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CLINICAL REPORT

Biofeedback therapy using accelerometry for treating dysphagic patients with poor laryngeal elevation: case studies

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Abstract—Dysphagia, a swallowing disorder, is a problem encountered frequently in the rehabilitation of stroke and head injury patients. In normal individuals, safe passage of a food bolus into the esophagus is ensured by laryngeal elevation and closure of the airway. Inadequate laryngeal elevation can lead to aspiration, choking, and even death. The course of recovery in the current clinical practice is rather tedious. Recently, investigators have developed and evaluated the accelerometry technique for noninvasive assessment of laryngeal elevation. The purpose of the present paper is to present case reports of patients with poor laryngeal elevation treated with computerized biofeedback therapy using dynamic acceleration measurements. Acceleration was measured from the dysphagic patient during swallowing, and was dynamically displayed on the computer screen along with an acceleration signal from a typical, normal subject. The patient was asked to elicit a swallow response such that his/her acceleration display matched the display of the normal subject. Each patient had nine therapy sessions, lasting about half an hour each. All five patients improved significantly in acceleration magnitude and in swallowing function as confirmed by the videofluorography evaluation.

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INTRODUCTION

Dysphagia, the disorder of the swallowing mechanism, presents a major problem in the comprehensive rehabilitation of stroke and head injury patients and others with paralyzing neurological diseases (1–7). Dysphagia can develop from lesions in certain areas of the cortex and brainstem that control the swallowing function, or from damage to the associated cranial nerves. Swallowing can be divided into three phases: 1) the oral phase; 2) the pharyngeal phase; and 3) the esophageal phase. The oral phase is a voluntary phase involving mastication of food and manipulation of the bolus toward the posterior aspect of the tongue. The pharyngeal phase is involuntary and complex, involving both sensory and motor components. This phase involves laryngeal elevation and closure by the epiglottis, pharyngeal contractions to propel the bolus downward, and relaxation of the cricopharyngeal sphincter (pharyngeo-esaphogeal or P-E segment) to facilitate bolus movement into the esophagus (1–3,7). The esophageal phase involves transit of the bolus into the stomach. Most of the problems related to swallowing are associated with the oral and pharyngeal phases. Dysfunction in the pharyngeal phase can lead to aspiration and choking, and even death. Proper protection of the airway with laryngeal elevation and its closure by the epiglottis is clinically important. Inadequate laryngeal elevation can lead to aspiration.

In current clinical practice, the pharyngeal phase of the swallowing mechanism is qualitatively evaluated by clinical or bedside assessments including visual examinations, tactile manipulation, and examination of vocal quality for any signs of possible pharyngeal residue, penetration, and/or aspiration (1–3). Various diagnostic procedures exist, yet all have their limitations. Videofluorographic studies are performed on those patients who are suspected of being at risk for aspiration, to confirm the clinical examination, define the overall function of the swallowing mechanism, and determine appropriate compensatory strategies. Each swallow is then carefully reviewed, frame by frame, to detect the movement of the bolus, which is usually liquid barium (1,3,8). While videofluorography is efficient, it is not available to most clinicians on a daily basis. In addition, the procedure is expensive and exposes the patient to radiation. Ultrasound can also be used as a diagnostic tool (9,10); however, this procedure is limited primarily to assessing the oral phase of swallowing and results can be difficult to interpret. Recently, a method based on impedance change has been proposed for the detection of pharyngeal stage disorder (11,12). Direct endoscopic evaluation is also used in some clinics (13), but requires extensive training and has several limitations. Crary and Baldwin (14) have explored the use of the surface electromyographic (SEMG) signal as a noninvasive diagnostic tool.

Reddy et al. (15–17) have identified and developed instrumentation and methods for noninvasive quantification of various biomechanical parameters that characterize the dysphagic patient, and have clinically evaluated their techniques by correlation with videofluorography examination (16,17). For assessment of the pharyngeal phase, they placed an ultra-miniature accelerometer on the throat at the level of thyroid cartilage and asked the patient to swallow (16). Swallowing in normal subjects gave rise to a characteristic acceleration pattern that was distorted or absent in dysphagic individuals (16,17). Recently, they have made simultaneous measurements of acceleration during videofluorographed swallowing and found that acceleration magnitude correlated with laryngeal elevation (18,19). Patient classification, using the acceleration technique, was consistent with clinical classification based on videofluorography and bedside evaluation (20,21). Although these results have validated the technique for aiding the physician in noninvasive diagnosis, it is not known whether the acceleration technique can be used in patient treatment protocols.

The treatment programs for the pharyngeal phase of dysphagia include exercises to stimulate the swallowing reflex, laryngeal adduction exercises, and implementation of specific swallowing strategies and swallowing maneuvers, such as head positioning exercises and supraglottic swallowing exercises (1–3). Exercises to stimulate the swallowing reflex include mirror-assisted thermal stimulation of the anterior faucial arch. A small, long-handled laryngeal mirror is cooled by contact with ice for approximately 10 min and then used to stroke or rub the anterior faucial arches. For patients who cannot tolerate liquids, the patient is asked to dry swallow and the clinician obtains information about the swallowing by placing the fingers at the thyroid cartilage, the hyoid bone, and the mandible. For those patients who can tolerate some liquid, ice water or iced ginger ale is typically placed near the location where the mirror was contacting the faucial arch. In some institutions, thermal stimulation exercises and laryngeal adduction exercises are prescribed. Laryngeal adduction exercises involve the patients lifting and pushing themselves from a chair while simultaneously vocalizing to produce a clear voice. None of these techniques involves biofeedback therapy, a therapy which, in other disciplines, has been shown to improve recovery, via enhanced patient motivation. Currently, there is no technique for biofeedback therapy of dysfunction at the pharyngeal phase.

Hemlich (22) has suggested that swallowing can be relearned. Sukthanakr et al. (23,24) have developed techniques for biofeedback therapy of the oral phase. Bryant (25) and Crary (26) have shown that biofeedback of SEMG signals can lead to increased swallowing function. More recently, Reddy et al. (27) have developed a computerized biofeedback technique for the therapy of poor laryngeal elevation using noninvasive acceleration measurements. The question remains whether biofeedback therapy using noninvasive acceleration measurements is clinically useful for treating patients with laryngeal elevation dysfunction. The purpose of this paper is to address this question by presenting some clinical case reports of patients treated with accelerometry biofeedback therapy.

METHODS

The Accelerometry Biofeedback System

The computerized accelerometry biofeedback system (28) filters and displays the acceleration signal measured from the patient along with the acceleration signal of a typical normal subject (**Figure 1**). The patient's acceleration signal, collected over a 15-s period, is displayed dynamically in real time on the right side of the screen. A window on the left side of the screen displays a typical acceleration signal obtained from a normal subject during wet swallowing (magnitude of 1 g; the unit of acceleration is expressed in " g" where " g" is 9.81 m/s^2). A blue color bar toward the center of the screen displays the magnitude of the signal from a typical normal subject. Immediately to the right of it, a green color bar displays the peak magnitude of the signal from the patient during the 15-s period.

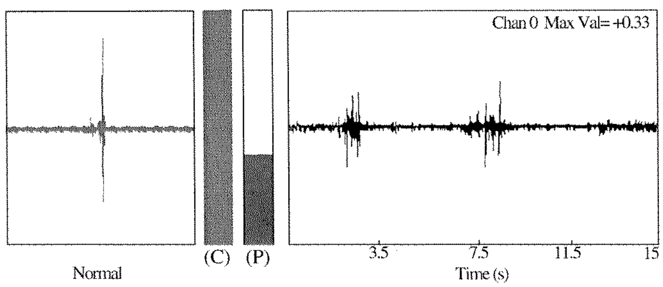

Figure 1.
The computerized accelerometry biofeedback system: A representative acceleration signal from a normal subject is displayed on the left side of the computer screen. The patient's acceleration signal is displayed in real time on the right side of the computer screen. Each data record consists of the patient's signal for a 15-s period. The patient is asked to swallow such that his or her signal matches that of the normal subject. In addition, the peak magnitude of the patient's signal is displayed as a bar graph (P) toward the center of the screen, immediately to the right of a bar graph of the magnitude from the normal subject (C).

An ultra-miniature accelerometer (Entran Devices, Inc., Model # EGAX-10g) was taped in place on the midline of the throat at the level of the thyroid cartilage, as shown in **Figure 2** (16, 17). For consistency, the accelerometer was positioned by the patient's speech pathologist after palpation of the tissue. The signal was bandpass-filtered in the range of 30–300 Hz, amplified (Gould, Inc., Universal amplifier), and acquired into a computer (PC) with a sampling rate of 1330 Hz. Each data record consisted of 15 s of data. Typically, for each therapy session, there were 15 to 18 such data records.

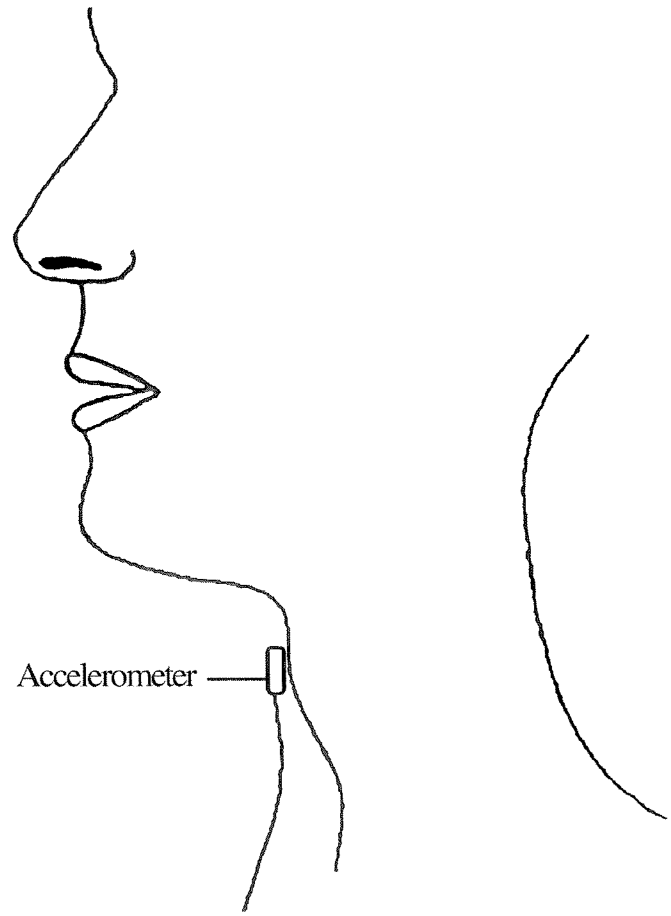

Figure 2.
An ultra-miniature accelerometer is placed on the skin at the midline of the throat at the level of thyroid cartilage.

Protocol

In a seated position, the subject was presented with food of various consistencies, as prescribed by the therapist. The subject was asked to swallow in a manner designed to match his or her acceleration to the normal acceleration. Both direct and indirect therapeutic techniques were administered. Initially, the patient was asked to dry swallow, and then to swallow foods of various consistencies. The patient was also asked initially to keep the chin up. However, if the acceleration response was poor, then other techniques such as chin down, Mendelson maneuver, and others were used. The effect of each maneuver was immediately evident to both the patient and the therapist.

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The procedure was repeated several times and each patient's biofeedback therapy session lasted for about 30 min. After the end of the session, the average magnitude of the acceleration responses was computed to compare the overall patient progress. Typically, there were two to three such therapy sessions each week; however, some patients had only one therapy session per week. Regardless of weekly frequency, each patient had a total of nine biofeedback therapy sessions.

RESULTS

Patient 1

The patient was an 83-year-old female who was diagnosed with a lacunar infract in the anterior limb of the right internal capsule on August 3, 1997. Medical history was significant for hypertension, thyroid disorder, and valvular heart disease. An initial modified barium swallow test was completed on August 5, 1997 in an acute care hospital. Results indicated moderate to severe pharyngeal dysphagia with an overall weak swallow and decreased hyolaryngeal excursion. The patient was admitted to Edwin Shaw Hospital for Rehabilitation (ESH) on August 6, 1997. Initial dysphagia evaluation revealed decreased labial and lingual strength and coordination, moderately to severely decreased laryngeal function, and decreased hyolaryngeal excursion with weak throat clearing or coughing noted. Indirect dysphagia therapy was initiated, including oral lingual and vocal cord adduction exercises with thermal stimulation.

Biofeedback therapy was initiated on August 13, 1997. Initially, the patient was asked to elicit a swallow response with dry swallows and with lemon ice. **Figure 3a** depicts the August 13, 1997 acceleration response as a function of time. The patient exhibited poor acceleration response with an average magnitude of less than 0.1 g. The patient's acceleration response improved by the fifth therapy session, which was held on August 20, 1997. The average acceleration magnitude was 0.25 g. However, the acceleration response was inconsistent. Swallowing with the chin down produced better acceleration response when compared to the no chin down condition. A repeat, modified barium swallow test was completed on August 20, 1997. Results revealed mild to moderate oral and pharyngeal phase dysphagia. Symptoms included residue of all consistencies in the valleculae and pyriform sinuses, decreased hyolaryngeal excursion, decreased mastication and anterior-posterior transit, and a mild swallow delay. Penetration of thin liquids was noted, without aspiration.

The patient's acceleration response had improved significantly by August 28, 1997 (ninth therapy session), shown in **Figure 3b**. The average magnitude of swallow had increased to 0.5 g with instances of 0.8 to 1.0 g. The

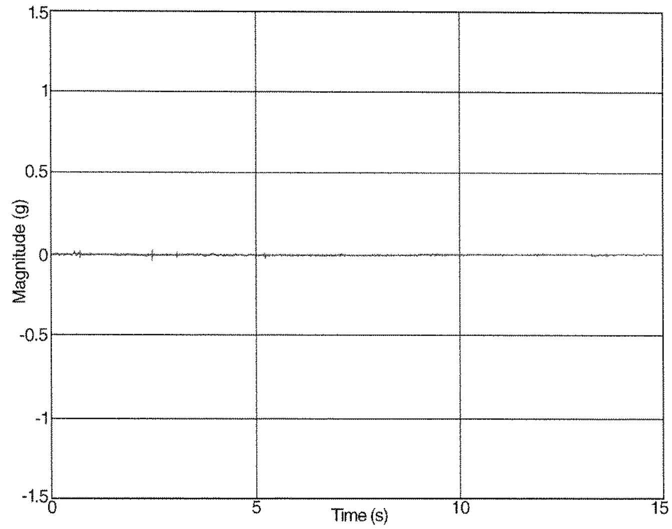

Figure 3a.
The acceleration responses from patient 1 obtained during the initial therapy session (August 13, 1997. The acceleration signal is plotted as a function of time. The unit of 1 g represents 9.81 m/s^2.

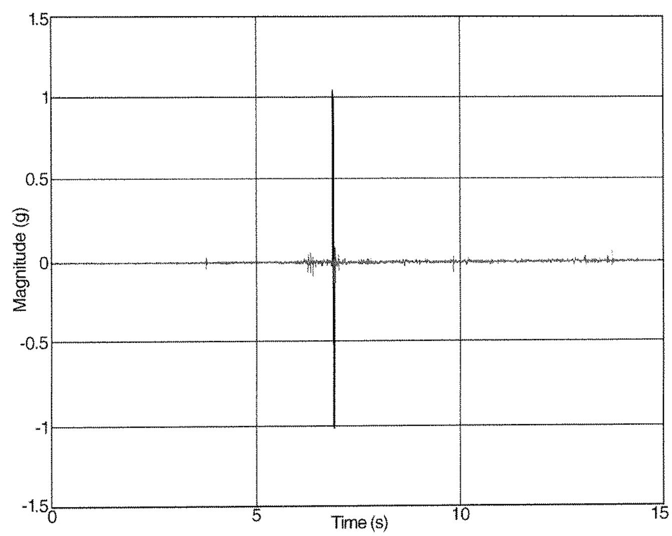

Figure 3b.
The acceleration responses from patient 1 obtained during the ninth therapy session (August 28, 1997). The acceleration signal is plotted as a function of time. The unit of 1 g represents 9.81 m/s^2.

overall patient progress, expressed as means and standard deviations of the magnitude of acceleration, is shown in **Table 1**. There was a statistically significant difference ($p<0.01$) between the mean acceleration magnitudes of the ninth therapy session and the first therapy session, as determined by unpaired, one-tailed t-tests.

The patient was discharged to home on September 2, 1997, tolerating a mechanical diet with thin liquids. Decreased coughing was noted, and the chin-tuck strategy was eliminated. The patient continued to progress and eventually was able to safely tolerate a regular diet.

Patient 2

The patient was a 75-year-old male who was diagnosed with anoxia following sudden cardiac arrest on March 6, 1996. Medical history was significant for hypertension, coronary artery disease, myocardial infarction (November, 1995), and coronary artery bypass graft.

The initial modified barium swallow test on March 20, 1996 revealed significant aspiration when given both thin and thick liquid, due to decreased hyolaryngeal excursion, decreased airway closure, and pharyngeal residuals. Indirect dysphagia therapy was initiated. The patient was admitted to ESH on April 5, 1996. It was recommended that he continue to be given nothing through the mouth (*non per os*; NPO)at that time.

Table 1.
Means±standard deviations of magnitudes of acceleration in g presented for each subject as a function of therapy session.

Session	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5
1	0.11±0.02	0.31±0.09	0.14±0.06	0.23±0.09	0.14±0.06
2	0.14±0.12	0.22±0.06	0.09±0.05	0.25±0.10	0.33±0.14
3	0.16±0.10	0.25±0.07	0.085±0.05	0.38±0.07	0.21±0.12
4	0.21±0.19	0.29±0.09	0.175±0.07	0.37±0.12	0.32±0.15
5	0.24±0.20	0.20±0.06	0.12±0.05	0.39±0.08	0.21±0.11
6	0.27±0.19	0.37±0.10	0.145±0.06	0.40±0.14	0.22±0.08
7	0.38±0.18	0.61±0.14	0.17±0.07	0.38±0.12	0.21±0.10
8	0.42±0.29	0.60±0.15	0.17±0.08	0.42±0.10	0.29±0.12
9	0.47±0.39	0.60±0.14	0.25±0.07	0.47±0.14	0.33±0.14

Initial dysphagia evaluation revealed an apparent delay in the swallow response with poor hyolaryngeal excursion. A repeat, modified barium swallow was completed on April 24, 1996. Results indicated mild oral dysphagia and severe pharyngeal phase dysphagia with mild aspiration of thin liquid, thick liquid, and lemon ice, and severe aspiration of puree textures. Decreased hyolaryngeal excursion, incomplete airway closure at the level of the vocal cords, and pharyngeal residuals were again noted.

Biofeedback therapy to increase hyolaryngeal excursion was initiated on May 6, 1996. The patient received thermal stimulation, liquid or puree textures, or was asked to dry swallow, and had poor acceleration response initially. **Figure 4a** shows the acceleration response obtained from the patient during biofeedback therapy on May 6, 1996. The patient's acceleration response improved by May 20, 1996, the ninth therapy session, and the response obtained that day is shown in **Figure 4b**. The patient improved significantly during the course of the therapy as measured by the mean acceleration magnitude (**Table 1**). There was a statistically significant difference ($p<0.001$) between the mean acceleration magnitudes of the ninth and the first therapy sessions, as determined by the unpaired, one-tailed t-test.

A repeat modified barium swallow test performed on May 22, 1996 revealed mild oral phase dysphagia with moderate pharyngeal phase dysphagia. While pharyngeal residuals and decreased airway closure were noted, residuals now cleared to minimal with multiple swallows. Questionable aspiration of thin liquids was identified.

The patient was discharged to home on May 28, 1996. The patient was tolerating therapeutic feeds of thin puree and chopped textures, as well as thick liquids, with speech pathologist supervision only. Compensatory strategies included small bolus size, suck/swallow, and multiple swallows. The patient demonstrated inconsistent hyolaryngeal excursion.

Patient 3

The patient was an 80-year-old male who was severely debilitated following medical complications in conjunction with bilateral total knee replacement surgery. Medical history upon admission to ESH was significant for hypertension, neuropathy, hypothyroidism, aspiration

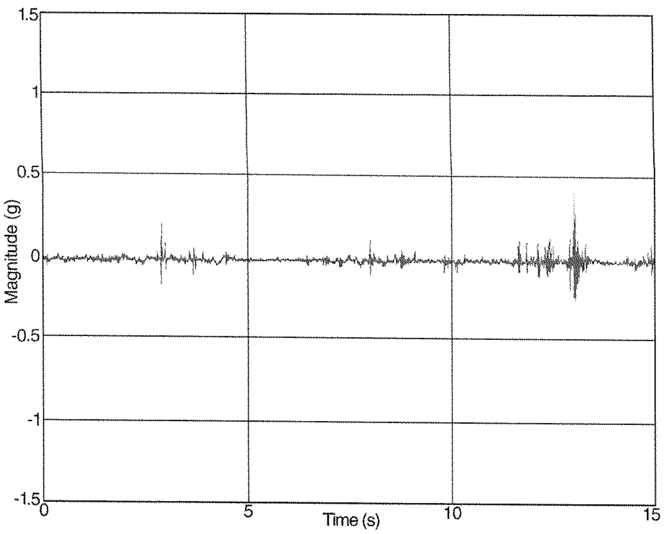

Figure 4a.
The acceleration responses from patient obtained during the initial therapy session (May 6, 1996). The acceleration signal is plotted as a function of time. The unit of 1 g represents 9.81 m/s^2.

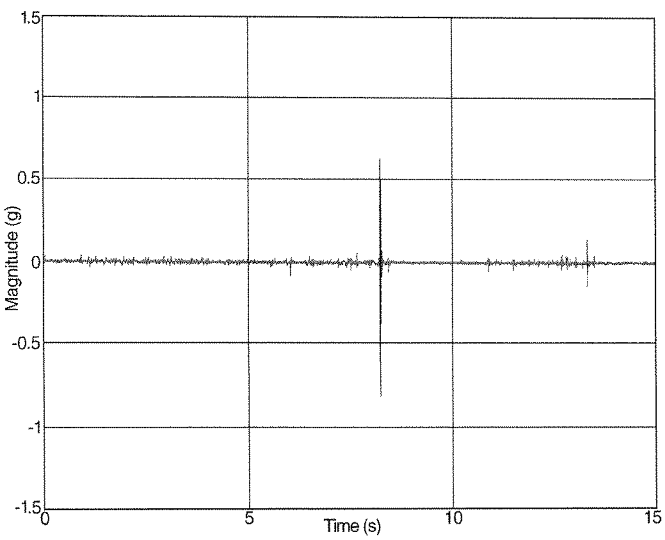

Figure 4b.
The acceleration responses from patient 2 obtained during the ninth therapy session (May 20, 1996). The acceleration signal is plotted as a function of time. The unit of 1 g represents 9.81 m/s^2.

pneumonia, respiratory failure, and placement of a percutaneous endoscopic gastrostomy (PEG) tube. Onset of this illness was on May 14, 1996. This patient developed aspiration pneumonia during his acute care stay.

A modified barium swallow test was completed on June 3, 1996. Results were reported as " marked-to-severe pharyngeal phase dysphagia" with details regarding the nature of the dysphagia not available.

Patient 3 was admitted to ESH on June 14, 1996. Initial dysphagia evaluation revealed apparent decreased hyolaryngeal excursion, throat clearing, wet vocal quality, lingual pumping to swallow saliva, and an apparent variable swallow delay. Indirect dysphagia therapy was initiated to increase lingual and laryngeal function for swallowing. A repeat, modified barium swallow test was completed on June 19, 1996. The results indicated mild to moderate oral phase dysphagia and severe pharyngeal phase dysphagia. Specifically, the patient experienced the following: aspiration of all consistencies, a delay in the swallow response, severe decrease in hyolaryngeal excursion, severe pharyngeal residuals, moderate oral residuals, premature bolus leakage with aspiration before the swallowing of thick liquids, and poor vocal cord adduction. Biofeedback therapy was initiated on June 26, 1996, and the patient had poor acceleration response on this day (Figure 5a).

While initial data indicated a decrease in hyolaryngeal excursion, the patient experienced pulmonary illness at that time. The patient had a temperature of 100ºF from June 26 to July 4, and on July 1 had a moist productive cough. Antibiotics were prescribed on July 5, 1996.

The acceleration response obtained from the patient on July 8, 1996, the ninth therapy session, is shown in **Figure 5b**. On July 17, 1996, a repeat, modified barium swallow test indicated a mild oral phase and a moderate pharyngeal phase dysphagia. The patient was noted to have a mild-to-moderate decrease in hyolaryngeal excursion, a mild swallow delay, penetration with puree, masticated, thin liquid, and thick liquid textures, and no aspiration. Residuals were minimal and cleared to a trace amount with multiple reswallows. The patient's improvement, in terms of the average magnitude of acceleration, is shown in **Table 1**. There was a statistically significant difference ($p<0.001$) between the acceleration magnitudes of the ninth therapy session and the first therapy session, as determined by the unpaired, one-tailed t-test.

The patient was discharged to an extended care facility on July 31, 1996, with a recommendation to receive therapeutic feedings of thick liquids and mechanical soft textures with a speech therapist.

Patient 4

The patient was a 42-year-old female who had been diagnosed with a brainstem stroke resulting in tetraplegia, dysphagia, dysphonia, diplopia, laterial erectus paresis,

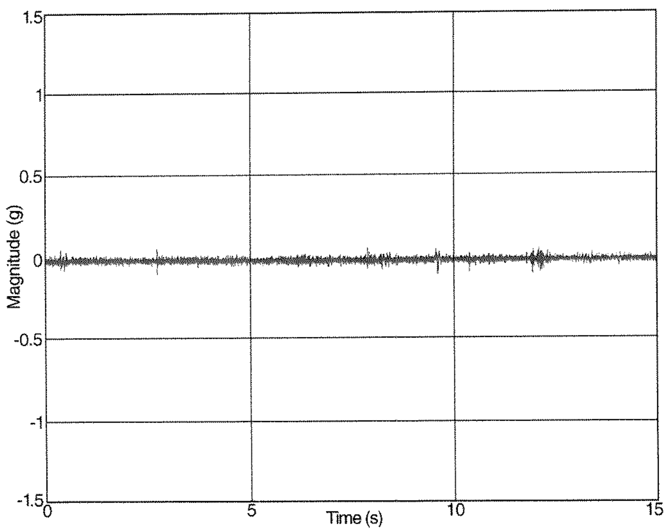

Figure 5a.
The acceleration responses from patient 3 obtained during the initial therapy session (June 26, 1996). The acceleration signal is plotted as a function of time. The unit of 1 g represents 9.81 m/s².

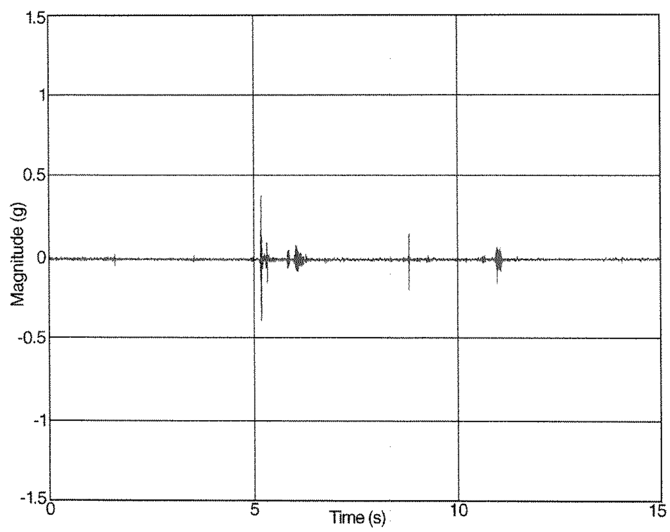

Figure 5b.
The acceleration responses from patient 3 obtained during the ninth therapy session (July 8, 1996). The acceleration signal is plotted as a function of time. The unit of 1 g represents 9.81 m/s².

and respiratory insufficiency. Medical history was significant for substance abuse and hypothyroidism. Onset of this illness was May 19, 1994. During the course of the acute care stay, the patient remained NPO and also had a tracheostomy tube in place. The patient was admitted to ESH on June 2, 1994. The tracheostomy tube was removed on August 9, 1994. The initial dysphagia evaluation, dated June 8, 1994, indicated that the patient was unable to manage oral secretions. Significant impairments in lingual and laryngeal function were noted, and NPO status was continued. Indirect dysphagia therapy to improve lingual and laryngeal function for swallowing was initiated.

An initial modified barium swallow test was completed on October 5, 1994. Recommendations to continue NPO status were made. A repeat, modified barium swallow test on November 30, 1994 revealed mild oral phase dysphagia and moderate pharyngeal phase dysphagia. Lingual weakness significantly affected performance, leading to a premature bolus leakage. A swallow delay was noted with all consistencies and aspiration of thin liquids was observed. Recommendations were made to initiate therapeutic meals of puree and chopped foods, and thick liquids with the speech therapist only. These started on December 6, 1994. By December 28, 1994, the patient demonstrated at least 3 coughing episodes per meal and required extensive time to consume 40 percent of meals.

Oral feeding was placed on hold on January 9, 1995, secondary to congestion, but was reinstated on January 17, 1995. Biofeedback therapy was initiated on February 13, 1995. The initial acceleration response is shown in **Figure 6a**. Videofluorography on February 14,1995 indicated 1–2 coughing episodes per meal, with meal completion requiring 60–75 min. The patient was on a two meals per day schedule. With improvements in acceleration response, on March 14, 1995, the patient was placed on three meals daily. However, the patient still exhibited one to two coughs during meals.

The patient's acceleration response was significantly improved by the first week of April, 1995. Videofluorography examination on April 11, 1995 indicated that the patient was tolerating thick liquids, had fair-to-good hyolaryngeal excursion, and exhibited no aspiration. Following the improved acceleration response exhibited on April 13, 1995 (**Figure 6b**), the patient was discharged on April 18, 1995 to an extended care facility. The patient exhibited minimum drooling during meals and was able to complete meals in decreased time. The means and averages of the acceleration magnitude for each therapy session are shown in **Table 1**. There was a statistically significant difference ($p<0.001$) between the acceleration magnitudes of the ninth and first therapy sessions, as determined by the unpaired, one-tailed t-test.

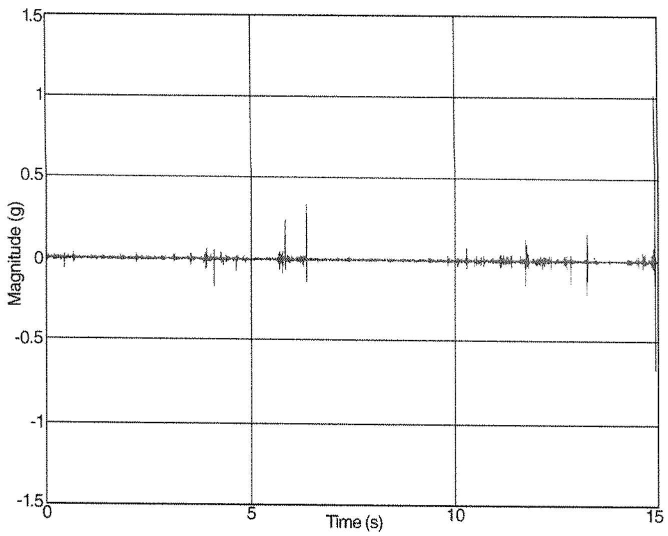

Figure 6a.
The acceleration responses from patient obtained during the initial therapy session (February 13, 1995). The acceleration signal is plotted as a function of time. The unit of 1 g represents 9.81 m/s^2.

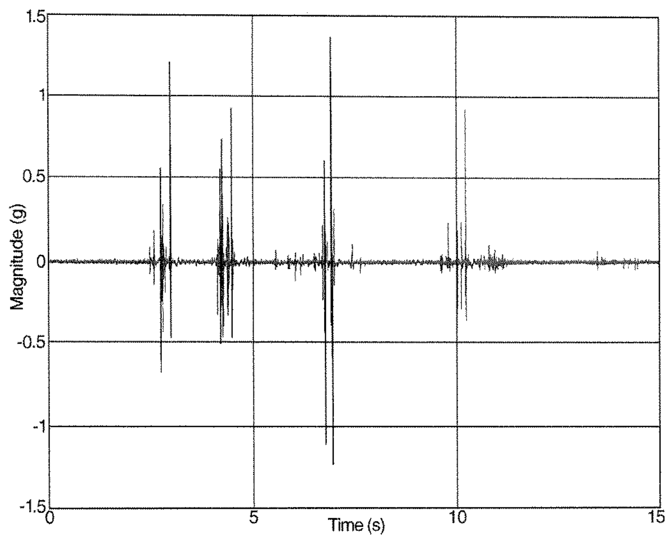

Figure 6b.
The acceleration responses from patient 4 obtained during the ninth therapy session (April 13, 1995). The acceleration signal is plotted as a function of time. The unit of 1 g represents 9.81 m/s^2.

Patient 5

The patient was a 59-year-old male, previously employed as an engineer, who was diagnosed with laryngeal cancer on June 10, 1995. His past medical history included metabolic encephalopathy with coma, pneumonia enterococcal septicemia, respiratory failure, tracheostomy, and PEG tube placement. He also received radiation and chemotherapy. The patient's swallowing abilities were evaluated via videofluoroscopy in acute care on July 5, 1995. Results revealed moderate to severe oral and pharyngeal dysphagia. There was premature pharyngeal entry (PPE) and aspiration during the swallow, with residue in the valleculae and pyriform sinuses. Hyolaryngeal excursion was severely reduced. Therapy included indirect dysphagia techniques due to NPO status.

A follow-up videofluoroscopic swallowing evaluation on August 2, 1995 revealed mild-to-moderate oral phase and moderate-to-severe pharyngeal phase dysphagia. He continued to exhibit severely decreased hyolaryngeal excursion, vallecular and pyriform sinus residuals and aspiration during the swallow. Alternate presentations of lemon ice and the Mendelson maneuver seemed to increase his ability to swallow. He was discharged on NPO status with nutrition/hydration via a PEG tube.

The patient was seen three times per week for intensive outpatient dysphagia therapy coupled with biofeedback therapy and home instruction. The acceleration response obtained from the patient on the first day of biofeedback therapy, August 3, 1995, is shown in **Figure 7a**. The patient showed improvements in acceleration response during the course of the therapy. **Figure 7b** depicts the acceleration response obtained from the patient on October 6, 1995, the ninth therapy session. A follow-up, modified barium swallow study (November 1, 1995) showed significant improvement with his pharyngeal phase (minimal-to-moderate versus moderate-to-severe). **Table 1** shows the corresponding improvements in the mean acceleration magnitudes. There was a statistically significant difference ($p<0.001$) between the acceleration magnitudes of the ninth therapy session and the first therapy session, as determined by the unpaired, one-tailed t-test.

The patient was discharged on a regular diet with recommendations for the use of compensatory strategies.

DISCUSSION

The present findings represent the first clinical study of computerized biofeedback therapy using acceleration measurements for treating dysphagic patients. With the subject in a seated position, the subject was asked to swallow such that his/her acceleration matched the acceleration from a typical normal subject. Both direct and

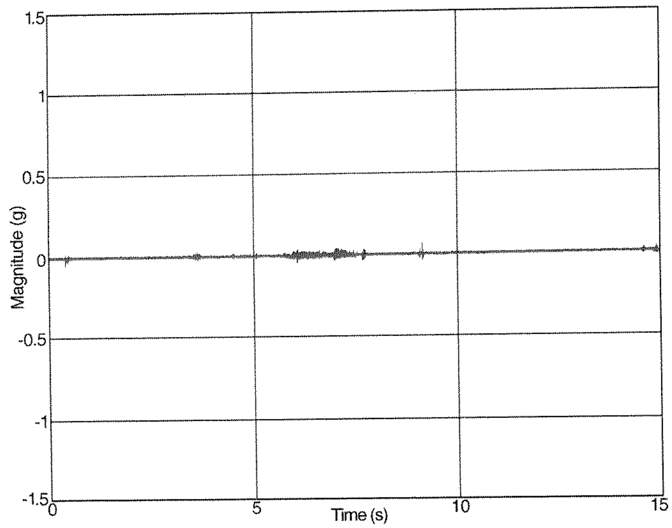

Figure 7a.
The acceleration responses from patient 5 obtained during the initial therapy session (August 3, 1995). The acceleration signal is plotted as a function of time. The unit of 1 g represents 9.81 m/s^2.

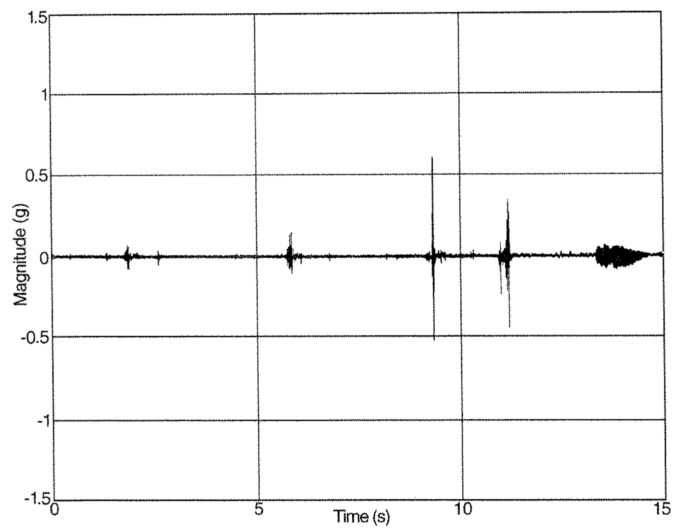

Figure 7b.
The acceleration responses from patient 5 obtained during the ninth therapy session (October 6, 1995). The acceleration signal is plotted as a function of time. The unit of 1 g represents 9.81 m/s^2.

indirect therapeutic techniques were administered. The presentation of solid and liquid textures varied with each patient's level of dysphagia. During the biofeedback treatment session, techniques such as positioning, specific swallow maneuvers, and other compensatory strategies were implemented. The effect of these maneuvers was immediately evident to both the patient and the therapist. The biofeedback therapy provides a dynamic, real-time, visual feedback for noninvasive quantitative measures of laryngeal elevation during swallowing. Inadequate laryngeal elevation is a frequent problem in dysphagic patients (1–4).

Patient motivation plays a major factor in any therapy. Biofeedback therapy actively involves the patient in the therapy process, providing visual feedback that challenges and motivates the patient to improve laryngeal elevation. The computerized biofeedback therapy provides synergy, since the signal on the computer increases with increasing amount of laryngeal elevation. The immediate nature of the feedback minimizes patient frustration and anxiety.

Cognition also has a major role in any biofeedback therapy. The patient must be able to attend to and focus on the task, the visual display, and the directions given by the speech therapist. In addition, patients must also be able to comprehend and evaluate their performance. For these reasons, biofeedback therapy is not indicated in patients with poor cognition or poor vision.

Similarly, etiology contributes to the performance of biofeedback therapy. A variety of diagnoses are represented here, but the list is not inclusive. In addition, the accelerometry technique may not be very effective in patients with significant amounts of loose skin, edema, or head/neck surgery. Extra care must be taken to ensure transmission of the vibration through the skin to the accelerometer, and proper taping of the accelerometer is essential for these patients. Patients who are deconditioned may need to undergo this treatment during peak performance times due to fatigue and variable performance ability. Conversely, individuals who have had a brainstem infarct may still benefit from this treatment since cognition is usually spared, versus those who have had a traumatic brain injury or right hemisphere infarct where vision is impaired. Other factors may preclude participation in this type of treatment. Many patients have a secondary diagnosis that will decrease or severely limit the effectiveness of biofeedback therapy for dysphagia, such as reconditioning, pneumonia, and degenerative diseases.

In the normal subject, average acceleration magnitude is 1.1±0.2 g, with a range of 0.5–2.3 g (16). In contrast, in the same study, the acceleration magnitude in the dysphagic patient ranged from 0–0.8 g with a mean of 0.25±0.19 g. However, patients who are recovering from dysphagia have been classified by their acceleration magnitude as: normal risk for aspiration, for an acceleration magnitude of ≥0.7 g; mildly dysphagic, if the acceleration magnitude is <0.7 and ≥0.5 g; moderately dysphagic, if the signal is <0.5 g but ≥0.2 g; and severely dysphagic, for magnitudes <0.2 g (16,17). An acceleration magnitude of 0.5 g or greater has been observed in most patients who have recovered from dysphagia. In the present study, the acceleration signal from the normal subject, displayed on the biofeedback screen, was representative of a signal obtained during wet swallowing (1 g). In a recent study (Gupta et al. [1]), we did not find statistically significant differences in the mean power of the signal between men and women of various age groups. However, the mean power of the signal was larger during wet swallowing than during dry swallowing.

The acceleration provides a measure of the extent of laryngeal elevation. Recently, we have made simultaneous measurements of acceleration during videofluorography examination and observed that the acceleration signal occurs during laryngeal elevation (18,19). The results revealed a direct linear correlation between the magnitude of acceleration and the amount of laryngeal elevation. Other events of swallowing, such as the P-E segment relaxation, cannot be assessed by accelerometry technique. Moreover, acceleration provides a measure of mechanical events only. Surface EMG could perhaps be used to assess the electrical events (29,30). Perhaps additional, non-invasive measures, such as ultrasound (9) or surface EMG, along with acceleration, can provide a more complete picture.

In the present study, the accelerometer measured acceleration only in the anterior to posterior (A-P) direction during laryngeal elevation. Tri-axial accelerometers could provide additional information, but these are bulky and their use could dampen the acceleration signal. The accelerometer used in the present study was light, weighing less than one gram, and therefore was effective in measuring the surface vibrations during laryngeal elevation. In addition, to minimize placement errors, accelerometers were placed following palpation by the therapist.

The present study involved biofeedback therapy only for laryngeal elevation. For patients with poor lingual abilities and other types of oral dysphagia, audiovisual biofeedback devices developed and evaluated by Sukthankar, et al. (23,24) can be used to improve the strength and mobility of lingual function.

[1]Gupta et al. unpublished study results; 1996.

Only nine therapy sessions were used in the present study due to staffing constraints and patient involvement in other therapies, such as physical and occupational. With additional numbers of biofeedback therapy sessions, the patients could improve further, and the recovery process could be accelerated. Since acceleration measurements are noninvasive, the biofeedback therapy can be performed at home with the therapist monitoring the patient via the Internet. We are in the process of developing such tele-therapy systems. Nevertheless, the present study, involving a limited number of clinical cases, has demonstrated the potential of accelerometry biofeedback therapy in enhancing patient recovery.

All five patients in the study improved significantly during the course of biofeedback therapy (**Figures 3–7**). The mean acceleration magnitude increased in each case (**Table 1**) and the differences in acceleration magnitudes between the initial and final (ninth) therapy session were significant for each patient ($p<0.01$ for patient 1 and $p<0.001$ for all other patients). The improvements in swallowing function were confirmed by the videofluorographic examination. Although there was no control group of subjects in the present study, the present results can be compared with the results of our previous studies (17) in which acceleration from dysphagic subjects was obtained initially and after a 3 wk period of traditional therapy and thermal stimulation. The present group of patients receiving biofeedback therapy exhibited significant improvement when compared to that group. Nevertheless, the current investigation presents case studies only. Results from the present study establish the need for a more comprehensive study, involving control subjects.

Biofeedback can be considered as a cybernetic technique of imparting therapy (31). By definition, biofeedback is a technique of using instrumentation to display select, physiological events to a subject, through visual and/or auditory modes, whereby the subject is trained or could self-train to manipulate the underlying physiological processes (32). According to Barofsky (33), an advantage of biofeedback is that it permits small changes in physiological processes to be noticed and reinforced, thus enabling increased control of these processes. Biofeedback has proved to be effective in treating a number of cardiovascular, neurological and psychosomatic ailments (32, 33). Sukthankar et al. (23, 24) have used biofeedback in the treatment of the oral phase of dysphagia using portable electronic devices. Crary (26) and Bryant (25) have used SEMG for treating a limited number of select, dysphagic patients, and have demonstrated improvements in the swallowing function. In these SEMG studies, a target threshold of SEMG was identified and the patients received audiovisual feedback only if their SEMG activity level surpassed the threshold activity. In contrast, in the present study, no such thresholds were used and the patients acceleration was dynamically displayed.

The computerized biofeedback system provides feedback to the clinician as well as to the patient. For each patient, the therapist can investigate and determine the best swallow therapy for the patient using the computerized biofeedback system. For example, the Mendelsohn maneuver might be useful for some patients, while for others the chin down or hard swallow might be more effective. Ohmae et al. (34) have shown that posture plays a role in preventing aspiration. The effect of touch, cold, etcetera (35) can be evaluated by the therapist for each patient. Similarly, the effect of bolus volume (36), temperature (37), or other parameters can be studied for each patient.

Videofluorography examination represents a gold standard in the evaluation of swallowing function. However, the present computerized biofeedback therapy can be used on a daily basis. If a significant change is observed in the acceleration magnitude during the course of the biofeedback therapy, it can then be confirmed by videofluorographic evaluation. Thus, accelerometry could act in concert with and complement the videofluorographic examination.

CONCLUSION

A computerized biofeedback therapy, using noninvasive acceleration measurements, was evaluated on five patients. Noninvasive acceleration measurements obtained from the patients during swallowing were dynamically displayed on the computer screen along with the signal from a typical normal subject. The patients were asked to swallow such that their acceleration signals matched the signal of the normal subject. All five cases studied demonstrated statistically significant improvements in acceleration magnitude and in laryngeal elevation, as confirmed by videofluorography.

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