Remote Programming of Cochlear Implants in the Adult and Pediatric Population

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Cochlear implants have become the standard of care for patients suffering from profound sensorineural hearing loss. Unfortunately, access to cochlear implantation as well as cochlear implant rehabilitation may be limited. In order to facilitate access to cochlear implantation and cochlear implant rehabilitation, implantation was performed at a satellite medical facility over 250 miles from the Carolina Ear and Hearing Clinic's cochlear implant center, and the implants were programmed over the Internet via a virtual private network (VPN). A separate video conferencing system was used to insure synchronization of the video and audio signals.

Initially, an IRB approved pilot study was conducted comparing the postoperative HINT and CNC word scores for seven patients who had undergone remote mapping and programming of their cochlear implants. Their scores were compared with the mean scores of seven patients who had been programmed at the Carolina Ear and Hearing Clinic by the same audiologist over a twelve-month period. All patients in each group were successfully programmed and there were no statistically significant differences in postoperative HINT and CNC word scores.

Based on the success of this pilot study, the remote programming system was expanded to include young children. Their ages ranged from 22 months to 5 years of age. All five children were successfully programmed remotely. To date, over 48 adult and pediatric patients have been implanted and successfully programmed using this remote programming system. The ability to remotely program cochlear implant patients offers the potential to extend cochlear implantation to areas without a tertiary cochlear implant center. This model, which is safe, effective, and maintains patient confidentiality, may have application for other implant centers attempting to provide patients access to cochlear implant technology.

**Key words**: Cochlear Implants, Remote fittings of cochlear implants, Telemedicine

**和文キーワード**: 人工内耳、遠隔地の人工内耳、患者のフィッティング、インターネット、遠隔医療

**INTRODUCTION**

Since its inception in the late 1960s and early '70s, telemedicine has continued to evolve. Technological advances in conjunction with the development of the Internet currently allow operators to remotely control computers in geographically dispersed locations. This
remote desktop application capability, coupled with specialized video conferencing equipment, affords cochlear implant centers a means to access patients who might otherwise be unable or unwilling to travel to the cochlear implant center for programming or mapping of their devices.

Despite the technical ability to perform remote programming of cochlear implants, other factors need to be considered: safety issues, patient privacy, real-time access with minimal signal interruption, and cost.

Beginning in 2007, the Carolina Ear and Hearing Clinic, based in Raleigh, North Carolina, U.S.A., established a satellite cochlear implant program in Greenville, South Carolina, U.S.A. To minimize patient inconvenience, the surgical procedures and cochlear implant mapping were performed in Greenville. Later, a cochlear implant audiologist in Raleigh, with the assistance of the local audiologist, remotely programmed the implants without having to visit Greenville. A variety of hardware and software applications were tested prior to selecting the current model.

This communication represents our efforts to ensure the effectiveness and quality of cochlear implantation at this satellite clinic where patients had their cochlear implant mapping and programming performed remotely via an Internet connection.

MATERIALS AND METHODS

In 2007, following IRB approval, a satellite cochlear implant program was established in Greenville, S.C., over 250 miles from the Carolina Ear and Hearing Clinic’s tertiary cochlear implant center in Raleigh, NC. Both sites were equipped with a desktop computer and standard, commercially approved cochlear implant programming hardware and software. The following additional layer of hardware and software technology was also installed to enable the remote programming capability: a) a commercial grade Internet connection was installed in both offices; b) for security concerns, routers with Virtual Private Network (VPN) capabilities (Netgear® ProSafe VPN Firewall Model FVS 318, San Jose, CA.) were installed to provide secure communication between sites; c) Virtual Network Computing (VNC) remote desktop software was installed and configured at both sites, allowing the computer in Raleigh to control the desktop in Greenville, SC; and, d) a low-end commercial video conferencing system, the Polycom® V700TM (Polycom® Inc., Andover, MA) was installed in the Raleigh and Greenville offices (Fig. 1).

In order to minimize inconvenience and cost for the cochlear implant patients, the cochlear implant evaluation, cochlear implant surgery, and the cochlear implant mapping were all performed in Greenville, SC.

The patients were scheduled for programming of their implant at one month, three months, six months, and twelve months postoperatively. HINT and CNC scores were obtained at that time.

The VNC remote desktop software transmits keystrokes and mouse movements from the Raleigh computer to the Greenville computer, and the Greenville computer returns screen updates to the computer in Raleigh. Although the cochlear implant audiologist inputs the commands for programming in Raleigh, the application on the computer in Greenville is actually programming the implant. This mimics the standard technique for cochlear implant programming.

Postoperative HINT and CNC word scores for the seven, post-lingually, deafened patients who had undergone remote mapping and programming of their Nucleus Freedom cochlear implant were compared with the scores of seven, post-lingually, deafened patients who had similar durations of deafness, and had been programmed in Raleigh by the same audiologist over a six to twelve month period. This group also had the Nucleus Freedom cochlear implant.

Based on the success of this initial pilot study, and following IRB approval, the same system was used to remotely program the devices of five young children, ranging in age from twenty-two months to five years.

RESULTS

All surgeries were performed without complications. Each of the patients’ implants was successfully programmed at the Greenville site by the cochlear implant audiologist over 250 miles away.

None of the patients experienced apparent signal
corruption or an AC electrical surge during programming. The commercial grade Internet connection, and the hardware and software used for remote programming proved reliable. The "round trip" signal time between Raleigh and Greenville was approximately 58 msec. This network latency did not interfere with the mapping, and the audiologist performing the programming could accurately observe patient responses. The patient and non-implant audiologist were also able to observe the implant audiologist during the implant programming procedure.

The preoperative and postoperative audiological test results for the Greenville patients are presented in Table 1, and the results from the Raleigh patients are presented in Table 2. Figure 2 shows comparisons between the Raleigh and Greenville cohorts for A) pure tone averages (PTAs) for the pre- and post-operative intervals; B) recognition of the HINT sentences for the pre-operative, 3 month, and 6 month intervals; and C) recognition of the CNC words for those same intervals. Selection of the pre-operative, 3 month, and 6 month intervals allowed inclusion of the maximum number of tested subjects for the two measures of speech reception. Speech test scores for adult cochlear implant patients generally asymptote at 3 to 6 months of experience with the devices.

Each set of bars in Fig. 2 was compared with a t test to evaluate the significance of possible differences. A p value of 0.05 or lower was regarded as indicating a significant difference.

None of the comparisons is significant except the difference between cohorts for the post-operative measures of PTAs (p < 0.001).

**DISCUSSION**

In reviewing the published literature, we could only find one article that evaluated the potential for remote programming of cochlear implants. This study was more of a "proof of concept" experiment, in which the remote station was only 300 meters away and the connection probably never left the phone company’s switch, thus avoiding latency issues. Skype was used
### TABLE 1.

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delayed audio/video signal were all taken into consideration with our remote programming set-up.

**PATIENT SAFETY AND CONFIDENTIALITY**

When developing a model for remote programming of cochlear implants, patient safety is obviously the first consideration. It is essential that all measures be taken to insulate the patient from a corrupt signal or an electrical surge during the mapping process.
A) Pure Tone Averages

![Pure Tone Averages Graph]

B) HINT Sentences

![HINT Sentences Graph]

C) CNC Words

![CNC Words Graph]

**FIG. 2.** Preoperative and postoperative audiological results, comparing remotely programmed cochlear implant patients in Greenville, SC, with a similar group of locally programmed cochlear implant patients in Raleigh, NC.

Both conventional and remote methods employ the use of a desktop computer and commercially approved cochlear implant programming software. The only major difference between the two techniques is the use of the Internet. Because the programming methods are otherwise identical, the risk of a corrupt signal during remote programming should be no greater than with conventional programming; the actual signal is being generated from the remote computer to the patient’s implant.

There is always the danger of an electrical surge, both in conventional and remote programming scenarios. However, all equipment used in programming our implant patients was grounded, connected to surge protectors, and had battery back-up. This included the routers and Internet switches.
In addition to patient safety, patient confidentiality is an important aspect of any remote programming technique that interfaces with the public Internet\(^{(3)}\). Remote programming requires electronic transmission of protected health information, and therefore needs to be compliant with the regulations set forth by the Health Insurance Portability and Accountability Act (HIPPA) of 1996.

Although the Internet offers a convenient conduit through which the information can be sent to distant locations, it also affords the potential for others to access the information. In order to ensure that the information cannot be intercepted and read, all data must be encrypted and sent in a special format. A virtual private network was established between the Raleigh and Greenville sites using the routers. The VPN created an encrypted “tunnel” (transmission path) through which all data flowing between the two points are secure. VPNs are relatively inexpensive to set up, but secure enough to meet HIPPA regulations. In addition, after installing the hardware and performing the setup, there is no further cost associated with running a VPN tunnel between sites.

Once the VPN link between the two offices was established, our cochlear implant audiologist was able to take control of the remote computer using VNC. Using this software package allowed the programming audiologist to control the remote desktop computer, while letting both sites simultaneously view the computer screen and video link.

There are two side benefits related to the simultaneous viewing by the non-implant audiologist: a) if there are any communication errors or problems with the remote programming procedure, the audiologist with the patient can immediately take control of the programming computer; and b) training of the non-implant audiologist occurs, because the audiologist at the Greenville site is able to view the programming technique used by the cochlear implant audiologist in Raleigh.

**AUDIO AND VIDEO SYNCHRONIZATION**

In addition to patient safety and confidentiality, it is important that the audio and video signals between the two sites be synchronized and minimally delayed. We originally attempted to run the audio, video, and computer programming software simultaneously via the computer; however, we found that the delays were unacceptable. Hearing impaired patients rely, in part, on lip reading, and synchronization of the audio and video signal is therefore especially important. Consequently, we used a Polycom\(^{®}\) V700\(^{TM}\) which uses a bandwidth of 768 kilobits/sec (kbps) and packages both audio and video signals into a single bundle, ensuring that both signals are synchronized. The bandwidth (768 kbps) does not exceed most small business Internet connection speeds. The device also has its own IP address, which allows routers / switches to prioritize the Polycom\(^{®}\) V700 over other network devices. The Polycom\(^{®}\) V700\(^{TM}\) costs approximately $2400 U.S. dollars, and is very easy to set up; simply plug in the network and power cables and answer a few set up questions. The V700 does have two power switches that must be in the “on” position for the unit to function.

When using the Internet, the quality of the audio/video streams between sites is dependent on the performance of the Internet connection. It is important to have qualified IT consultants involved in setting up this link. Most U.S. consumer grade Internet Service Providers (ISPs) are not adequate for the quality of signal required. For example, a home IP connection might have an 8 mb download speed, but only a 384 kb upload speed. A commercial grade Internet connection should be used by both offices when performing remote programming. A consistent one megabit/sec connection in both directions is the minimum required for optimal performance. Even though the Polycom\(^{®}\) V700\(^{TM}\) is a low-end commercial grade video conferencing unit, it requires 768 kbps in both directions for optimal performance. We used a T1 line, which has a bandwidth of 1,500 kbps for the Polycom\(^{®}\) V700\(^{TM}\) unit. Unfortunately, the T1 costs $400 per month; however, this can be used for other networking needs at each site when programming is not taking place.

In order to check for lost packets or long network delays that would adversely affect the audio/video sig-
nal, we used the software program, PingPlotter (Messsoft, LLC). PingPlotter is a network troubleshooting tool for Windows®. It uses a combination of “tracerrout”, “ping”, and “whois” to demonstrate the “hops” on the Internet the signal packets are taking, and the length of time required. Usually, the fewer hops the packets take, the better. There were 12 Internet “hops” in our connection with Greenville. If one uses the same Internet provider for the hub and remote sites, the packets often stay on the ISP’s “back-bone”. This minimizes the number of “hops” and provides much better and more consistent transmission times.

Patients and the parents of the children implanted seemed to genuinely appreciate the convenience of having their cochlear implant placed and programmed locally in Greenville. No significant difference was found between the Greenville and Raleigh cohorts in the scores for the HINT sentence test or the CNC word test. These results show the equivalence of fitting cochlear implants locally or remotely, with the proper equipment, communication links, and safeguards for the latter. Although no similar cohort comparison was made for the young children implanted, they were all successfully programmed remotely and seemed to enjoy watching the Polycom® V700™ as if it were a TV.

We do not contend that remote programming will ever replace live, one-to-one direct patient interaction; however, it does extend the reach of the cochlear implant audiologist to those who may not be able or willing to travel to a tertiary cochlear implant center. Even in the United States, there is substantial disparity in the number of cochlear implant audiologists in a given region (Fig. 3). Globally, a similar or even greater disparity exists, particularly in underdeveloped

![Number of Cochlear Implant Audiologists per 1,000,000 People](image)

**FIG. 3.** Current distribution of cochlear implant audiologists in the U.S.A. The test sites at Greenville, SC, and Raleigh, NC, are highlighted with star symbols on the map.
countries. In our study, the patients were pro-
gammed over 250 miles away from our center in
Raleigh, N.C.; however, as the Internet continues to
expand, this model may have potential for use in more
remote areas.

CONCLUSION
In conclusion, we have demonstrated the feasibility
of remote programming of adult and pediatric cochlear
implant patients using the Internet. The patients pro-
grammed remotely have done as well as our locally
programmed patients. This model, which is safe, effec-
tive, and maintains patient confidentiality, may have
application for other implant centers attempting to
provide patients access to cochlear implant technology.

Acknowledgements
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