ABSTRACT

Our research group is currently developing a number of new methods for assessing and treating laryngeal voice disorders. The overall thrust of this work has been the incorporation of previously unexploited technologies into new approaches for improving the clinical management of voice disorders. A brief overview shows that ongoing projects are utilizing Advanced Audio Coding (AAC) technology, as well creating new imaging and physiological/biomechanical instrumentation, to better quantify vocal function for improved clinical voice assessment. In addition, biomedical technologies are being utilized to develop innovative methods for treating patients with damaged (scarred vocal folds) and/or non-functional (laryngectomy) phonatory mechanisms. Current progress in two projects is described in greater detail: (1) Ambulatory Phonation Monitor (APM) is a wearable monitoring and feedback system for evaluating and treating voice disorders that can reliably and unobtrusively provide long-term, continuous tracking of important parameters of vocal function, and provide feedback to the user when voice parameters exceed 'safe' limits and/or target phonatory behaviors are not maintained. (2) Improved Electrolarynx (EL) with Neural Interface is designed to more closely approximate normal voice and speech production than current poor-quality EL devices. This is being accomplished in laryngectomy patients by developing a neural interface to provide hands-free control of an improved EL sound source, i.e., a voice neural prosthesis. Work supported by grants from NIH/NIDCD, W.M. Keck Foundation, Department of Veterans Affairs, Community Foundation for the National Capital Region, and Eugene B. Casey Foundation.

INTRODUCTION

Voice disorder refers to a problem in producing voice that is primarily caused by a disturbance or loss of normal laryngeal function. Disordered voice production can result from a wide variety of pathological conditions; with effects ranging from mild disturbances in vocal quality (e.g., slight hoarseness) to complete loss of the ability to produce laryngeal voicing (e.g., laryngectomy to treat cancer). A relatively large segment of the population suffers from voice disorders. It has been estimated that anywhere from 3-9% of the general population has some type of voice abnormality at any given moment in time (Ramig and Verdolini, 1998). While most normal speakers take voice production for granted, reduction or loss of the ability to produce voice can disrupt or preclude normal oral communication and thus have far-reaching social, professional, and personal consequences (NIDCD, 1995).

This report provides an overview of current work that is being carried out by a multidisciplinary group of clinicians and scientists in the Boston Area with the overall goal of incorporating previously unexploited technologies into new approaches for improving the diagnosis and
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treatment of voice disorders. In addition to an overview, two projects within the program are described in greater detail.

SCOPE OF THE RESEARCH PROGRAM
Current clinical voice assessment relies heavily on subjective perceptual evaluation of both auditory and visual information, which can lead to wide discrepancies in clinical judgments about the diagnosis, and subsequent treatment of voice disorders. One primary thrust of our research program is to reduce such subjective sources of variation in the diagnostic process by developing more objective/quantitative methods for assessing vocal function. Methods are being developed to better quantify a variety of vocal parameters/mechanisms including the acoustic signal, dimensional characteristics of normal and pathological vocal fold structures, and the mechanics of phonation. In a related project that will be described in more detail, an ambulatory monitor is being developed to provide objective information on a patient’s daily voice use.

Multidisciplinary projects are also underway to improve methods for treating two major types of voice disorders, vocal fold scarring and complete loss of the larynx (laryngectomy) secondary to treatment for advanced laryngeal cancer. A more detailed description will be provided about efforts to develop of a voice neural prosthesis for laryngectomy patients.

DEVELOPMENT OF VOCAL FUNCTION ASSESSMENT METHODS
Current methods for assessing voice quality in patients with voice disorders that rely solely on either auditory perception, or acoustic analysis, are inherently inadequate (Kreiman et al., 1993; Titze, 1995; Hillman et al., 1997). There is a pressing need to develop a reliable and objective measure of voice quality can be derived automatically from the acoustic signal, and at the same time is consistent with human perception. Towards this end we are developing an Automated Psychoacoustics-Based Voice-Quality Assessment (APVA) approach that is based on the well established principals of human psychoacoustics imbedded in contemporary signal compression technology (MP3 and AAC). Thus far this work has produced a perceptually weighted signal-to-noise (SNR) measure for continuous speech that has been shown to correlate well with reliable listener judgments of voice quality.

Laryngeal videoendoscopy combined with stroboscopy has become a mainstay for clinically assessing how the larynx functions to produce voice. Evaluation of laryngeal videostroboscopic recordings is currently limited to subjective visual judgments that can be influenced by a number of factors including examiner bias resulting in diminished reliability. To address this shortcoming we have developed a laser-based projection system that can be built into a standard flexible fiberoptic endoscope, with an accompanying computer-based video measurement system for automated dimensional calibration of videoendoscopic images (Rosen et al., 2003). This system enables the sizes of normal and pathological laryngeal structures to be accurately measured, as well as the quantification of important vocal parameters such as speed of arytenoid movement during voice onset and offset gestures, and glottal area changes during phonation.

Examination of vocal fold vibratory characteristics via videoendoscopy with stroboscopy is currently limited to awake, cooperating patients. We are developing a method for extending this capability to anesthetized patients in the operating room so that surgeons can assess vocal fold...
vibratory function before, during, and after surgical procedures to ameliorate vocal fold pathology (e.g., injection of synthetic material to repair vocal fold scarring). The current version of the Aerodynamic Vocal Fold Driver (AVFD) is a surgical-sized instrument that is designed to enable intraoperative assessment of vocal fold vibration at phonation frequencies, simultaneous measurement of aerodynamic variables, and testing of each vocal fold individually. Testing of the AVFD in excised larynges has produced data that generally mimic established normal relationships between phonatory parameters of subglottal air pressure, glottal airflow, and fundamental frequency.

**Ambulatory Phonation Monitor with Biofeedback Capability**

The most common voice disorders are chronic or recurring conditions that are likely to result from faulty and/or abusive vocal behavior patterns (cf. Aronson, 1985; Boone and McFarlane, 1988). Such behaviorally based disorders are difficult to accurately assess, and effectively rehabilitate, because of a lack of capability to perform long-term monitoring and to provide instantaneous feedback outside of the clinical voice-therapy situation. To meet these clinical needs, we have developed an ambulatory monitoring and feedback system for evaluating and treating voice disorders that can: (1) reliably and unobtrusively provide long-term, continuous tracking of important parameters of vocal function, and (2) provide feedback to the user when voice parameters exceed 'safe' limits and/or target phonatory behaviors are not maintained. The ambulatory voice data will provide previously unavailable objective information about voice use-related parameters that are believed to be important etiologic agents in many common voice disorders. The feedback feature is expected to improve the compliance of voice-disordered patients with prescribed programs of vocal rehabilitation (e.g., vocal hygiene, voice conservation). Such feedback is also expected to facilitate the adoption (i.e., carryover or generalization) of improved vocal function behaviors in these patients after the new behaviors have been established in the clinic via voice therapy rehabilitative approaches.

![Figure 1. Example of an APM data display that shows amount of time phonating, mean SPL, and maximum SPL averaged every 15 minutes across 7.5 hours of continuous monitoring for one subject.](image-url)
The Ambulatory Phonation Monitor (APM) is a belt-worn computer that measures voice production parameters via a 8 x 5.5 x 2 mm accelerometer that can be mounted out of sight at the base of the neck (hidden by a shirt with a collar). The APM pre-processes and stores data (phonation duration, intensity and fundamental frequency) for downloading and subsequent ‘off-line’ analysis on a PC. The APM can also deliver (private) instantaneous feedback to the wearer via a belt-worn pager vibrator, based on setting thresholds for selected voice attributes. Figure 1 shows an example of the kind of data display (Voice Use Profile) that we think will be very useful in clinical voice evaluation.

Current work with the APM is aimed at developing it into a clinically useful system carrying out a series of group-based clinical trials that are designed to: (1) determine develop sampling strategies for reliably estimating "typical" voice use for future clinical and research applications (e.g. determining how long and when the device should be worn in order to acquire statistically meaningful data), (2) assess the ability of the device to reliably track vocal function in patients with common voice disorders that are considered to involve voice use as an etiologic component (vocal abuse/vocal misuse/phonotrauma), and (3) begin to evaluate the clinical validity of ambulatory monitoring of voice use with the PVA device by comparing results between normal and voice-disordered groups, as well as between normal groups considered to have different levels of risk (different occupations) for developing voice disorders. The biofeedback capabilities of the APM are also being tested in pilot studies on patients from three clinical populations that are likely to benefit from using the device as part of their voice therapy treatment program. One group is comprised of Parkinson’s patients who are receiving voice therapy that focuses on increasing their vocal loudness (Ramig et al., 1995). Preliminary results indicate that the APM biofeedback is effective in maintaining increased vocal loudness in Parkinson’s patients undergoing this type of voice therapy.

DEVELOPMENT OF METHODS FOR TREATING VOICE DISORDERS

We are involved in a large multidisciplinary project that is relying heavily on tissue engineering to restore function to scarred vocal cords. Generic “scarring” is the leading cause of voice disorders and there is currently no truly effective treatment for most of its manifestations. Such scarring can result from vocal abuse/overuse, trauma, laryngeal disease and/or secondary to surgical management of laryngeal disease. The project involves close collaboration with biochemical and tissue engineers who are developing bio-implants to replace damaged vocal cord tissue (Jia et al., in press). A photo-medicine group is also contributing by developing new laser technology that will assist in the diagnosis (mapping) and treatment (tissue softening, bio-implant site preparation) of scarred vocal cord tissue. All of the vocal function assessment methods that we are developing (see above) are expected to play important roles in helping to evaluate the efficacy of new treatments for vocal fold scarring. This work has the potential to restore voice to a wide range of affected patients, with particular significance for patients who rely on voice for employment (teachers, lawyers, singers, etc.), patients treated for laryngeal cancer, and individuals with congenital laryngeal defects.

Voice Neural Prosthesis

About half the laryngectomy population uses hand-held electrolarynges (EL) as their primary means of communication (Hillman et al., 1998). Unfortunately, currently available EL devices produce speech that sounds non-human (mechanical, robotic, monotone), has reduced intelligibility and loudness, and draws undesirable attention to the user (Bennet and Weinberg,
The poor quality of EL speech has been traced to limitations in performance of current EL sound generating transducers, and to the loss of the fine control of pitch, amplitude, and voice onset and offset timing that is normally provided by the laryngeal mechanism (Meltzner et al., in press). Loss of fine control causes deficits in voice-related segmental (e.g., voiced-voiceless distinctions for consonants) and suprasegmental (e.g., intonation, syllabic stress) speech parameters. Use of one hand to control an EL is also physically limiting since it precludes normal bimanual function, i.e., performing manual tasks that require the use of both hands while talking.

We are developing an improved EL communication system that more closely approximates normal voice and speech production. This is being accomplished in laryngectomy patients by developing a neural interface to provide hands-free control of an improved EL sound source. Thus far we have proven the feasibility of using phonation-related surface electromyographic (EMG) signals from neck strap muscles to control an EL (EMG-EL) (Heaton et al., in press). In addition, a new EL sound source we developed has already been shown to be more “normal/natural” sounding than a leading commercially-available EL based on judgments by naïve/blinded listeners. Figure 2 shows a schematic of the EMG-EL system.

**Figure 2. Schematic of the EMG-EL system.**

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**ACKNOWLEDGEMENTS**

Work supported by grants from NIH/NIDCD, W.M. Keck Foundation, Department of Veterans Affairs, Community Foundation for the National Capital Region, and Eugene B. Casey Foundation.
REFERENCES


