Use of Computer and Respiratory Inductance Plethysmography for the Automated Detection of Swallowing in the Elderly

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Abstract

Deglutition disorders can occur at any age but are especially prevalent in the elderly. The resulting morbidity and mortality are being recognized as major geriatric health issues. Because of difficulties in studying swallowing in the frail elderly, a new, non-invasive, user-friendly, bedside technique has been developed. Ideally suited to such patients, this tool, an intermediary between purely instrumental and clinical methods, combines respiratory inductance plethysmography (RIP) and the computer to detect swallowing automatically. Based on an automated analysis of the airflow estimated by the RIP-derived signal, this new tool was evaluated according to its capacity to detect clinical swallowing from among the 1643 automatically detected respiratory events. This evaluation used contingency tables and Receiver Operator Characteristic (ROC) curves. Results were all significant ($\chi^2(1,n=1643)>100$, $p<0.01$). Considering its high accuracy in detecting swallowing (area under the ROC curve greater than 0.9), this system would be proposed to study deglutition and then deglutition disorders in the frail elderly, to set up medical supervision and to evaluate the efficiency of a swallowing disorder remedial therapeutic.

Keywords:
Frail elderly; Respiratory inductance; Plethysmography; Deglutition; Automatic data processing; Deglutition disorders.

1. Introduction

Swallowing disorders can occur at any age but are especially prevalent in the elderly [1]. They can have serious consequences [2,3]. The resulting morbidity and mortality are being recognized as major geriatric health issues. Ongoing research into swallowing disorders has highlighted inconsistencies in clinical evaluation and in instrumental decision making [4]. New tests were elaborated and evaluated for their effectiveness in predicting aspiration [5]. The relationship between breathing and swallowing has already been studied in healthy subjects and elderly adults using various instrumental methods [6].

Furthermore, instrumental evaluations are often not feasible in a frail population. In order to overcome these difficulties, a new system was developed. It combines the respiratory inductance plethysmography (RIP), a user-friendly, non-invasive bedside tool, and the
computer, an objective tool, in order to detect swallowing by using an automated processing of the airflow signals obtained through RIP. If such is the case, this system affords a user-friendly objective bedside clinical tool for the detection and then the analysis of swallowing in the elderly. Its objective nature derives from the use of automated analysis elaborated specifically in this study.

2. Materials and methods

Materials

The RIP system used was the computer assisted Visuresp®. The sensor consisted of an elasticized jacket that could easily be worn by the patients over their usual clothing. The abdomen and rib cage signals obtained through RIP were combined to provide a volume signal. This latter was smoothed by low-pass filter and then differentiated to provide a valid estimation of the airflow signal [7]. A software was developed in order to analyze the airflow signal and detect swallowing automatically. This software, written in R (a language and environment for statistical computing and graphics) and in TCL/TK, consisted of two parts: the first part enabled the respiratory cycles to be delimited in an automatic way. In the second part, a test was elaborated to detect swallowing automatically. This test was based on the identification of a zero on the airflow signal (AS) as, during swallowing, the airflow is interrupted by a brief closure of the larynx, to protect the airway from the aspiration of ingested matter. In order to obtain this zero identification, a confidence interval of zero airflow was defined and totally determined by a cutoff value p. This confidence interval represented p percent (0 ≤ p ≤ 100) of the distribution of values of the airflow signal around zero airflow.

Clinical protocol

Swallowing was studied with this combined system in 14 patients aged 75-100 in a geriatric ward after obtaining informed written consent from each subject or their legal representative. Each patient, in a standardized but natural mealtime setting, wore the jacket in order for his or her breathing to be recorded continuously, and performed four swallowing: two swallowing of water, the first in a static mode (a 20 ml glass of water being given to the subject by the nurse), the second, in a dynamic way (the patient raised the 20 ml glass of water to his mouth to drink); two other swallowing of gelatinous water, with a little spoon, according to the same protocol. This clinical protocol was chosen in order to ascertain whether movement or the nature of the food would perturb the RIP signal. Each swallowing was carried out at our request after a regular respiratory rhythm had been observed. For each swallowing, the initial instant (when water or gelatinous water were placed in the mouth) and the final instant (the observed ceasing of larynx movement) were noted.

Test evaluation

The test was evaluated according to its capacity to detect the clinical Time-Marked Swallowing (TMS) from among the automatically detected respiratory cycles. Contingency tables were used. The test was performed for the two sets of respiratory cycles P1 and P2. The first, P1, was made up of elementary events. Each of these was in turn the set of respiratory cycles occurring during one TMS. The second, P2, was the set of respiratory cycles during which there was no TMS. Sensitivity, specificity, positive predictive value, negative predictive value, concordance rate and chi-square were computed for the test described above. Its accuracy was calculated by the area under the Receiver Operating Characteristic.
The best zero AS confidence interval was determined from the best balance between sensitivity and specificity obtained from the ROC curve.

3. Results

Figure 1 - An example of the automated detection of a gelatinous water swallowing. On the upper part, the dotted curve represents the recording of the airflow signal during a swallowing of gelatinous water. The straight line D corresponds to the threshold used for the automated detection of respiratory cycles. Z(p) is the confidence interval of the zero airflow (p=10). On the lower part, S and E are the beginning and the end of the clinical swallowing of gelatinous water. The thin vertical lines represent the start points of each inspiration. A clinical swallowing is detected if and only if the parts of the airflow signal which lie in Z(p) are not monotonous (thick lines).
Figure 2 – The ROC curve is built from computed sensitivity and 1-specificity (cross-points). The area under the ROC curve (AUC) is greater than 0.9. The best balance between sensitivity and specificity is obtained for the M Point, where the optimal computed p-cutoff value is 18.05 with a sensitivity and a specificity at 91.37 and 87.20 percent respectively.

Among 56 swallowing, only 51 were correctly located in time. The recorded breathing period was $351.3 \pm 93.7$ seconds ranging from 189 to 583 seconds. 1592 respiratory cycles were automatically identified (see figure 1). Results for contingency tables computed for different values of the p-cutoff were all significant ($\chi^2(1, n=1643) > 100$, p-value<0.01). The receiver operating characteristic (ROC) curve once computed (see figure 2), the accuracy of the elaborated test was calculated being the area under the curve (AUC): AUC > 0.9, which established its high accuracy [8]. At the best balance between sensitivity and specificity, the computed optimal p-cutoff was 18.05 with a sensitivity and a specificity at 91.37 and 87.20 percent respectively.

4. Discussion

There have been very few studies comparing airflow and RIP-derived signal under physiological conditions. The RIP-derived signal has been validated as providing an estimation of airflow acquired by pneumotachogram under physiological conditions and with varying postures [7].

We modified the water TMS from the water swallowing test [5] which serves as a method of evaluating the swallowing ability of patients. We also varied the type of swallowed food, as swallowing disorders may vary according to the ingested food texture. Indeed, the combination of water and food swallowing tests provided an enhancement in sensitivity for detecting swallowing dysfunctions.
We compared static and dynamic (movement of the arm) food intake, to ascertain if movement would perturb the RIP signal. We observed that the automated detection of swallowing was not impaired by change of food texture or movements of arms.

The present study was performed on only 14 patients. In order to obtain reliable data, the active participation of the patient is required. In addition, the patient should be capable of performing simple tasks. Although the AS analysis was possible with arm movements, it is difficult to carry out the protocol on restless patients.

Being solicited to take water or food could possibly induce stress in the patient, which might then affect respiratory events preceding swallowing, but not larynx closure during the swallowing. It was for this reason that zero airflow detection was used. This protocol differs from one where random swallowing is provocated [9].

The interplay of swallowing and breathing has been studied using other - and for these frailer patients - often unpleasant – methods (an electrode attached to the cheek, a throat microphone, a soft polythene tube inserted into a nostril, sub mental electromyography or a mouthpiece [9,10]). On the other hand the recording procedure used in this study was well accepted by the elderly, since the device consisted of a jacket worn over their usual clothing and the recordings were performed in their usual mealtime environment. Furthermore, the user-friendly nature of this equipment makes this method an appropriate bedside clinical tool. We have no knowledge of the existence of any study of a similar nature.

The detection of swallowing by means of automated recordings and analysis thanks to the computer was an essential prerequisite of an objective analysis. The use of the AS, time-derivative of the volume signal, providing zero airflow detection, made this automation possible.

Although the reliability of the automated detection appears to be sufficiently high in this study, as evidenced by the high sensitivity and specificity at the optimal p-cutoff computed, automated AS analysis may be refined by a more precise characterization of the events to be detected.

Because apnoeas are not specific to swallowing, the specificity of the detection will be reduced in a different experimental clinical context. Nevertheless, we prefer to attach greater importance to the sensitivity of the automated detection because of the serious, even fatal, consequences of dysphagia in the elderly.

We would tend to think that measurement of airflow could provide a valid method of detecting dysphagia. We suspect that when aspiration occurs, the recorded airflow will differ from that during a normal respiratory cycle, through being disrupted by the ingested material in the airway. Furthermore, we also suspect that the post-aspiration airflow will differ in a characteristic way (for example, post swallowing coughing) and that it will be possible, thanks to an automated signal analysis by the computer, to detect this difference among other physiological respiratory cycles.

However, as swallowing is only inferred from the respiratory recordings and not directly observed, it is essential for any detected dysphagia to be confirmed by means of a gold standard such as videofluorography.

We also intend to establish one-to-one relationships between the clinical events and the patterns of these events depicted on the AS. This opens up the possibility of monitoring swallowing by recording the airflow with the RIP and, using the recordings, to reveal certain swallowing disorders, as, for example, by identifying coughing during a meal. Such a tool would be very useful in enabling medical supervision [11] of swallowing to be put in place for acutely affected patients (e.g. recent cerebral stroke patients) or those with chronic diseases (e.g. Parkinson's disease) and also for monitoring the effectiveness of swallowing disorders therapy.
5. Conclusion

This study shows that the combined system developed enables swallowing to be detected in a non-invasive, convenient, bedside, automatic and objective way with high accuracy. To our knowledge, no other protocol exists offering such an approach to the detection. According to these results, this combined system will enable to study and monitor swallowing in order to detect certain swallowing disorders and so to prevent the frail elderly from their deleterious effects.

6. References


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Section 2: Computerized Patient Record