Impedance Pharyngography to Assess Swallowing Function

T KUSUHARA¹, T NAKAMURA¹, Y SHIRAKAWA², K MORI¹, Y NAOMOTO² AND Y YAMAMOTO¹

¹Faculty of Health Sciences, Okayama University Medical School, Okayama, Japan; ²Department of Gastroenterological Surgery, Transplant and Surgical Oncology, Okayama University Graduate School of Medicine and Dentistry, Okayama, Japan

We evaluated impedance pharyngography (IPG), a new method to assess swallowing function based on changes in the electrical impedance of the neck during swallowing. The electrical impedance of the neck, recorded by the 4-electrode method, changed with the equivalent cross-sectional area of the route of the electric current due to reflex activities of related organs during swallowing. IPG waveforms accurately recorded the swallowing process, therefore. We recommend IPG for assessing swallowing function because we expect IPG to provide the following advantages over conventional diagnostic techniques: it is a quantitative method that allows for the objective assessment of swallowing function; it is a simple procedure that is convenient for the patient and could be used for screening; it is inexpensive and non-invasive, so could be performed repeatedly in situations such as rehabilitation; and it uses highly portable equipment suitable for community use.

KEY WORDS: DYSPHAGIA; SWALLOWING FUNCTION; AGEING; BIOELECTRICAL IMPEDANCE; IMPEDANCE PHARYNGOGRAPHY

Introduction

Swallowing is the process by which food boluses are transported from the mouth to the throat and oesophagus. It is accomplished by an intricate swallowing programme which is performed by the organs involved in the process. Dysphagia occurs when the execution of this process is disturbed by causes such as oesophageal cancer, degenerative disorders of nerves and muscles, and ageing.¹² Dysphagia, which affects increasing numbers of patients in the ageing population, has become a social welfare problem that can markedly reduce the patient’s quality of life. Dysphagia is usually diagnosed by a combination of experience and subjective observation by physicians and patients, using methods such as inquiry, observation and palpation, combined with ultrasonography, endoscopy and X-ray fluoroscopy if appropriate.¹² The complex structure of the pharynx is difficult to delineate by ultrasonography, and swallowing is impossible during video endoscopy, so making real-time observations of the swallowing process is difficult. X-Ray fluoroscopy is of considerable diagnostic value because it provides information about the position of the lesion, the severity of dysphagia, and swallowing dynamics, but it cannot be performed frequently because of
the risk of repeated exposure to X-rays and the cost implications. Also, the quantitative evaluation of swallowing function is difficult by X-ray fluoroscopy.

The medical application of bioelectrical impedance has a long history,3,4 and both Cole5 and Schwan6 have been recognized for their basic research in this area. Attempts to apply the use of electrical impedance have been made in several fields.7,8 Many early attempts tried to measure skin resistance or skin impedance as a diagnostic index because this was an easy measurement to make,9 but subsequent research interest has been directed towards the cardiovascular10–13 and respiratory systems.14 The majority of previous research measured physiological functions, and studies were performed in the resting state. Recently, the measurement of bio-impedance has been applied to dynamic states with measurements being made during exercise.15–18

In our study, we investigated the use of impedance pharyngography (IPG), using neck electrical impedance, as a new method for the assessment of the dynamic process of swallowing. Impedance pharyngography has several merits that made it worth investigating, including low cost, a simple non-invasive measurement procedure, portable apparatus, and the provision of quantitative results. If successful, the clinical application of IPG would be expected to allow swallowing function to be assessed quantitatively at all sites while providing minimal stress and inconvenience to the patient. Therefore, we evaluated the basic aspects of IPG including the design of the hardware, optimal electrode positioning, and how the IPG waveform was generated.

Subjects and methods

SUBJECTS

The subjects were healthy individuals, aged 20 – 29 years of age, and all gave informed consent. Ethics committee approval for the study was unnecessary.

DESIGN OF THE MEASUREMENT SYSTEM

Impedance pharyngography must reflect the changes in impedance in areas of the body where the organs involved in swallowing are located. Figure 1 shows a block diagram of the impedance meter, which used the four-electrode method to avoid the effects of skin impedance,19 and constant sinusoidal current (50 kHz, 0.5 mA) to avoid interference by application of an electric current.20 The impedance meter used a voltage-current converter to convert the output voltage from the oscillator (Vosc) into an electric current of the same phase. The electric current was applied to the neck via the current electrode. As a result of this electric current, changes in the electrical impedance in the neck were detected as changes in the difference in potential (Vnk1) and were amplified by the differential amplifier. The output from the differential amplifier was multiplied with Vosc, and the resultant component with twice the frequency of Vosc was removed by the low pass filter (LPF; cut-off frequency 25 Hz) in the next step. As a result, a voltage proportional to the equivalent serial resistance component of internal neck tissue impedance appeared in the output from the LPF (Vlpf). In ordinary IPG measurement, the output from the dZ terminal after elimination of neck electrical impedance in a resting state was recorded by shifting the level of Vlpf.

Figure 2 shows the IPG and swallowing sound measuring system, which used the impedance meter shown in Fig. 1. The swallowing sounds caused as a bolus passed through the pharynx were measured using an acceleration-detecting-type heart sound sensor (MIC; TA-701T, Nihon Kohden Corp., Tokyo, Japan) to determine whether the
FIGURE 1: A block diagram of the impedance meter used in this study of the assessment of swallowing function, which used the 4-electrode method and constant sinusoidal current (50 kHz, 0.5 mA). The multiplying method was also used to detect the equivalent serial resistance component of the internal neck tissue impedance. OSC, oscillator; VIC, voltage-current converter; LPF, low pass filter; nk, neck

FIGURE 2: The impedance pharyngography (IPG) and swallowing sound measuring system. In addition to the IPG measurements made by the impedance meter, the swallowing sounds caused as the boluses of water passed through the pharynx were recorded using an acceleration-detecting-type sensor (MIC). HPF, high pass filter; fc, cut-off frequency
Impedance pharyngography to assess swallowing function

Timing of the movements of the organs involved in swallowing matched the movement of the bolus. The relationship between the IPG waveforms and the occurrence of the swallowing sounds was expected to differ in subjects who were likely to aspirate food compared with healthy individuals, and as a consequence it was thought that it might be useful for assessing swallowing function. Impedance pharyngography data collected from the impedance meter and swallowing sounds data from the MIC were converted from analogue to digital at a sampling frequency of 2 kHz, and displayed on a screen. The data were also recorded in a notebook-type personal computer.

DETERMINATION OF ELECTRODE ARRANGEMENT
The position of the electrodes on the neck was an important factor in IPG measurement. Standard electrodes were considered to be in an optimum position when: the waveforms reflected swallowing activities; they were not affected by activities other than swallowing; they showed large absolute changes and percentage changes; and there were clear references for the determination of the positions. The centres of the current electrodes (I+, I–) were placed at a position on the line of intersection between the plane that contains the bilateral gonions, the articular processes of the mandible and the surface of the neck 20 mm below the gonions (Fig. 3). The potential electrodes (P+, P–) were placed on the line of intersection between the plane parallel to the mandibular floor that passed the current electrodes and the surface of the neck at a centre-to-centre distance of 25 mm. The potential electrodes were placed anterior to the current electrodes. The electrodes were non-polarizing Ag–AgCl skin surface electrodes (Nihon Kohden Corp.) and were 10 mm in diameter. The electrode paste used was GELAID (Nihon Kohden Corp.). The MIC for recording swallowing sounds was attached below the potential electrode at a centre-to-centre distance of 25 mm.

EXPERIMENTAL PROCEDURE
The subjects sat in a chair that was inclined to 75° and were instructed to keep a bolus of water (10 ml) in their mouth before the measurement took place. They were requested to start swallowing the water when the signal lamp flashed. Measurements were continued for 10 seconds at a time including the periods of rest before and after swallowing.

Results
NORMAL IMPEDANCE PHARYNGOGRAPHY
Figure 4 shows a normal IPG trace from a 21-year-old male. The signal to start swallowing was given at 0 s. The results of
previous videofluorography tests confirmed the following stages: stage I was the oral stage, in which the bolus was transferred in the oral cavity; stage II was the pharyngeal stage, in which the swallowing reflex occurred and the bolus passed through the pharynx; and stage III was the oesophageal stage, in which the swallowing reflex was completed and the organs involved in swallowing returned to their original state.\textsuperscript{21,22}

Since the time from the peak to the bottom of the IPG waveform corresponded with the pharyngeal stage, the IPG waveform was easy to read with regard to swallowing activities (Fig. 4). With regard to the relationship between the IPG waveform and swallowing sounds, the latter occurred frequently as the bolus of water passed through the pharynx. These findings were highly reproducible and were observed in all subjects in this study. This IPG waveform was considered to be a ‘normal IPG’ observed in individuals with normal swallowing function.

**ELECTRODE POSITION AND THE IMPEDANCE PHARYNGOGRAPHY WAVEFORM**

It was impossible to avoid some variation in the location of the electrodes among different subjects or if electrodes were attached in the standard positions in the same subject repeatedly. Therefore, we evaluated the reproducibility of IPG when the position of the electrodes was altered. Impedance measurements were made in the same subjects after moving the potential electrodes up, down and forward by 10 mm compared with the standard locations (Fig. 5).

The impedance change that was recorded following an upward shift of the potential electrode was nearly identical to that recorded when the electrode was in the standard location, but it was reduced when the electrode was moved forward or downward. The IPG waveform was similar when the potential electrode was in all four positions, and we did not consider any of the information concerning the actions of the organs involved in swallowing to have been lost as a result of moving the potential
Impedance pharyngography to assess swallowing function

The reproducibility of impedance pharyngography (IPG) when the position of the potential electrode was changed to the positions shown in A. The IPG waveform was similar at all potential electrode positions and no information concerning the actions of the organs involved in swallowing appeared to have been lost (B). The times taken to reach the peak and the bottom of the IPG waveform were also unchanged.

FIGURE 5: The reproducibility of impedance pharyngography (IPG) when the position of the potential electrode was changed to the positions shown in A. The IPG waveform was similar at all potential electrode positions and no information concerning the actions of the organs involved in swallowing appeared to have been lost (B). The times taken to reach the peak and the bottom of the IPG waveform were also unchanged.

Since it was primarily the impedance of the laryngeal region that was measured in IPG, the swallowing reflex increased the equivalent cross-sectional area and reduced the impedance of the measured region. The elevation of the larynx associated with the swallowing reflex was thought to contribute to the decrease in impedance during the pharyngeal stage of the IPG waveform.

Discussion

From our observations, the IPG waveform was considered to reflect the movements of
Impedance pharyngography to assess swallowing function in the organs involved in swallowing and to be useful for assessing swallowing function. We wish to recommend IPG using neck bio-electrical impedance as a new method for assessing swallowing function. Information obtained by IPG included: absolute changes (or percentage changes) in impedance during the pharyngeal stage that reflected the organs involved in swallowing during the swallowing reflex. The larynx moves forward and upward. Since it was primarily the impedance of the laryngeal region that was measured by impedance pharyngography (IPG), the swallowing reflex increased the equivalent cross-sectional area and reduced the impedance of the measured region.
the level of activity of the organs involved in swallowing; the duration of the pharyngeal stage that reflected the smoothness of the swallowing motion; the pattern of the IPG waveform reflected the normality of the movements of the organs involved in swallowing; and the number of swallowing reflexes that appeared during one measurement, which might suggest the possibility of neck stenosis. Impedance pharyngography should be able to detect dysphagia and quantitatively express swallowing function if parameters are set for the duration of the pharyngeal stage, the impedance change in the pharyngeal stage, the waveform pattern and the number of swallowing reflexes observed. The evaluation of the swallowing sounds recorded simultaneously with the IPG waveform would be expected to indicate the presence or absence or the risk of silent aspiration, when no objective signs of aspiration such as choking and difficulty breathing have been observed.

The simplicity of the IPG procedure, and the fact that it causes minimal discomfort or inconvenience to the patient, suggests that it would be an effective screening method in the clinic. With statistical analysis of a large number of samples in advance, normal and abnormal parameters of swallowing function could be established. These could then be used to indicate, following screening, those people for whom close evaluation of dysphagia or swallowing function would be necessary. As IPG is non-invasive and can be performed as many times as required, we believe that it could be effectively used during rehabilitation. Rehabilitation plans are made on the basis of subjective judgements from the instructors and patients, but using quantitative IPG results would allow appropriate goals to be set and achievements to be confirmed. This might lead to the development of more appropriate rehabilitation plans and enhanced motivation of patients during their rehabilitation.

References


• Received for publication 28 April 2004 • Accepted subject to revision 11 May 2004
• Revised accepted 12 July 2004
Copyright © 2004 Cambridge Medical Publications
Impedance pharyngography to assess swallowing function


17 Nakamura T, Yamamoto Y, Yamamoto T, Tsuji H: Fundamental characteristics of human limb electrical impedance for biodynamic analysis.


Address for correspondence

Dr Y Yamamoto
Faculty of Health Sciences, Okayama University Medical School, 2-5-1 Shikata-cho, Okayama 700-8558, Japan.
E-mail: yyama@md.okayama-u.ac.jp