Department of Veterans Affairs

Journal of Rehabilitation Research and Development Vol. 31 No. 4, November 1994
Pages 335–344

Toward classification of dysphagic patients using biomechanical measurements

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Abstract—Identification of a patient at risk of aspiration is a major problem in the rehabilitation of the dysphagic patient. The present methods of diagnosis are based on clinical evaluation or videofluorography or fiberoptic endoscopic examination of swallowing (FEES). Recently, we developed biomechanical techniques for noninvasive quantitative assessment of the dysphagic patient. The purpose of the present investigation was to assess the clinical validity of the technique. In a double-blind study, both biomechanical test results and videofluorography (including bedside evaluation) results were used to independently classify the patients into four categories of risk for aspiration. Of the 36 patients studied, there was complete agreement between the biomechanical and clinical classifications in 21 patients. In 11 patients, the biomechanical technique overestimated the risk by one category, and underestimated the risk by one category in four patients. The biomechanical technique presents a useful tool for continued patient assessment; however, further studies are needed.

Key words: *accelerometry, aspiration, classification, diagnosis, dysphagia, noninvasive measurements, swallowing disorders.*

INTRODUCTION

Proper diagnosis of swallowing disorders (dysphagia) presents a continuing problem in the rehabilitation of patients with stroke and head injury, and of other patients with paralyzing neurological diseases. Dysphagia can occur as a result of lesions in certain cranial nerves, their nuclei, fiber tracts, or in the cortex. Aspiration is a major problem associated with dysphagia. Identification of the patient at risk of aspiration is important from the clinical viewpoint (1–3). The current clinical methods of diagnosis are qualitative and are based on clinical (bedside) evaluation and videofluorography examination (1–4). The videofluorographic examination (VFE) may involve radiation hazard and therefore may have a limitation as a diagnostic tool. Ultrasound has been suggested as a possible method of assessment (5,6). Investigators have used electroglottography as an assessment tool (7,8). Fiberoptic endoscopic examination of swallowing (FEES) has been used for clinical evaluation (9). However, there continues to be a need for developing noninvasive diagnostic techniques to identify the patient at risk of aspiration and to aid in the treatment of dysphagia. Recently, we identified and developed techniques to quantify noninvasively various biomechanical parameters that characterize the oral (10) and pharyngeal phases of swallowing (11). However, the question remains whether the patient at risk of aspiration can be identified and classified using the noninvasive biome-

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This project is being supported, in part, by Edwin Shaw Hospital, and a grant from the National Institutes of Health (NIDCD 1R15-DC0156401).

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chanical measurements. The purpose of the present investigation is to address this question.

METHODS

Biomechanical Measurements of the Oral Phase

We have identified several biomechanical parameters involved in the oral phase of swallowing, and have developed techniques and instrumentation to noninvasively quantify these parameters (8). The biomechanical parameters are 1) lip closure (interface) pressure, 2) lip pulling (shear) force, 3) tongue thrust in the two lateral directions, 4) forward tongue thrust, and 5) swallow suction pressure.

The lip closure (interface) pressure was measured with an ultraminiature flat pressure transducer (Entran Devices Corp., Fairfield, NJ, Model EPL-125). The transducer, in a disposable wrapping paper, was placed between the lips at three different locations: right lateral, midline, and left lateral.

The lateral tongue thrust transducer was constructed by placing miniature strain gauges (Measurements Group Inc., Model EA-125-BZ-350) on a small plastic cantilever bar. Lateral forces on the bar exert a bending moment near the base which is detected by the strain gauge (**Figure 1**). The subject's head was placed in a head restraining system, as shown in **Figure 1**. For the measurement of forward tongue thrust, a cup was attached to the end of a small bar that ran through an ultraminiature load cell (**Figure 2a**).

A measure of the lip interface shear force was obtained by measuring the pulling force exerted by the lips on a flat spoon-like device. The lip interface pulling (shear) force transducer was constructed with a small plastic bar to which an ultraminiature load cell (Sensotech Inc., Columbus, OH, Model 121102) was attached (**Figure 2b**). The flat side of the transducer was placed between the lips, and the patient was asked to exert maximum pulling force with the lips. The pulling force was measured by the load cell. The subject's head was placed in the same head restraining system. Swallow suction pressure was measured with a miniature catheter connected to a hydraulic pressure transducer (Cobe, Inc., Lakewood, CO). Measurements obtained from dysphagic patients were signifi-

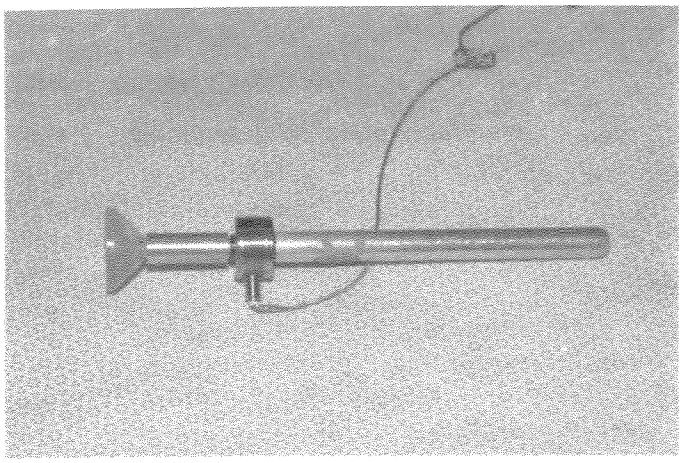

Figure 2a.
The forward tongue thrust transducer consists of a small cup-like dish attached to a miniature plastic bar with a miniature load cell (force transducer). The patient is asked to push the cup with his tongue while the device is held stationary.

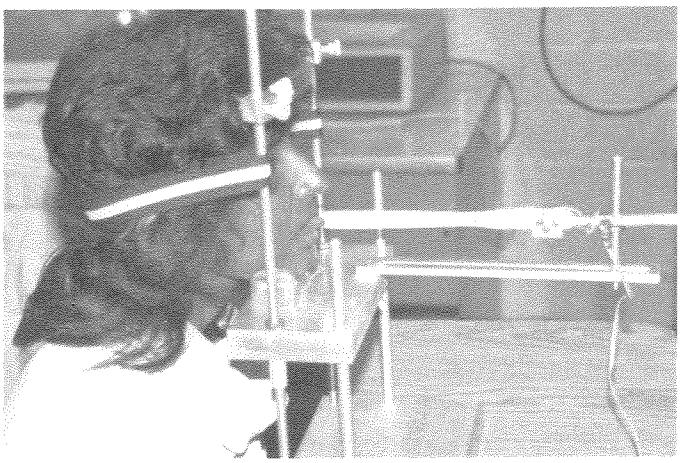

Figure 1.
Lateral tongue thrust measurement system consists of a strain-gauged miniature cantilever plastic bar. The patient's head is positioned in a jig during the measurement.

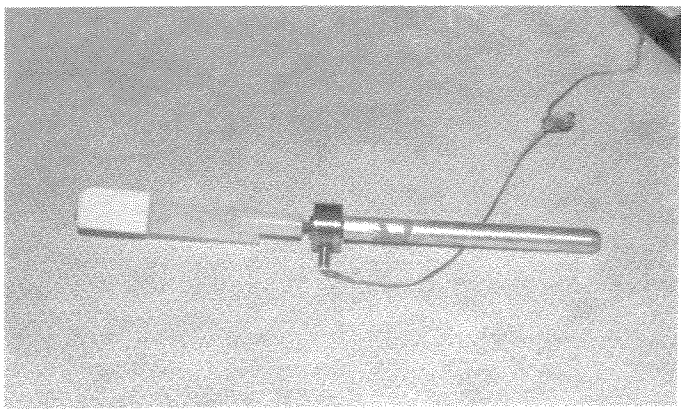

Figure 2b.
The lip interface shear force transducer consists of a small flat plastic bar attached to a miniature bar through a load cell (force transducer).

cantly lower in magnitude when compared to nondysphagic subjects (10).

Biomechanical Measurement of the Pharyngeal Phase

We have developed the accelerometry technique to noninvasively assess the swallowing mechanism (11). We placed two ultraminiature accelerometers (Kulite Semiconductor Inc, Ridgefield, NJ, Model GY-125-10) on the skin at the throat (**Figure 3**). Accelerometer 1 was placed at the midline at the level of the thyroid cartilage and accelerometer 2 at the midline at the level of the cricoid cartilage. Simultaneously, we measured the swallow suction pressure with a catheter, with the tip placed on the midline toward the posterior aspect of the tongue, and connected to a hydraulic pressure transducer (Cobe Inc.).

In nondysphagic individuals, swallowing gave rise to a characteristic acceleration pattern (**Figure 4**). The peak acceleration during swallowing ranged from 1 to 3 g. The swallow pressure was biphasic. There was no latency (time lag) between the appearance of the pressure wave and appearance of the acceleration wave characteristic of swallowing. Moreover, only one attempt was required to produce a swallow.

In dysphagic patients, the acceleration pattern typical of swallowing was either absent (**Figure 5**) or delayed (11). In those patients who could trigger a swallow, significant lag times were found between the pressure waveform and the acceleration waveform. In patients who could trigger a swallow, several attempts were required to produce the response. The amplitude of peak acceleration measured in dysphagic patients ranged from 0 to 0.5 g.

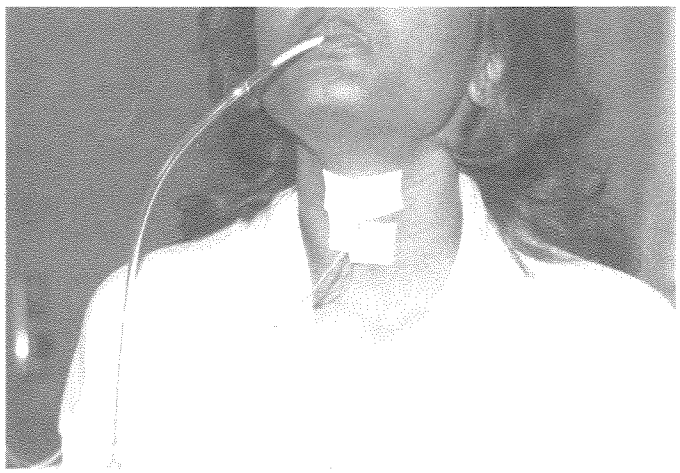

Figure 3.
The pharyngeal phase is assessed by attaching two ultraminiature accelerometers on the skin over the throat over thyroid and cricoid cartilages. A catheter is placed midline in the mouth toward the posterior aspect of the tongue to measure swallow pressure.

Figure 4.
Acceleration and swallow pressure measurements obtained from a nondysphagic subject. Top and bottom accelerometers drive the top and bottom channels; the middle channel reflects swallow pressure. Swallow pressure is biphasic (changes direction) and the characteristic nondysphagic acceleration pattern is developed. There is no latency between the swallow pressure and acceleration responses.

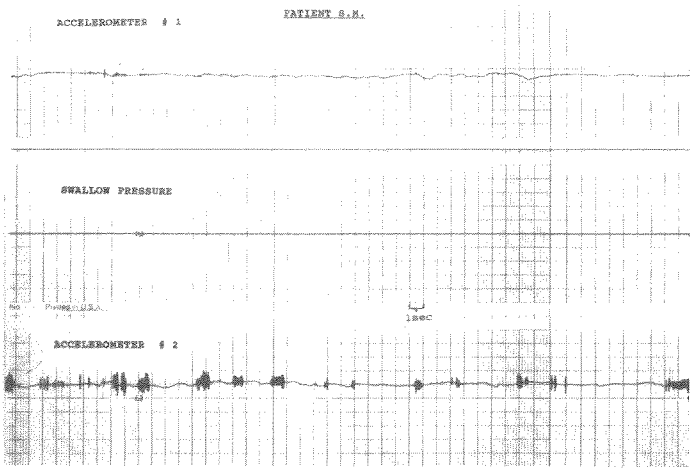

Figure 5.
Acceleration and swallow pressure response obtained from a patient.

Classification of the Risk for Aspiration Using the Biomechanical Measurements

In 36 physician-referred patients from whom consent was obtained, we made biomechanical measurements of the oral and pharyngeal phases within 7 days of the clinical

bedside evaluation and VFE in a double-blind study. The biomechanical results and VFE and clinical bedside evaluation results were independently classified into four categories of risk for aspiration: 1) normal (no risk), 2) mild risk, 3) moderate risk, and 4) severe risk. The VFE and clinical classification was made by a single speech pathologist. The biomechanical classification was made by a biomedical engineer. Both classifications were compared at the end of the study. The investigators conducting the biomechanical evaluation did not know the patient etiology or clinical classification. Similarly, the clinical evaluator did not have the biomechanical measurements or classifications. Also, at the end of the study, the biomedical engineer examined the VFE records and compared them with certain features in the biomechanical recordings.

First, the oral biomechanical measurements were classified into four categories. Then, the pharyngeal biomechanical (accelerometry) measurements were classified into four categories, and finally, an overall biomechanical classification was made of the combined oral and pharyngeal phases.

The oral biomechanical measurements were classified as follows:

Category	Criteria
a) normal	near normal lip closure pressure (**LP**) AND near normal tongue thrust (**TT**) in all directions: [**LP** ≥ 70 mmHg] **AND/OR** [**TT** ≥ 250 g]
b) mild	low tongue thrust AND/OR low lip closure pressure: [15 mmHg < **LP** < 70 mmHg] **AND/OR** [125 g < **TT** < 250 g]
c) moderate	moderately lower tongue thrust AND/OR moderately lower lip closure pressure: [5 mmHg < **LP** < 15 mmHg] **AND/OR** [20 g < **TT** ≤ 125 g]
d) severe	very low lip closure pressure AND/OR very low tongue thrust: lip closure pressure below 5 mmHg AND/OR tongue thrust below 20 g. [**LP** ≤ 5 mmHg] **AND/OR** [**TT** < 20 g]

The pharyngeal phase biomechanical measurements were classified as follows:

Category	Criteria
a) normal	normal acceleration pattern (**AP**) AND near normal acceleration magnitudes (**AM**) AND near normal suction pressure (**SP**) One number of attempts to swallow (**NA**): [Normal **AP**] **AND** [**AM** ≥ 0.7 g] **AND** [**SP** ≥ 40 mmHg] **AND** [**NA** = 1]
b) mild	[Normal **AP**] **AND** [**NA** < 2] **AND** [0.5 g < **AM** < 0.7 g) **AND/OR** (**SP** < 40 mmHg)]
c) moderate	[(Slightly distorted **AP**) **AND/OR** (**2** < **NA** < 4)] **OR** [(0.2 g < **AM** < 0.5 g) **AND/OR** (**SP** < 30 mmHg)]
d) severe	very low acceleration magnitude (below 0.2 g) or very low swallow pressure (below 10 mmHg) OR more than four attempts to swallow OR significantly distorted acceleration pattern [(Significantly distorted **AP**) **AND/OR** (**NA** ≥ 4)] **OR** [(**AM** < 0.2 g)] **OR** [(**SP** < 10 mmHg) **AND** (**SP** Monophasic)]

Each patient was then assigned an overall biomechanical rating based on the biomechanical classification in the oral and pharyngeal phases. The overall rating was given as described below:

Category	Criteria
a) normal	normal oral phase AND normal pharyngeal phase
b) mild	normal oral phase AND mild pharyngeal phase OR mild oral phase AND normal pharyngeal phase OR mild oral phase or mild pharyngeal phase

c) moderate	moderate oral phase AND mild or normal pharyngeal phase OR moderate pharyngeal phase AND mild or normal oral phase OR moderate oral phase AND moderate pharyngeal phase OR severe oral phase AND mild pharyngeal phase
d) severe	severe oral phase AND moderate pharyngeal phase OR severe pharyngeal phase

Clinical and VFE Assessment

The biomechanical classification was correlated with the classification assigned by the speech pathologist after the double-blind study. The speech pathologist's classification was based on findings of the clinical (bedside) evaluation and VFE.

The clinical evaluation of the pharyngeal phase included assessment of velar function in terms of elevation, asymmetry, gag, and nasality, and assessment of the laryngeal function in terms of hoarseness, breathiness, gurgling, pitch and loudness of sound, and voluntary and reflective cough strength. Clinical evaluation of the oral phase included evaluation of labial and lingual function in terms of range of motion, coordination, and strength.

The VFE was conducted with thick liquid and pureed consistency. The patient was in an upright seated position. The examination involved observation of the oral phase in terms of tongue motion, residue in oral cavity, oral transit time, and premature pharyngeal entry. The assessment of the pharyngeal phase involved laryngeal elevation, pharyngeal transit time, laryngeal penetration, and residue in valleculae, pyriform sinus, and laryngeal vestibule. Each parameter was judged normal, mild, moderate, or severe. An overall classification was assigned for each patient based on all these parameters as a part of the hospital protocol. This classification was compared with the biomechanical classification at the completion of the double-blind study.

Data Analysis

A non-parametric statistical test (Wilcoxon test) was performed to study the statistical significance in the differences between the biomechanical and clinical classifications based on VFE and clinical bedside examination.

Observations

After the comparison of the biomechanical and clinical classifications, one of the authors examined the VFE records and made observations relating the events of the VFE with the following characteristics of the pharyngeal biomechanical recordings: acceleration pattern, acceleration magnitude, high frequency noise (blurring in the record) in the acceleration recording, and magnitude of swallow suction pressure.

RESULTS

In 21 of the total of 36 patients, there was complete agreement between the biomechanical classification and VFE and clinical classification of risk for aspiration (**Table 1**). In 11 patients, the biomechanical classification overestimated the risk by one category. In four patients, the biomechanical classification underestimated the risk by one category. Wilcoxon test (a non-parametric test) did not indicate any significant statistical difference between the two methods.

The acceleration response of patient **M.W.** with a mild pharyngeal phase risk of aspiration is shown in **Figure 6**. The peak acceleration magnitude was 1.17 g from accelerometer 1 and 2.3 g from accelerometer 2. The swallow suction pressure was 35 mmHg. The patient had

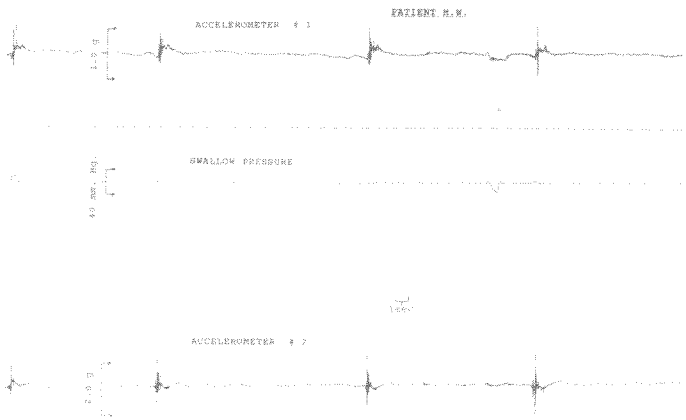

Figure 6.
Acceleration and swallow pressure recorded from dysphagic subject **M.W.** with mild risk of aspiration.

Table 1:
Correlation of biomechanical and clinical risk ratings.

PATIENT	ORAL PHASE Biomech	PHARYNG PHASE Biomech	OVERALL BIOMECH RATING	VFE & CLINICAL EVALUATION	PATIENT ETIOLOGY	Age
M.P.	Moderate	Moderate	Moderate	Moderate	RCVA	71
M.V.	Mild	Moderate	Moderate	Severe	RCVA	75
M.M.	Moderate	Moderate	Moderate	Severe	Guillain Barré Syndrome	37
P.C.	Mild	Moderate	Moderate	Mild	LCVA, diabetes	72
A.F.	Moderate	Severe	Severe	Severe	Tubercular Meningitis	52
G.M.	Severe	Severe	Severe	Moderate	RCVA	90
R.R.	Mild	Moderate	Moderate	Moderate	CVA	67
G.J.	Severe	Severe	Severe	Severe	LCVA	77
E.M.	Moderate	Mild	Moderate	Mild	LCVA	65
H.P.	Moderate	Mild	Moderate	Moderate	LCVA	73
J.G.	Mild	Moderate	Moderate	Moderate	CHI, anoxia	49
D.A.	Moderate	Mild	Moderate	Moderate	LCVA	76
G.H.	Moderate	Mild	Moderate	Moderate	LCVA	79
D.S.	Mild	Severe	Severe	Severe	CHI	19
E.P.	Severe	Severe	Severe	Severe	LCVA	69
B.S.	Moderate	Severe	Severe	Moderate	RCVA	67
M.W.	Severe	Mild	Moderate	Mild	Cerebral Infarction	75
F.S.	Moderate	Mild	Moderate	Moderate	Mult. Laminar Infarction	68
H.J.	Moderate	Mild	Moderate	Moderate	LCVA	72
G.M.	Mild	Moderate	Moderate	Moderate	RCVA	90
W.C.	Severe	Severe	Severe	Severe	Astrosystoma Brainstem	43
V.F.	Severe	Severe	Severe	Moderate	LCVA	82
S.G.	Moderate	Severe	Severe	Severe	CHI	29
M.C.	Moderate	Mild	Moderate	Moderate	LCVA	76
D.M.	Severe	Severe	Severe	Severe	RCVA	83
G.W.	Moderate	Severe	Severe	Severe	Bilateral CVA	73
T.N.	Mild	Moderate	Moderate	Mild	Bilateral CVA	45
D.F.	Moderate	Severe	Severe	Moderate	Anoxia	62
J.V.	Moderate	Mild	Moderate	Mild	LCVA	49
C.G.	Moderate	Severe	Severe	Severe	Bilateral CVA	50
E.S.	Mild	Severe	Severe	Moderate	RCVA	81
J.S.	Mild	Mild	Mild	Moderate	LCVA, Lacunar Infarction	84
G.W.	Moderate	Severe	Severe	Moderate	Bilateral CVA	73
M.T.	Mild	Moderate	Moderate	Moderate	Parkinson's Disease	76
D.M.	Moderate	Severe	Severe	Severe	Subarchanoid Hemorrhage	49
H.G.	Mild	Moderate	Moderate	Severe	RCVA	73

PHARANG = pharangeal; VFE = videoflouroscopic examinaton; CVA = cerebrovascular accident; RCVA = right CVA; LCVA = left CVA; CHI = closed head injury

a lip closure pressure of only 5 mmHg, and a lip pulling force of only 33 g. The patient was unable to perform the tongue thrust and had a 0 g of lateral tongue thrust. Biomechanically, the patient was classified as having a mild risk for the pharyngeal phase and a severe risk for the oral phase. He was given an overall biomechanical rating of moderate. His VFE and clinical bedside evaluation revealed that he had a mild pharyngeal phase dysphagia. A delayed triggering of the pharyngeal phase was noted primarily due to reduced initiation in the oral phase. He had moderate to severe oral phase dysphagia clinically. However, the overall clinical rating was mild. **Figures 7** and **8** show the acceleration patterns of two patients (**D.M.** and **W.C.**) who were classified at significant risk by both biomechanical and VFE and clinical examinations.

Figure 9 shows the acceleration and pressure measurements from patient **H.J.** at moderate risk for aspiration. The peak acceleration magnitudes were 2 g for accelerometer 1 and 1.25 g for accelerometer 2. He had a swallow pressure of 33.2 mmHg. Although the magnitudes of ac-

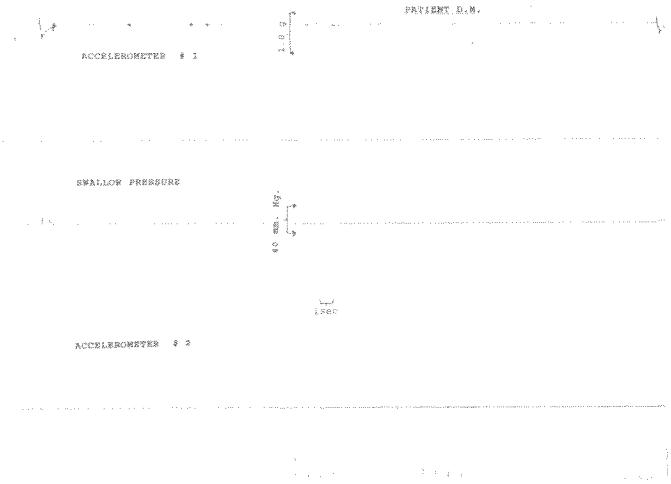

Figure 7.
Acceleration and swallow pressure measurements obtained from dysphagic patient **D.M.** with significant risk for aspiration.

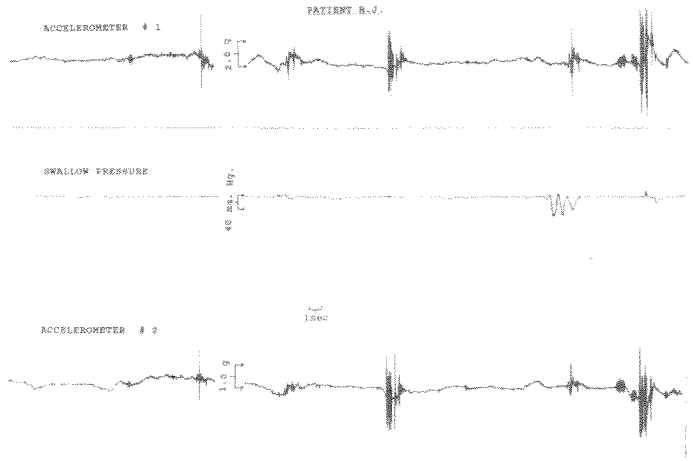

Figure 9.
Acceleration and swallow pressure response obtained from dysphagic patient **H.J.** with moderate risk for aspiration.

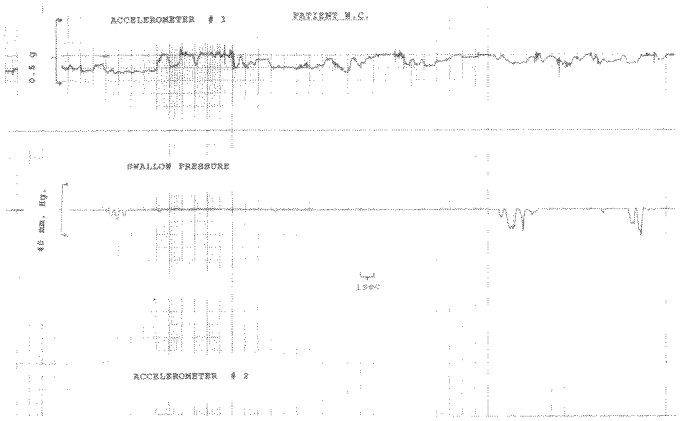

Figure 8.
Acceleration and swallow pressure measurements obtained from dysphagic patient **W.C.** with significant risk for aspiration.

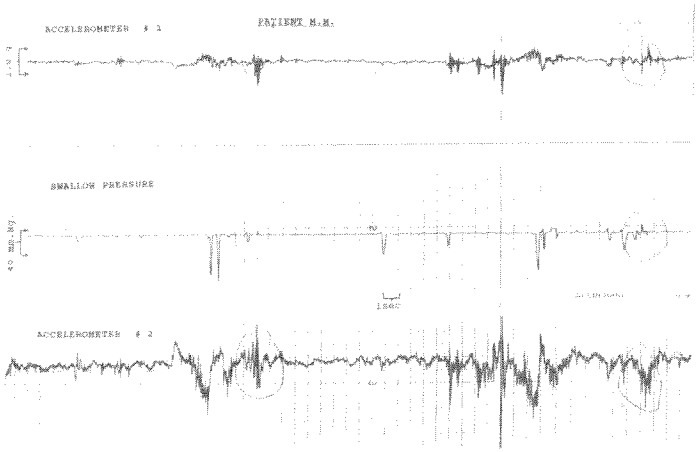

Figure 10.
Acceleration and swallow pressure response obtained from dysphagic patient **M.M.** with significant risk for aspiration.

celeration were normal, the acceleration pattern had a slight high frequency blurring. His oral measurements were not obtained as he had dentures which interfered with the measurements. The patient was assigned an overall biomechanical rating of moderate risk. Clinically, the patient had a moderate oral phase dysphagia. He had mild to moderate amounts of residue in the valleculae and demonstrated trace residual pooling in the pyriform sinuses. The patient was assigned an overall clinical rating of moderate risk.

The acceleration and swallow suction pressure patterns of patient **M.M.**, who is at severe risk of aspiration, is shown in **Figure 10**. The VFE revealed that the patient had severe pharyngeal phase dysphagia with a moderate to marked residue in the vallecular spaces which she was unable to clear with repeated swallows. The biomechanical evaluation revealed that the acceleration pattern had blurring. Although the acceleration pattern was distorted, one swallow was noted in five minutes. Since the swallow was noted, the patient was given a biomechanical classification of moderate risk. Her clinical classification was severe risk.

Several observations were made by the biomedical engineer when examining the VFE records after the completion of the double-blind study. Although the following

observations were made qualitatively, further systematic investigation is needed. In cases of patients who had food stasis or food residue in the vallecular spaces as confirmed by the VFE, the acceleration response showed slight high frequency blurring (high frequency noise in the acceleration signal). For instance, patient **F.S.** had food residue and also had laryngeal penetration as observed by the videofluorography, and had high frequency noise (blurring in the record) in the acceleration response shown in **Figure 11**. This case can be contrasted with the acceleration recording from patient **M.W.** who did not have any food stasis and the acceleration record is free of high frequency noise (**Figure 6**). The magnitude of the characteristic acceleration was small in patients who had poor laryngeal elevation. The characteristic acceleration pattern was absent in patients who had little or no laryngeal adduction. **Figures 7** and **8** show the acceleration patterns from two such patients. Pumping action was observed in the swallow pressure response in patients who required a large number of attempts to swallow (e.g., patient **G.W.** in **Figure 12**). The acceleration signal from a dysphagic patient with Parkinson's disease (**M.T.**) contained low frequency oscillations (**Figure 13**).

DISCUSSION

The present results have demonstrated the potential of the biomechanical measurements in noninvasive assessment of the dysphagic patient, and in the identification of the patient at risk of aspiration. The biomechanical technique presents the clinician with a noninvasive tool to demonstrate the clinical improvements for continued patient assessment in terms of the biomechanical parameters. Moreover, the biomechanical method can be used more frequently to aid in the identification of patients who need a VFE.

Currently, there is no unique method of classification of risk for aspiration, and the clinical classification itself is somewhat subjective and could vary from clinician to clinician. In spite of this, there was complete agreement in

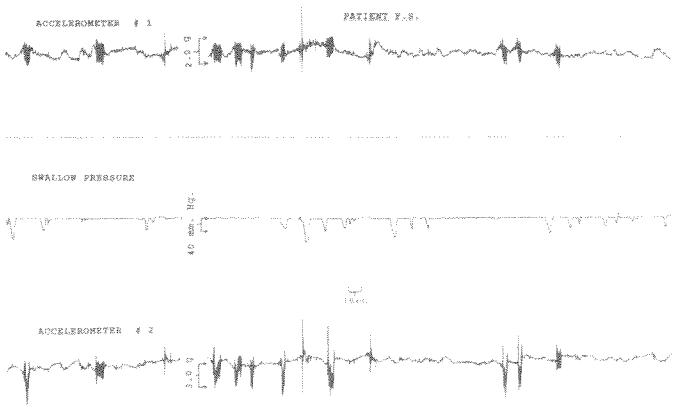

Figure 11.
Acceleration and swallow pressure measurements obtained from dysphagic patient **F.S.** who had pharyngeal penetration.

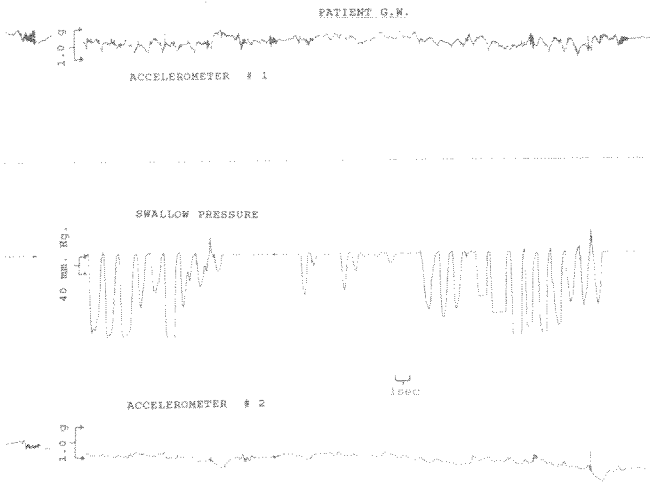

Figure 12.
Acceleration and swallow pressure measurements obtained from dysphagic patient **G.W.** who required many attempts to swallow. The biomechanical classification was significant risk and the clinical classification was moderate risk for aspiration.

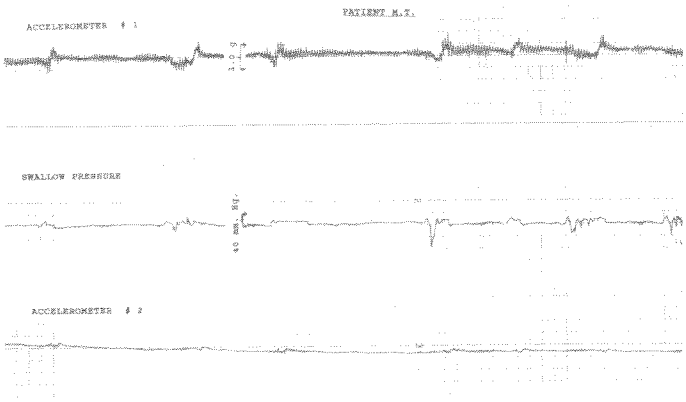

Figure 13.
Acceleration and swallow pressure measurements obtained from a dysphagic patient with Parkinson's disease.

21 of 36 patients and the biomechanical technique overestimated the risk in 11 subjects and underestimated the risk in 4 subjects by one category. The disagreement could be attributed to several factors. First, the positioning of the patient may be an important factor. In the biomechanical examination, the patient is seated vertically. In the VFE, the patient may be examined in a number of positions (12). A semi-erect position can assist the disordered patient in compensating for the dysphagia (12). Second, the biomechanical method involved dry swallow. In the VFE, the patient is given food boluses of various consistencies. Viscosity was progressively changed to test the patient's tolerance depending upon other conditions, such as etiology, age, or history. Third, in the biomechanical measurement, the patient is given a 5-minute duration for the pharyngeal examination during which the patient may or may not swallow. In the VFE, the patient is given food boluses of various consistencies, and the speech pathologist and/or the radiologist wait(s) for the patient to initiate a swallow. The duration of the wait is left to the discretion of the radiologist. Finally, the condition of the patient might have changed slightly between the VFE and biomechanical measurement.

The noninvasive biomechanical measurement procedure required from 20 to 30 minutes. The present recording instrumentation is not portable; therefore, patients who could not be readily transported to the laboratory were excluded from the study. Also excluded were those patients who could not follow instructions.

Success of the biomechanical method depends on the cooperation, mood, and alertness of the patient. Cognition is an important factor. For instance, a head injury patient may have a very short attention span or be irritable and noncooperative. Measurements obtained from such a patient may not be as comprehensive or accurate as desired.

The high frequency noise observed in some patients might be occurring due to the presence of food or food penetration and should be further investigated. Also, smaller magnitudes of acceleration observed in patients with poor laryngeal elevation, and distorted or absent acceleration patterns observed in some patients with little or no laryngeal adduction, were only observations in some patients and should be further investigated systematically.

In the present investigation, only 36 subjects were used. With the limited number of subjects, it is difficult to confirm in which categories the biomechanical method is most effective in the assessment of the risk. Also, the present investigation with a limited number of patients cannot conclusively reveal which parameter is most indicative of the risk for aspiration. Parameters of the pharyngeal phase may be very important. However, oral phase parameters may also be important. For instance, the lateral tongue thrust indicates the ability for tongue lateralization. Control of the tongue is important to prevent premature pharyngeal entry. Further investigations are being undertaken to unravel the importance of each of the parameters.

Arbitrary rules were used in the present study to classify the biomechanical measurements into various risk categories. The parameters separating the categories (mild, moderate, etc.) were chosen based on the experience from our previous studies (10–12). In reality, we have an expert system based on limited previous data. With continued studies with a large number of patients, this classification procedure can be improved. Nevertheless, the present investigation represents the first step in using the biomechanical measurements for patient classification. Perhaps a computerized neural network model can be developed to classify patients based on the biomechanical measurements. Such models and measurements are being undertaken.

Compact, portable instrumentation is needed to quantify the swallowing mechanism and to detect aspiration at the bedside. With further refinement, the biomechanical techniques facilitate the development of such instrumentation. However, automatic pattern recognition techniques have to be developed to automatically classify the acceleration patterns such that the measurement and interpretation can be made by the clinician. Although two accelerometers were used in the present study, only one accelerometer placed at the thyroid cartilage is sufficient.

In current clinical practice, the swallowing mechanism is evaluated by clinical evaluations and the VFE. The clinical evaluation involves visual observation of the oromotor functioning in terms of the strength, coordination, range of motion, and functional tasks in swallowing. Laryngeal elevation is also examined as a part of the bedside evaluation. Vocal quality is examined for signs of gurgly quality which would indicate laryngeal and/or pharyngeal food residues. The VFE is generally used to confirm the clinical evaluation in those patients in whom there is a risk of aspiration or penetration. This examination involves the administration of food boluses of various consistencies mixed with barium. The patient is asked to swallow, and each swallow is carefully examined frame-by-frame to detect the movement of the bolus in relation to the structures.

In clinical practice, prescription and administration of proper food depends on the clinician's determination of the

dysphagic patient's risk for aspiration, his nutrition, and medical condition. The number of risk categories used varies from hospital to hospital. The actual classification is subjective as the clinician takes into account the VFE, the bedside evaluation, patient etiology, age, and other conditions. Also, the determination of the actual risk may require patient follow-up.

Since the videofluorographic technique may cause radiation exposure, repeated examination on a daily basis cannot be performed. Fiberoptic endoscopic examination of swallowing (FEES) developed by Langamore et al.(9) is a direct assessment tool and can be performed on a daily basis, but is rather invasive. Ultrasound has been suggested as a diagnostic tool for evaluation of the oral phase. Electroglottography (EGG), a method based on impedance change, has been suggested recently for the detection of the pharyngeal stage (7). However, the latter two methods have not been used in clinical practice.

The biomechanical method, therefore, presents a useful tool for comprehensive, quantitative, and noninvasive assessment of the dysphagic patient, and for identification of the patient at risk of aspiration. This technique complements other techniques such as the VFE, FEES, ultrasound, and EGG. Before the method is adopted for clinical use, studies are needed correlating the events of the biomechanical recordings with the motions of various structures involved in the pharyngeal phase of swallowing. Moreover, the biomechanical technique is not indicated in patients with poor cognition and in patients on whom the transducers cannot be placed (e.g., patients with neck braces or tracheal tubes). Also, the tongue thrust measurement requires placing the head in a jig to restrain the jaw, head, and neck motion. Only the pharyngeal phase measurements can be obtained in such cases. The biomechanical method may be useful in patients who cannot tolerate the risk of aspirating very small quantities of food. Nevertheless, the method complements the other existing techniques and should be investigated further. A study on a larger population of patients is necessary.

CONCLUSIONS

The biomechanical measurement technique presents a potential tool for noninvasive identification of the dysphagic patient at risk of aspiration; however, further studies on a larger population of patients are necessary before the technique can be used in the clinic. This technique may be combined with clinical bedside evaluation to determine the need for the VFE. Further refinements in terms of automation might be necessary to facilitate clinical application.

ACKNOWLEDGMENTS

The authors would like to express sincere thanks to Ms. Susan Gough, MA, CCSP for her assistance in the clinical assessment and videofluorography. Ms Gough was in the Department of Communicative Disorders at Edwin Shaw Hospital.

Support from the National Institutes of Health and from Edwin Shaw Hospital is thankfully acknowledged. The authors also thank Dr. Daniel Church, president and CEO of Edwin Shaw Hospital, for his continued encouragement.

REFERENCES

1. Logemann JA. Evaluation and treatment of swallowing disorders. Boston: Little Brown and Co., 1983.
2. McIntosh J, Martin G, Sacchett C. Recognition of the diverse and complex nature of neuromuscular swallowing disorders: a basis for treatment. Clin Rehabil 1987:1:39–45.
3. Veis SL, Logeman JA. Swallowing disorders in persons with cerebrovascular accident. Arch Phys Med Rehabil 1985:66:372–5.
4. Logemann JA. Manual for the videofluorographic study of swallowing. Boston: Little Brown and Co., 1985.
5. Sterns D. Ultrasound swallow. Br Med J 1978:2:1789–90.
6. Sonies BC. Instrumental procedure for dysphagia diagnosis. Semin Speech Lang 1991:12:185–92.
7. Sorin R, McClean MD. Electro-glottographic examination of swallowing. Arch Phys Med Rehabil 1987:68:232–5.
8. Perlman AL, Grayhack JP. Use of electroglottograph for measurement of temporal aspects of swallow: preliminary observation. Dysphagia 1991:6:88–93.
9. Langamore SE, Schatz K, Olson NO. Endoscopic and videofluoroscopic evaluation of swallowing and aspiration. Ann Otol Rhinol Laryngol 1991:100:678–81.
10. Reddy NP, Costarella BR, Grotz RC, Canilang EP. Biomechanical measurements to characterize the oral phase of dysphagia. IEEE Trans Biomed Eng 1990:37:392–7.
11. Reddy NP, Canilang EP, Casterline J et al. Noninvasive acceleration measurements to characterize the pharyngeal phase of swallowing. J Biomed Eng 1991:13:379–83.
12. Jones B, Donner MW. How I do it: examination of the patient with dysphagia. Dysphagia 1989:4:162–72.