied by nausea that I tried to ignore. I would have loved to take a nap....there was no time for a nap" (Tucker, 2009, p. 34). Activation refers to the process of programming each electrode individually to determine the range of levels at which sound is soft to uncomfortably loud for the patient. The combination of all these levels for all the electrodes is referred to as the patient's "map" ("System," 2010). Once the map is completed, the patient can hear sound for the first time. Tucker describes how she felt, "On came the sound. And out came my tears...In truth, the tears were falling because I was overwhelmed to be hearing sound. I did not have the words to describe what I felt, and I didn't even try...Sound. I heard it. Sound. It was amazing. Yes. Sound" (Tucker, 2009, pp. 34-35). Because this is such an emotional experience in a person's life, some clinics, such as the University of Michigan Cochlear Implant Center, offer video monitoring and taping so that family members can capture this special moment without distracting the patient. Most places also allow educators, therapists, family members, and others closely associated with the patient to attend the activation as well as any follow-up appointments the patient may have ("System," 2010).

Activation is the first of multiple appointments to the audiologist for mapping the speech processor. As the brain learns to accommodate and interpret auditory stimulation, comfort levels for sound fluctuate and the patient must return for remapping. Remapping takes about two hours and is usually done every two weeks for the first few months after activation ("System," 2010). Sometimes,
side effects of the sudden stimulation of the brain include dizziness, tinnitus, and an overall dissatisfaction with the implant due to the overwhelming effect sound has on a patient who only knew silence. Tucker was particularly unhappy with her implant, as she experienced these side effects. She says,

I heard the toilet flushing—and not just when I flushed it, but also when others flushed it. It sounded like I imagined Niagara Falls would sound. It was loud and horrible...I heard more than toilets, though. I also heard motorcycles. Every time a motorcycle drove in the vicinity of wherever I happened to be, I almost went crazy. It hurt; it really hurt (Tucker, 2009, pp. 35-36).

The amount of time needed to adjust to the cochlear implant differs from person to person. Unfortunately, some people never adjust and resort to removing the external processor and living without sound for the rest of their lives.

For those that do adjust to the new stimulation and work toward learning to use the implant effectively, many different approaches and techniques for aural (re)habilitation are applied. The first approach, which can begin as soon as the patient hears sound, is auditory training. This is often a short-term therapy to help the patient understand the environmental sounds that surround them. Auditory training can be used in patients who are deaf and want to continue using sign language for communication, but want the safety benefits that the cochlear implant can provide. Because the sound quality from an implant is much different from that of normal hearing, patients who have previously had hearing, as well as patients who have never heard any sound before, must learn how to interpret the sounds they hear. The focus of this type of therapy is on listening. With enough practice, patients begin to label sounds from the environment, such as birds chirping, water running, or cars passing. Once they are accustomed to those sounds, the patient begins to practice speechtracking, which is learning to listen to speech sounds. The focus when practicing speechtracking begins with recognizing differences in the length and speed of sounds, words, phrases, and sentences, until eventually, the patient can recognize the actual sounds and words. This helps to improve the patient’s comprehension of spoken
words, sentences, and paragraphs (Frank, 2010).

A common type of (re)habilitation for children who are still developing language skills and want to learn how to speak is Auditory-Verbal Therapy (AVT). Although this approach can be used with any recipient of a cochlear implant, it is most effective with maximizing the benefit of the cochlear implant in children. The focus of this approach is to help the child to function, "in a regular learning and living environment that enables them to become independent, participating and contributing citizens in mainstream society" ("System," 2010, p.1). AVT is a continuous evaluation of the child's progress as he or she learns to listen to vocalizations, both their own and of others, and understand spoken language. AVT focuses only on listening and processing skills so that the child can keep up with children who have normal hearing in the mainstream classroom ("System," 2010). One program developed to help children learn to listen to speech is the Developmental Approach to Successful Listening II (DASL-II). Developed by Gayle Goldberg Stout and Jill Van Ert Windle (2010), it is a, "sequential, step-by-step listening program..." that is, "easy to implement [and ] progresses in very small steps to allow the children to succeed" (Stout & Van Ert Windle, 2010, p. 1). This program can be used by both professionals and family members.

The DASL-II begins with the most simple task first; that is, with sound awareness skills to help the child recognize when sound is present. The next step is a series of screening tests which help the child learn to recognize specific speech sounds and to discriminate one sound from another (Stout & Van Ert Windle, 2010). One example of a screening test used in DASL-II is the Ling 6 Sound Test. This test focuses on six different sounds: "oo, ah, ee, sh, mm, and ss." The parent, or therapist, stands three feet away from the child and says one of the six sounds at a normal conversational volume while covering his/her lips. The child, who has his/her cochlear implant turned on and functioning properly, then has to repeat the sound he/she heard. If the child cannot identify what he/she heard, the speaker can give hints to the child, such as, "this is what you say when the doctor looks inside your mouth," for "ah."
Eventually, as the child learns to distinguish the six sounds without any clues, the speaker gives the test again at four feet away, then six feet, and finally twelve feet. An important issue for the speaker to keep in mind is that the "ss" sound is softer than the others and, sometimes, a child will not actually hear it, but knows that he should be hearing it and will respond correctly. To eliminate this "cheating," the speaker can add another "sound" to the test, which is really just silence. That way, the speaker can be sure that the child is hearing all the sounds he/she is supposed to, but also realizes when no sound is produced (Sindrey, 2010). After the screenings have been completed for the DASL-II, the next part consists of phonetic listening skills and auditory comprehension skills. These can be administered similarly to the Ling 6 Sounds Test, where a speaker covers his/her lips and the child has to repeat the word or sentence spoken. To help the child with these goals, the speaker can provide a specific topic, word list, or set of pictures so that the child has some idea for what they are listening. Gradually, the goals can progress from words to phrases to sentences, until the child can participate in a conversation with little difficulty (Stout & Van Ert Windle, 2010).

Another (re)habilitation approach is the auditory-oral technique. Like AVT, the auditory-oral approach is used to help children understand spoken language well enough to fit in with the mainstream classroom rather than using sign language and needing interpreters for daily communications. The difference between AVT and the auditory-oral approach is that AVT focuses solely on hearing, interpreting, and understanding spoken language, whereas the auditory-oral technique teaches children how to use contextual cues and speech reading, or lip-reading, skills in addition to what they can hear in order to accurately comprehend speech. The long term goals of the auditory-oral approach involve: mainstreaming the child academically, socially, and professionally, improving reading skills, and providing more opportunities in the world (Moog, 2000). The decision for which approach to use, AVT or auditory-oral, highly depends on the child. The better the quality of sound the cochlear implant provides, the more likely the child will be to succeed with AVT. If the child does not benefit as much
from the implant, then the auditory-oral approach might be more appropriate.

Speechtracking is a (re)habilitation technique used for people with cochlear implants. This technique is used more with adult clients, rather than with children. It can be applied to either AVT, by covering the mouth of the speaker, or the auditory-oral approach, by allowing the client to use speech reading or context cues. Using this technique, a clinician sets a time limit. For that amount of time, the clinician will read from a text one phrase at a time. The client's task is to repeat the phrases back to the clinician. If the client does not do so correctly, the clinician can use strategies, such as repeating the phrase, giving clue words, or paraphrasing, to help the client repeat the original phrase (Cooper & Craddock, 2006).

All these techniques can be taught using one of two different methods, depending on the clinician's discretion. The first method is referred to as an analytic approach. This is when the client is expected to understand every last sound. For example, a clinician using the analytic approach to (re)habilitation would help the client to discriminate between voiced sounds and voiceless sounds, such as "p" versus "b." The philosophy behind the analytic approach is that, "an improved ability to discriminate between minimal speech contrasts will result in an improved perception of words, phrases, sentences, and connected discourse" (Cooper & Craddock, 2006, p. 302). The second method is referred to as a synthetic approach. The philosophy behind the synthetic approach is that, "the ability to predict meaning, rather than identifying individual speech components, should be the paramount aim in visual training" (Cooper & Craddock, 2006, p. 302). With the synthetic approach, the client is expected to grasp the general concept of what was said, rather than every sound that was made. With this method, close counts.

In addition to listening skills, some patients with cochlear implants may also need speech and language therapy. Those who were born deaf will need help learning the voicing, resonance, and placement of the articulators for each sound that comes naturally to those who developed language
from infancy. Those who later acquired a hearing loss significant enough to receive a cochlear implant have lost many of the speech skills that they once possessed. They are likely to need less speech-language therapy than those born deaf, but many of them will need extra practice with speech production to enhance their verbal communication skills. The speech pathologist will conduct frequent evaluations until the client reaches an acceptable level of speech intelligibility ("Pediatric (Re)Habilitation," 2010).

The previously explained techniques are only some of the great ways to help patients maximize the benefits of their cochlear implant. Each patient responds differently to the various techniques, and a number of various professionals, as well as supportive educators and family members, are vital to determining and implementing the best combination that will help the patient to succeed. With further improvements to technology, the current techniques are sure to advance as well. Further improvements are allowing more people to be considered candidates for cochlear implantation. It is important for the professionals to remain educated and continue modifying their approaches as necessary so that, not only can more people gain candidacy, but more people can also gain benefits from cochlear implants.

Today's Products

In regard to the cochlear implant, technology has come a long way from the designs discussed previously. The three major cochlear implant manufacturers today, Advanced Bionics, Cochlear Americas, and Med-El, offer top of the line products with multiple features to help the user gain as much benefit as possible (Cooper & Craddock, 2006). The products currently offered by Advanced Bionics include the Harmony HiResolution Bionic Ear System, which includes the HiRes 90K implant, and either the Harmony Sound Processor or the Platinum series processor. Med-El produces a cochlear implant system and a middle ear implant system. The cochlear implant offered by Med-El is called the Maestro Cochlear Implant System. Cochlear Americas' newest cochlear implant design is called the
Nucleus 5. In addition to the cochlear implant, this company also produces a device for bone conduction treatment.

The Harmony HiResolution Bionic Ear System offered by Advanced Bionics includes the HiRes 90K implant, which is designed in such a way that its user will be able to upgrade the device as technology advances without having to undergo another surgery. Its name comes from the fact that the implant updates 90 Kilobytes of data every second. The HiRes 90K Implant is small, making it an excellent option for young recipients, and is built to form to the shape of the user's ear, making it more comfortable to wear. Because MRI scans are so common for recipients of cochlear implants, before the surgery as well as after, the HiRes 90K Implant has a removable magnet to make this process easier. Other features of the HiRes 90K Implant include: internal memory, 16 independent output circuits, 120 bands of spectral information, broadband data transmission, integrated circuit computer technology, and HiFocus electrodes for neural targeting ("HiRes 90K Implant," 2009).

The Harmony HiResolution Bionic Ear System can use either the Harmony Processor or the Platinum Series Processor. The Harmony Processor is a behind the ear (BTE) design with an electronically integrated transmitter coil, and comes in three different colors: beige, silver, or dark sienna. The Harmony Processor can have up to 120 spectral bands which provide a frequency range of 150Hz-8000Hz. Such a large frequency range gives the wearer a significantly improved quality of sound. The Platinum Series Processor offers the same frequency range and number of spectral bands as the Harmony Processor, but it is a body-worn design rather than a BTE design. This design may be preferable for children who are too small for a BTE processor, or for adults who prefer not to wear a device on their ear ("HiRes 90K Implant," 2009).

Med-El's Maestro Cochlear Implant System consists of either the OPUS 1 Processor or the OPUS 2 Processor, the Fine Tuner, either the SONATA implant or the PULSAR implant, and the Med-El electrode wiring system. The most basic difference between the OPUS 1 and the OPUS 2 is the design.
The OPUS 1 is designed for people who want to make adjustments on the processor itself, via a switch. The OPUS 2 Processor, however, is the first processor in the world that does not use a switch. Instead, it uses the Fine Tuner remote control, which can be used to turn the implant on or off and make volume or sensitivity adjustments as necessary. The SONATA implant is an energy-efficient, lightweight, titanium implant. Its design includes capabilities for future software and audio processing upgrades so that the wearer can stay up-to-date with continuously developing technology. The PULSAR is the world's smallest implant and is made of ceramic, making it more resistant to impact. As with the SONATA, the PULSAR is also equipped with future software and audio processing capabilities so that the wearer can easily upgrade as technology progresses. The electrode array designed by Med-EI is unique in that the electrodes are made with wave-shaped wires to provide a softness and flexibility unlike the typical straight-wire design ("Implant Solutions," 2010).

The Cochlear Nucleus 5 System, produced by Cochlear Americas, includes the Cochlear Nucleus CP810 Sound Processor, the Cochlear Nucleus CI512 Cochlear Implant, and the Cochlear Nucleus CR110 Remote Assistant. The CP810 Sound Processor is a BTE design, but is extremely small, making it more comfortable for both adults and children. It is the only processor that is water resistant, meaning that it can be placed into three feet of water for up to thirty minutes without permanent damage. Although this does not mean that it is intended for swimming, the wearer can at least spend time around water without worrying. Cochlear Americas' Nucleus 5 System also comes with a Remote Assistant which gives the wearer the option of making adjustments to their processor more discretely. The CI512 implant is made of titanium and is 30% thinner than any other titanium implant, while maintaining reliable durability. The implant uses curved electrodes and the most advanced chip technology. The implant also contains built-in space for more chips so that the wearer can upgrade easily as technology advances ("Introducing Nucleus 5," 2010).
Bilateral Implants

Recently, cochlear implant candidates have been presented with a new option to consider; bilateral cochlear implants. This means placing an implant in both ears. This option would give the patient binaural hearing, or hearing in both ears, which is a giant stride toward giving someone next to normal hearing. Before 1995, bilateral implantation was rarely performed, and when it was, it was usually either to offer the patient a technology upgrade without having to first remove the older implant, or to compensate for an inadequate device in the other ear. By 1996, however, a bilateral implant was given to a patient with the intention of restoring binaural hearing. In 1998, the first child received bilateral implants in an attempt to restore binaural hearing (Med-EI, 2010).

The gift of binaural hearing to someone who was once deaf is an extremely important advancement of today’s technology. One advantage of having two cochlear implants is that if one implant is unsuccessful, or if one malfunctions, the recipient is still able to hear some sound through their second implant. More importantly, however, hearing in both ears helps in sound localization, which is important in knowing how to respond to what the listener hears. It is also helpful in distinguishing speech in situations with substantial background noise, like a classroom or restaurant. Hearing with only one ear makes these tasks much more difficult, requiring more effort to achieve less benefit. Not only does binaural hearing provide a person with more sound, but also with a much improved quality of sound. Another advantage to bilateral implantation, which studies have proven, is that bilateral cochlear implants in deaf people, particularly in children, help them to socialize more easily because they are more confident and willing to participate in group conversations ("Bilateral Cochlear Implants," 2010).

While so many advantages to bilateral cochlear implants exist, the process does come with some disadvantages as well. Having a second cochlear implant device costs much more money. The extra surgery, the additional device and its maintenance, and programming a second speech processor
will factor in more expenses for the patient. A major disadvantage to any cochlear implantation is that the recipient will most likely lose any residual hearing in the implanted ear. If the patient is not completely deaf, he/she may not want to risk losing all of the residual hearing by implanting both ears. Although technological progress provides benefits to cochlear implant wearers, the speed at which it progresses could also act as a disadvantage. If a person receives bilateral implants, he/she will most likely have to use the same technology for the rest of his/her life. Some people only implant one ear with the intention of receiving a second implant at a later date when they can benefit from more advanced technology ("Bilateral Cochlear Implants," 2010).

Candidates for bilateral cochlear implants are the same people who are candidates for one cochlear implant ("Bilateral Cochlear Implants," 2010). Two options are available to candidates considering bilateral cochlear implantation. They could receive the implants simultaneously, or they could receive the implants sequentially. The benefit to implanting at the same time is that they are both activated at the same time and the brain only has to adjust to the stimulation once. Some people who chose to receive their second implant a significant amount of time after their first may not always have the same success that they would had they implanted simultaneously. Success, however, depends greatly on the individual and researchers have not yet determined if the timing significantly affects results (Med-El, 2010).

One study that examined the effectiveness of bilateral cochlear implantation, conducted by Ruth Y. Litovsky, Aaron Parkinson, Jennifer Arcaroli, Robert Peters, Jennifer Lake, Patti Johnstone, and Gonqiang Yu (2004), was titled Bilateral Cochlear Implants in Adults and Children. This study involved seventeen adults and three children who participated in three months of testing after the activation of both, or their second, implant. The subjects participated in both sound localization measurements and speech intelligibility measurements. The results suggested that bilateral implants do improve sound localization and the ability to understand speech in situations where more than one person is speaking
at a time. After individual examination of the subjects' performances, the researchers concluded that those who used bilateral hearing aids for a significant amount of time before the bilateral cochlear implant performed better on the localization task than those who did not. The children in this study also showed signs of improvement with sound localization. The involvement of more children in this particular study would have contributed better results (Arcaroli, et al., 2004).

Multiple findings suggest that patients can reap considerable benefits from bilateral cochlear implantation. Though the process does have its disadvantages, candidates should carefully consider the advantages that can be gained before passing up this opportunity. Because of the enormous success of this new procedure, "provision of binaural hearing should be considered the standard of care for hearing impaired patients whenever it can be provided without significant risk" (Peters, 2006, p. 1). Normal hearing occurs with the use of two ears. Now that technology has provided a means of making that available for so many more people than ever before, society has taken a huge stride toward giving all people the quality of life they deserve.

Cost of Ownership

A process as complex as receiving a cochlear implant produces an incredible amount of expense for the recipient to cover. Depending on the source consulted, the total cost can fall anywhere between $40,000 and $100,000. The total cost includes expenses accumulated through every step of the process: the medical and audiological evaluations, the CT or MRI scans, the hearing aid trial, the surgery, the cochlear implant device, the physicians' fees and operating supplies, the programming of the implant, and the (re)habilitation therapy. Despite the high cost of this process, it is one of the most cost-effective procedures in the medical profession. A child who only uses sign language will often end up costing the community approximately one million dollars over the course of his/her life, but the use of a cochlear implant gives that child many opportunities which help alleviate the cost that falls upon society.
Though the patient is held responsible for some of the expense involved with cochlear implantation, programs such as Medicare, Medicaid, and private insurance help cover a significant portion of the expense. The policies regarding coverage are complicated and depend on many factors regarding each individual’s situation. Generally, however, Medicare recognizes cochlear implants as Durable Medical Equipment (DME) and treats them as other prosthetic devices, covering around two-thirds of the total cost. Although Medicare usually provides services to older adults, in some circumstances, children can also receive coverage for the cochlear implant procedure through Medicare. If a person qualifies for Medicaid, on the other hand, they can apply for benefits under the Early and Periodic Screening, Diagnosis, and Treatment Program (EPSDT), for children, or the Americans with Disabilities Act (ADA), for adults. The benefits from these programs often provide full coverage of the cost of a cochlear implant. Finally, private insurance companies usually offer some amount of coverage for cochlear implants, however, the exact amount highly depends on the individual’s situation (Clements, Freilich, Hartmann, Kuo, & Reuter, 2004).

Current Attitudes Towards Cochlear Implants

Most medical professionals would agree that the cochlear implant is a wonderful contribution to society. It has FDA approval, indicating that the general population remains open to the option. "The American Medical Association and the American Academy of Otolaryngology-Head and Neck Surgery recognizes it as a standard treatment for profound deafness for children" (Delost & Lashley, 2000, p. 1). Some people would compare receiving cochlear implants for hearing difficulties with receiving glasses for sight deficits. Others would say it is a matter of equality that every person be given the necessary accommodations to blend in with mainstream society (Delost & Lashley, 2000). Still, others see the cochlear implant as an improvement to the quality of life. While all these views see the cochlear implant
in a positive light, few people in the Deaf Community share that view. In fact, the cochlear implant is a highly controversial device within the Deaf Community. A documentary called Sound and Fury uses a single family to illustrate both sides of this debate.

The film focuses around two brothers and their families. The brothers were born to hearing parents. Chris was born hearing, but Peter was born deaf. As a child, Peter admits that he felt lost because of the lack of communication with other people, especially his parents. When he learned sign language, however, he says that he was able to begin living a better life. He became an active member of Deaf Culture and married a woman who was also deaf, while Chris went on to marry another woman who could hear (Aronson, 2000).

When the documentary was released in the year 2000, both Chris and Peter had young children of their own. Chris had infant twins, one of which was hearing and the other born deaf. Chris and his wife, Mari, decided that they wanted to give their son a cochlear implant because they wanted him to fit in with the hearing world. Mari had experienced the Deaf Culture growing up because both her parents were deaf. Given both their experiences with deaf people, both Chris and Mari agreed that a cochlear implant would make their son's life easier. Peter had a five year old daughter, Heather, who was born deaf, but began asking if she could have a cochlear implant. When asked why she wanted one, Heather would tell people that she wanted to hear alarms, saws sawing, hammers hitting nails, the telephone, cars, and people talking. The noises that many hearing people take for granted would be a dream come true for this five year old girl. Heather's parents were surprised when they realized that she wanted to be able to hear, but they talked to professionals and actively researched to find out if giving Heather a cochlear implant would benefit their family (Aronson, 2000).

Although they tried to remain impartial in Heather's decision, Peter and Nita were fighting an emotional battle which hindered their ability to view the cochlear implant through Heather's eyes. Peter's attitude toward the implant was particularly negative. As a child, Peter said that his life did not
truly begin until he learned sign language. That moment in his life, when he could communicate with others via sign language, was monumental and he could not understand why Heather did not feel the same way. Peter also feared that if Heather received a cochlear implant, she would be neither deaf nor hearing and would feel isolated and helpless. Nita, on the other hand, was a little more open to the idea. She understood why Heather would want to hear and even looked into receiving a cochlear implant herself. When the professionals told Nita that she would not be a good candidate for an implant, mostly due to her age, she became discouraged in her pursuit, and Heather's as well. Peter and Nita took Heather to several schools, some that focused heavily on speech, and others that focused more on sign language and decided Heather would fit in better at the school that used sign language. Ultimately, Peter and Nita decided that they wanted Heather to wait until she was older so that she could make her own decision about receiving a cochlear implant. They also decided to move to Maryland, where a strong Deaf Community had formed, and send Heather to a deaf school where they felt she could receive a quality education (Aronson, 2000).

Chris and Mari, on the other hand followed through with the cochlear implant for their son. They wanted their son to develop speech and language because they felt he would have the chance to receive a better education and that more opportunities would be afforded to him if he could hear. This was difficult for Mari's parents, who were deaf, to accept. In contrast, Peter's parents were extremely supportive and wished that Peter and Nita would give Heather a cochlear implant as well. They told Peter that had the cochlear implant been an option when he was a child, they would have given it to him without hesitation. By the end of the documentary, however, Peter and Nita, remained unpersuaded to give Heather the cochlear implant (Aronson, 2000).

A follow-up to the documentary was released in 2006, called Sound and Fury: 6 Years Later. Chris and Mari chose not to participate in the follow-up, but Peter and Nita described the events that followed after their move to Maryland. Issues arose which lead to general unhappiness in the family.
Peter worked in New York and could only come home to be with his family on the weekends. Nita, although happy with the Deaf Community, began to feel like a single mother and also missed her extended family. Because the move proved to be so difficult, Peter and Nita decided to move back. As before, however, the controversy regarding cochlear implants for Heather and her brother resurfaced, with Peter's parents pushing harder than ever for implantation of the children. Eventually, Peter decided that implantation was best for his children and would allow them the opportunity for happiness. When Heather and her brother finally received implants, she was nine years old. Heather was highly motivated to learn speech and excelled in therapy and in her academics. An interpreter was present in the classroom to offer help when she needed additional explanation. Her teacher reported that Heather placed in the top ten percent of her class, an incredible step as her class was comprised of all normal hearing children. Heather felt extremely satisfied with her implant and commented that having people treat her like a hearing person, rather than someone who has a handicap, made her feel special (Aronson, 2006).

Peter's fear that Heather would live in isolation dissipated when he realized that Heather functioned well in both the hearing and the deaf worlds. Nita, who had previously considered a cochlear implant for herself, reconsidered the idea. She received her own cochlear implant, and although she did not develop speech the way her children did, she gained significant benefits in speech understanding and was able to participate in the hearing world as well. At the end of the follow up footage, Irene Leigh, Professor of Psychology at Gallaudet University, insightfully concluded, "There is a place in the Deaf Community for those kids with cochlear implants. And they are contributing also to the changing perception of the Deaf Community. The bridges have been crossed and that I think is the story of the Deaf Community" (Aronson, 2006). Hopefully, Leigh is correct and the cochlear implant trend will catch on so that every person has the opportunity to participate in the gift of hearing.
Interviews

Much information can easily be found in regard to cochlear implants. An abundance of information such as their history, how they function, the surgical procedure, and even strategies for therapy and orienting people to their new device is available to any person who wants to do the research. Companies that produce these devices, such as Cochlear Americas, Advanced Bionics, and MED-EI all provide ample information about the devices themselves. Other groups, such as the American Speech-Language-Hearing Association provide information to potential candidates or family members about what to expect, what types of therapy a person will need after implantation, or even the various options, other than an implant, that are available to him or her. I have included all this research into this project, but discovered that the stories of individuals who have a cochlear implant or who work closely with someone who has a cochlear implant are not readily available, yet are a vital aspect of fully understanding the device. I have collected data through personal interviews that has provided personalized, first-hand accounts of the cochlear implant process which includes, but is not limited to, the effectiveness, strengths, and weaknesses of cochlear implants.

Interviews: Steve and Jan

The first couple interviewed, Steve and Jan, chose the cochlear implant device for their two sons, David and Michael. David, the older son, was five years old at the time I interviewed Steve and Jan, and Michael was three. When asked if hearing problems run in the family, both Steve and Jan answered that they did not and were extremely surprised when their first child failed his newborn hearing screening. They immediately decided that they wanted to give their son a cochlear implant and embarked on the long candidacy process which eventually determined that David could benefit from implantation. When asked what the process was like, Jan said it was long and, "you start off with doing your hearing test. Then, you have to do an MRI, 3-6 months of hearing aid trials, you have to go back to
the sound booth to do behavioral tests, and then they decide if you are a good candidate or not" (Jan, 2010). By the time David received his implant, he was a year and a month old. Steve and Jan said that David's reaction to hearing sound for the first time was extremely emotional and that he cried. When asked how the implant has affected their family, Steve answered, "It has given him the opportunity to hear, whereas, without this, he would not have that opportunity. It lets everybody communicate. It's still a learning process with all the family, but at least everybody is able to communicate somewhat with him. He's able to communicate somewhat with them" (Steve, 2010).

Since his implant, David's parents sought therapy for him through First Steps until he was three, and then they enrolled him at the Ball State University Speech and Hearing Clinic, where he currently attends therapy sessions. When asked where David fell in comparison with children who have normal hearing, Steve said, "He missed out on the first year he was born...so he is really a year, year and a half behind, but he is making pretty good progress"(Steve, 2010). In addition to professional therapy, Steve and Jan work extensively with David's communication skills at home. They "force him to talk for what he wants," and "try to stay away from signing because we did the implant so that he could hear and he could talk" (Jan, 2010).

In regard to their second son, Michael, Steve and Jan said that he had hearing when he was born. When he was a year and a half to two years old, however, they noticed that Michael's hearing was gradually deteriorating, and eventually, he went completely deaf. They were not sure of what caused it, but were told it could have been a genetic trait between the two of them. They have not consulted a geneticist, however, to officially determine that was the cause. As soon as they tested Michael and determined that he had permanently lost his hearing, Steve and Jan immediately knew they wanted to give him a cochlear implant as well. When asked about the candidacy process for Michael, Jan said, "His was faster. They rushed him because of his age. They do not like to implant after the age of three" (Jan, 2010). Steve said Michael's hearing aid trial was only two weeks long, as opposed to the three months
or so that David endured. By the time Michael received his implant, he was a little more than two and a half years old. His reaction to hearing sound again after almost a year without hearing was to cover his face. The family's reaction to Michael's implant was happiness and excitement. When asked about any changes they have noticed in Michael's behavior since he received the implant, Steve said, "He is more quiet now, but he is more vocal. Instead of hollering and screaming, he has quit doing that and he will do other things...not be as loud all the time" (Steve, 2010).

Since his implant, Michael has received therapy from Ball State University Speech and Hearing Clinic, where he is also currently enrolled. As with David, Steve and Jan are extensively involved in working on communication skills at home. When asked about the differences in how they approach home therapy with David and Michael, Jan said, "For David, we are a little bit harder on him because he has a little more experience and knows what he is supposed to be doing. Michael, he has a little progress to go, so we have to take baby steps" (Jan, 2010). Michael has only had his implant turned on for one month, so his communication is all sign right now, but he is becoming more accustomed to the stimulation of sound.

When asked about the disadvantages to using a cochlear implant, Steve said, "There are certain things that he cannot do while he has it on. He cannot get in a pool. He cannot play in the ocean. Nothing to do with water [sic]. He cannot play on plastic playground equipment" (Steve, 2010). Jan said, "Sports are going to be a big issue because of head contact" (Jan, 2010). Steve replied that, "[Sports will be] dangerous because if he gets hit on that side of the head, it could severely damage his skull" (Steve, 2010). When asked about the benefits they have seen due to the cochlear implants in their children, Steve and Jan smiled while they said, "[Children that] can hear!" (Jan, 2010). Neither Steve nor Jan had suggestions for improvements to the technology. They said that while David has a Nucleus Freedom, which requires extreme caution against water and static, Michael has the Nucleus 5, which is water
resistant and allows much more freedom. Both parents were extremely satisfied with their decision to give their sons cochlear implants.

**Interviews: Susan**

The next person interviewed was Susan. She is the legal guardian of her granddaughter Maddie. Maddie is seven years old and received her cochlear implant when she was three. When Maddie was born, her parents and grandparents had no idea that she was deaf. She was, "a happy baby, alert, and intelligent" (Susan, 2010). Susan said that when Maddie was about five or six months old, Susan was working in the kitchen while Maddie played on the kitchen floor. Susan dropped an item that made a huge clatter and Maddie did not even budge. So she dropped it again to see what would happen, and again, Maddie showed no sign that she had heard the noise. At that point, Susan insisted that her daughter, Maddie's mother, take Maddie in for testing. Through this process, the family discovered that Maddie had failed three different newborn hearing screenings, but the doctors and nurses never provided that information to the family. Maddie was given a year of hearing aid trials as part of her candidacy process for cochlear implantation. During that process, some members of the Deaf Community talked with Maddie's family and encouraged her parents not to implant. After even more encouragement from Susan, however, Maddie's parents decided to go through with implantation.

When asked what the candidacy process was like for Maddie, Susan implied that it was too long. She did not believe that the hearing aid trials should have lasted for an entire year. She attributed its unnecessary length to the fact that the parents were feeling pressured from the Deaf Community to not follow through with the surgery. When Maddie received her implant, Susan said that, for the most part, family members and friends thought it was great and they were glad she could hear. Maddie's brother, however, had a different perspective. He was happy that his sister could hear, but he also resented the device to some extent because his friends at school would often tease him due to his sister's "bionic hearing."
Maddie received therapy through First Steps until she was three. For most of that period, however, she was still trying to find benefit through the use of hearing aids. After she grew out of that program, an audiologist worked with her at the preschool she attended, and she began to attend therapy at Ball State University's Speech and Hearing Clinic. When asked how Maddie performed academically, Susan stated that, "she is slow. [She is] performing at the level of a child between two or three years old" (Susan, 2010), when she is really seven. Maddie has just received a second implant so that she now has bilateral hearing. Susan said, "[The second implant] helps also in getting her caught up" (Susan, 2010). Susan and her husband are preparing to move to Indianapolis, where Maddie will attend St. Joseph's Institute for the Deaf, a school where she can learn in an environment better suited for her needs. Susan is confident that attendance at this school will help improve Maddie's academic skills to help her catch up on what she missed while she was deaf.

Susan reports that Maddie's communication has improved greatly. She said that before the cochlear implant, Maddie would try to communicate by voicing, "Ahhh" and her needs could not easily be interpreted. Now, however, Maddie is learning to speak, she has learned to sign, and can read lips. Although communication is still slow, it is much easier and more accurate. Susan mentioned that communication at school is much more difficult for Maddie. She has been in trouble with the teachers for issues that were miscommunications rather than intentional disobedience. Susan gives the example that, "Maddie would ask about getting in line at lunch and the teacher would say, 'It's not time,' but what she heard was 'Get in line,' so they would give her a strike" (Susan, 2010). Episodes like this were frequent and is one reason that Susan has decided to send Maddie to St. Joseph's.

When asked what the benefits of Maddie's cochlear implant were, Susan responded that, "She would never be able to talk or communicate [without the implant]" (Susan, 2010). Maddie loves music and is able to enjoy it much more because of the implant. She even plays the drums. Susan said Maddie was, "becoming a normal child all the way around" (Susan, 2010). Susan also admitted, however, that
the cochlear implant does have some disadvantages. For example, Maddie could not wear it around water, so if she was taking a bath, swimming, or walking in the rain, she would have to remove it and temporarily give up her ability to hear. She could not play on plastic slides because of the static, which could ruin an implant. Susan’s suggestions for improving the cochlear implant would be to correct the issues around water, but also to make improvements on the design and size of the devices. "Maddie is very petite and doesn’t wear the processor on her ears because it folds them down and hurts her" (Susan, 2010). Instead, Susan attaches the processor to Maddie’s ponytail to help make it a little more comfortable for her. In regards to those suggested improvements, Susan says, "I can see it coming. They are getting smaller and smaller" (Susan, 2010). Not only would a smaller processor be more comfortable for Maddie, but Susan believes it would also help boost her self-esteem. Maddie’s classmates tease her because the device looks different and Susan states that, "society makes us want to look a certain way" (Susan, 2010). A smaller device would be more cosmetically pleasing and would help to alleviate the self-esteem issue for many cochlear implant users.

Interviews: Fred

My next interview was with an eighty year old man, named Fred, who received his cochlear implant when he was 74 years old. When asked about his hearing history, Fred said, "Well, it started out a long time ago, 1954. I was in the Navy and I was the driver of a fire truck, and in those days they did not use the earplugs in the fire department. I noticed that I kept missing different sounds" (Fred, 2010). He went to an Ear-Nose-Throat professional (ENT) and was told that he was not hearing higher pitched sounds. Because his hearing had become so poor, Fred was discharged from the service. He continued to have difficulty, so Fred, "made contact with the Veteran’s Administration (VA) and, to make a long story short, they gave me a hearing aid" (Fred, 2010). He tried this for a little while but, "it got to the point that I could not communicate with the customers. I was missing too much" (Fred, 2010).
Eventually, the VA gave Fred 100% disability due to his hearing loss and sent him to a VA hospital in Ann Arbor, Michigan. There, "they said that they had a surgical procedure that was 98% successful in improving my hearing, so I said, 'well, let's try that.' Well...it was not successful. I lost everything that I had. [I] could hear nothing" (Fred, 2010). Although the result was disappointing, Fred went through professional testing to determine if he was an acceptable candidate for cochlear implants. This process was fairly quick because he had already been trying to use hearing aids and had determined that they were not providing much benefit. One question raised by both Fred and the professionals was whether his age would be an issue in the success of an implantation. The professionals decided to let him try, so he went through with the implant surgery, which turned out to be extremely successful. Describing the moment when the implant was turned on, Fred says, "She [the audiologist] said, 'Now, I'm going to turn it on,' and I said, 'Okay.' She turned it on and she said, 'Can you hear me, Fred?' and big ole tears ran down my cheeks. That was the start of a very good thing" (Fred, 2010).

When asked how the implant has affected him, Fred said, "I was suddenly able to hear again. That's quite an experience. I honestly thought that there was no way that you could take a hearing that is no longer there and make you hear again" (Fred, 2010). In regards to the reactions of family members and friends, Fred said that they were, "most happy. They didn't have to write me a note...they don't have to say, 'Huh?' anymore" (Fred, 2010). Fred has noticed much improvement with his daily activities since his implant because he is more aware of what is going on behind his back. For example, he does not have to be looking at the television to know that it is on.

Fred did not receive any additional therapy after receiving his implant, because he had already developed language and had learned how to lip-read through a class provided to those coming out of the service due to hearing loss. In most situations where Fred is unable to understand a particular person, usually, his wife, Sally, is able to repeat or rephrase the words so that Fred can make sense of them. Fred said that the most important benefit of the cochlear implant is, "being able to hear" (Fred,
2010). He also stated that, "I can turn the implant off [when I'm tired or upset]" (Fred, 2010). Fred lists misunderstanding words, short battery life, maintenance of the implant device, and having to remove the processor when showering or swimming as disadvantages to using a cochlear implant. Fred points out another important disadvantage when he states,

One of the big things I found out about being deaf is that even your close family, close friends, if they know that you are deaf and that they are going to repeat and repeat, they more or less shorten the conversation, or don't even begin the conversation to begin with. I'm sure that all people that wear an aid can say that. A lot of times, there are stories that someone would just love to tell me, but they know that I would not get most of it, so they just eliminate it altogether. That's probably my biggest complaint about being deaf (Fred, 2010).

When asked if there were any improvements that could make cochlear implants better, Fred simply said, "No. I'm happy with what I've got" (Fred, 2010).

**Interviews: Sally**

Next, I interviewed Fred's wife, Sally, to obtain information about what life is like living with a spouse who has a cochlear implant. Sally did not know Jack before he received his cochlear implant, so she described what communication with Fred was like, but could not compare it to his communication skill level before the implant. She said, "When he gets his mind on something, he doesn't hear you. He's not ignoring you...he's concentrating so hard that he doesn't hear you. If I get excited, [and start talking really fast] he'll say, 'Slow down! Now, what did you say?'" (Sally, 2010).

When asked what benefits she has experienced due to the cochlear implant, she mentioned that, "it looks nice" (Sally, 2010), as compared with the bulky hearing aids that Fred had to wear before. "He doesn't have the wires hanging from his ears" (Sally, 2010). Sally mentioned that she noticed this advantage while looking at pictures of Fred when he was younger. Disadvantages of Fred's cochlear implant that affect Sally include,

He doesn't enjoy and have fun [when we go swimming]. Or, trying to tell him a joke that you've heard. You have to repeat and repeat and repeat, and you've lost the fun of the joke. It's hard to
share with him something exciting because it loses the excitement. And going to a meeting, I try to take notes so he can read them. Going to church, I used to write the notes so that he could piece together the sermon (Sally, 2010).

Finally, when asked about improvements that Sally would like to make to the device, she said, "No...cause I think what they have given him gives him a quality of life" (Sally, 2010).

**Tomorrow**

**Where is Technology Going?**

All areas of technology are quickly advancing, which means that improvements specifically to the cochlear implant are advancing as well. Ongoing research on binaural hearing, through the use of either two cochlear implants, or one cochlear implant and one hearing aid, continues to provide information about its potential benefits. It is likely that bilateral implants will become more standard in the near future. Some researchers are trying to determine if the device can provide any benefit for people with other, less severe, types of hearing loss. Other researchers are trying to determine if there is a way to make the cochlear implant provide clearer speech sounds. Another possibility professionals are exploring is whether the implant can be better tailored to individuals' needs. For example, if a person has a hearing loss of only higher frequencies, using a shorter electrode array which is placed in only part of the cochlea, rather than entirely destroying it may be a possibility. This would allow the person to use his/her normal hearing for the lower frequencies, but the cochlear implant would be used to help hear the higher frequencies ("Cochlear Implants," 2010).

Another prospect for change to cochlear implants in the future involves researching why the performance varies so much from one cochlear implant user to another. Researchers have yet to explore variables such as the activation of the central auditory system by the implant or the role higher level cognitive processes play in the performance of the cochlear implant. Further research, involving longitudinal studies, comparing the language development in children across multiple hearing situations,
including those with cochlear implants, hearing aids, normal hearing children, and deaf children, needs to be done in order to account for advancements made in technology. Also important to the future of cochlear implants is the continued study of the relationship between speech perception and speech production in cochlear implant users. Finally, researchers should look more closely at the relationships between neural activity and auditory perception so as to find better ways to increase the survival of neural elements in those who receive cochlear implants (Clements, Freilich, Hartmann, Kuo, & Reuter, 2004).

Epic Biosonics, a cochlear implant company in British Columbia, Canada, is currently working on a cochlear implant model called, “The Epic.” This implant will require a much shorter and less invasive surgical procedure due to its tiny size and weight; only measuring three by five centimeters and weighing less than three grams. These measurements will lend The Epic toward implantation in newborn babies. During the procedure, a microphone will be placed under the skin in the ear canal. The speech processing device, which will be placed under the skin behind the ear, will receive the sound from the microphone and convert it into an electrical signal. The signals will then be sent to the electrode array, which will consist of 48 electrodes, rather than today’s average which is between 20-24 electrodes. The electrodes will stimulate the nerve cells that will tell the brain sound is occurring.

Although The Epic will work similarly to the cochlear implants of today, it will do so without the use of any external components, making it much more cosmetically appealing to cochlear implant candidates. The Epic will use a state-of-the-art speech processing chip which combines both analog and digital technology and requires much less energy than a device that is completely digital. The device will use less than a millionth of the amount of energy a light bulb uses. The battery used for The Epic will not involve liquid electrolyte, which means that the patient does not need to worry about leakage. It will also be rechargeable with the use of an external battery that uses radio frequency to transmit the charge to the internal battery. Only one to two hours per week will be needed to recharge The Epic
Although technological advancements to the cochlear implant will continue to make the device easier to use and more effective, other researchers have begun to look into the more distant future. Studies designed to find a way to cure hearing loss have already begun. If such a cure is ever found, devices, such as the cochlear implant or hearing aids, will no longer be necessary. The main way researchers are going about this task is through the use of Gene Therapy. Gene Therapy provides a way to prevent the death of hair and spiral ganglion cells and can be accomplished through two different methods. The first method is to send protective antioxidants to the hair cells in the cochlea via a virus. This method was successful in preventing antibiotics from killing the hair cells. The second method uses a protein to protect the spiral ganglion neurons in the event that the hair cell has already been destroyed. Both methods have demonstrated success in animals and, if perfected, could be applied to humans to help prevent, or at least postpone, the destruction of hair and spiral ganglion cells ("Gene Therapy to Prevent Hearing Loss," 2010).

The review of a study conducted by Duan, Venail, Spencer, and Mezzina (2004), titled Treatment of Peripheral Sensorineural Hearing Loss: Gene Therapy, describes the possibility of using gene therapy inside the cochlea in an effort to treat deafness. The review suggests a positive attitude toward this new technique and states that, “the cochlea is anatomically well suited for in vivo gene therapy. The relative isolation of the cochlear compartments minimizes unwanted effects of the introduced gene into other tissues" (Duan et al., 2004, p.1). One possibility that looks particularly promising is the use of neurotrophin gene therapy. Neurotrophin is a substance secreted by both hair cells and spiral ganglion cells. They play a critical role in inner ear development and in protecting the inner ear against ototoxic chemicals and noise, both of which could cause serious damage. The use of neurotrophin gene therapy could help protect against acquired damage contributing to hearing loss, and it can also assist in regeneration for already damaged cells. Although this technique will hopefully cure deafness and
hearing loss altogether, it may be many years before the method is perfected enough to perform in
humans. A possibility for the use of gene therapy in the meantime, however, is to use it to improve
cochlear implant function. If gene therapy were to be used during the cochlear implant surgery, the
neurotrophin could help protect and improve neural growth, on which the performance of the cochlear
implant depends (Duan et al., 2004). Though gene therapy is still in the preliminary stages, it holds great
promise for improvement to today's technology for the future.

My Career

After all this research, I am left with the question: How will any of this affect me? Hearing
impairments do not run in my family and I have known few people who used hearing aids or cochlear
implants throughout their lives, yet I have put a substantial amount of effort into gathering information
and piecing together every important aspect regarding cochlear implants that I could find. Through the
duration of this project, I have gained a more professional understanding of cochlear implants and the
issues that accompany the devices. Not only have I found the topic interesting, but as I researched, I
began to see how this information would be pertinent to my professional work in the future. The
knowledge I have gained through this research will become important as I embark on a career in speech-
language pathology because I am certain that, at some point, I will work with a person who has received
an implant.

In the future, when I have a client who wears a cochlear implant, I will have a better
understanding the emotional aspects of living with a cochlear implant, including the lengthy and
strenuous process they went through to receive it, the technological details of the device, and the
variety of techniques available to help the client through the (re)habilitation process. The feedback I
received from those I interviewed provided me with valuable information to keep in mind about the
setbacks and frustrations that can occur along with the successes and improvements that people with
cochlear implants experience. This information will help me to handle sensitive situations with tact and
have a general awareness of the needs and expectations of the client. My research on the technical mechanisms of the cochlear implant has provided a better understanding of how to troubleshoot problems that a client may have with the device. I have gained knowledge about the problems that can be corrected by the client or myself and the problems that require the service of another professional.

Though all the information I have gained throughout this project is valuable, the most important and relevant to my future career is that learned regarding the techniques of (re)habilitation for clients after receiving a cochlear implant. I have learned not only a variety of techniques, but also when to use certain methods to achieve the most effective results. I feel my research has given me a head-start in this area, which I will learn even more about as I become closer to beginning my career. To answer the question initially raised, the completion of this project will affect me by contributing to my overall competence in my professional career.
References


Institutional Review Board

DATE: August 18, 2010
TO: Michelle Welage
FROM: Ball State University IRB
RE: IRB protocol # 171579-4
TITLE: Cochlear Implants: Yesterday, Today, and Tomorrow
SUBMISSION TYPE: Revision
ACTION: APPROVED
DECISION DATE: August 18, 2010
EXPIRATION DATE: August 10, 2011
REVIEW TYPE: Expedited Review

The Institutional Review Board has approved your Revision for the above protocol, effective August 18, 2010 through August 10, 2011. All research under this protocol must be conducted in accordance with the approved submission.

As a reminder, it is the responsibility of the P.I. and/or faculty sponsor to inform the IRB in a timely manner:

- when the project is completed,
- if the project is to be continued beyond the approved end date,
- if the project is to be modified,
- if the project encounters problems, or
- if the project is discontinued.

Any of the above notifications should be addressed in writing and submitted electronically to the IRB (http://www.bsu.edu/irb). Please reference the IRB protocol number given above in any communication to the IRB regarding this project. Be sure to allow sufficient time for review and approval of requests for modification or continuation. If you have questions, please contact Chris Mangelli at (765) 285-5070 or cmmangelli@bsu.edu.