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Normal contractile algorithm of swallowing related muscles revealed by needle EMG and its comparison to videofluoroscopic swallowing study and high resolution manometry studies: A preliminary study

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The purpose of this study was to investigate the function and importance of infrahyoid muscles with the suprahyoid muscles during swallowing, and to investigate swallowing sequences using kinematic analysis, high-resolution manometry (HRM) and electromyography (EMG). As a preliminary study, ten healthy subjects were prospectively enrolled. A needle EMG evaluated the onset latency, peak latency and duration of the suprahyoid and infrahyoid muscles. HRM measured the time intervals among the velopharynx, tongue base, and upper esophageal sphincter. We also evaluated hyoid motion using an automated kinematic analysis software® (AKAS). All of these parameters were synchronized with a tilting motion of the epiglottis. In the EMG analysis, the activations of the suprahyoid muscles developed about 300 ms earlier than that of the infrahyoid muscles. There was a significant relationship between the differences of suprahyoid and infrahyoid muscles' latency and total duration of the hyoid motion ($p < 0.05$). The interval time of anterior hyoid motion has a significant correlation in the upper esophageal sphincter (UES) opening time. In conclusions, the functions of the infrahyoid muscles are also as important as that of the suprahyoid muscles for prolonged laryngeal elevation and UES opening. Moreover, kinematic analysis of videofluoroscopic swallowing study (VFSS) and HRM studies could reflect results of needle EMG study and replace EMG study.

1. Introduction

Swallowing is a complex sensorimotor behavior involving the coordinated contraction and inhibition of the musculature located around the mouth and at the tongue, larynx, pharynx, and esophagus by different levels of the central nervous system from the cerebral cortex to the medulla oblongata (Ertekin and Aydogdu, 2003). Currently, several clinical tools, such as videofluoroscopic, endoscopic, manometric, and electromyographic (EMG) studies, have been used in a clinical assessment of dysphagia (Choi et al., 2011; Ertekin and Aydogdu, 2003; Ertekin et al., 2001; Park et al., 2016).

Needle EMG studies are one of the best evaluation tool to observe the temporal pattern of sequential activation of individual muscles related to swallowing, especially between the suprahyoid and infrahyoid muscles (Ertekin and Aydogdu, 2003; Inokuchi et al., 2014). A considerable number of studies regarding the activation pattern of diverse swallowing muscles have been performed to understand the complex physiology of deglutition and pathophysiology of swallowing problem (Ertekin and Aydogdu, 2003; Inokuchi et al., 2014). To achieve clinical significance, however, this muscular activation sequence needs to be compared with the function of swallowing muscles, such as movement of hyolaryngeal structures or pharyngeal muscular pressure generation. Nowadays,

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we can apply videofluoroscopic swallowing study (VFSS) and high resolution manometry (HRM) for these evaluations.

VFSS is considered as the primary evaluation tool, and a kinematic analysis of VFSS can provide detailed movement of the anatomical structures and bolus, revealing subtle abnormalities of swallowing (Kendall et al., 2000; Lan et al., 2015; Lee et al., 2013). However, manual extraction processes of kinematic analysis require expert skills as well as a lot of time and labor. Moreover, the accuracy of diagnosis can vary in accordance with the degree of skillfulness of the examiner; there is a great potential for inter-examiner and intra-examiner variability. Therefore, an automatic analysis software could be helpful to improve accuracy and promptness of kinematic analysis. To overcome these limitations, we developed an automated kinematic analysis program (AKAP) that analyzes the trajectory of the hyoid bone via a visual tracking method, and applied this program to analyze the normal swallowing process (Lee et al., 2017).

Recently, HRM has been used to provide information regarding pressure generation from the velopharynx to the upper esophageal sphincter (UES) and timing variables, which could not be measured by VFSS (Mielens et al., 2012). In contrast to the conventional manometry, HRM has pressure sensors at 1–2 cm intervals and uses a solid catheter, which has improved sensitivity, reliability, and accuracy (Mielens et al., 2012; Ryu et al., 2015; Schultz et al., 1994).

. Although VFSS and HRM studies do not directly measure the temporal pattern of sequential activation of individual muscles related to swallowing, VFSS and HRM studies could also measure the timing variables of the hyolaryngeal structures and pressure generations (McCulloch et al., 2010; Park 2017; Ryu et al., 2016, 2015). Therefore VFSS and HRM could be used in clinical practice to reflect the overall features of swallowing. To the best of our knowledge, there has been no study to investigate the activation sequence of swallowing related muscles using the EMG, VFSS and HRM. Therefore, the first purpose of this study was to find out the activation sequence of suprahyoid and infrahyoid muscles using needle EMG, and to investigate their clinical significance compared to hyolaryngeal movement and pharyngeal pressure generation. The second purpose is to find out the correlation among needle EMG, kinematic analysis and pressure analysis compared to the chronological sequence of normal swallowing.

2. Materials and methods

2.1. Participants

Ten subjects initially participated in this study with the approval of the Institutional Review Board (BD2013-075). As a preliminary study, all subjects were healthy without swallowing, neurological, or gastrointestinal disorders. The average age of these 10 subjects is 29.2 ± 7.2 years. Seven were male and 3 were female.

2.2. Needle EMG study

The multi-channel needle EMG was recorded simultaneously with VFSS using an EMG device and software (Medelec Synergy; CareFusion Corporation, San Diego, CA) for synchronization. A needle EMG study was performed for two suprahyoid muscles (mylohyoid m. and anterior belly of digastric m.) and three infrahyoid muscles (thyrohyoid, sternohyoid and sternothyroid m). During the study period, active needle electrodes (28 gauge and 25 mm monopolar needle electrode, Chalgren™ Enterprises, Inc., USA) were inserted into the evaluated muscles, and the reference surface electrodes were attached to the subjects' anterior surface of the mandible and clavicle. For precise needle placement, the needle electrodes were inserted with an ultrasound guidance, and paper plaster was used to fix the electrodes. All participants rested for 5–10 min to adjust the needle and swallowed for two times. Subjects swallowed 5 mL of thin-liquid to minimize the confounding effect of volume and viscosity, and the activation of muscles were recorded with a needle EMG study. The average value of needle EMG test in two swallowing tests was used in the analysis. High and low frequency filters were set at 500 Hz and 30 Hz, respectively. The sweep speed and gain were 1 s/div and 100 μV/div, respectively (Inokuchi et al., 2014).

2.3. Kinematic analysis of laryngeal structure

We measured various time intervals during VFSS, as recorded by a camcorder (Samsung SMX-C14®) running at 30 frames per second, including that of the epiglottis contact with the bolus, laryngeal elevation, pharyngeal constriction, and UES opening, by using a multimedia player (Gomplayer; Gretech®). We used a coin as a defined dimension to determine distance (Choi et al., 2011; Lee et al., 2013; van der Maarel-Wierink et al., 2011).

The onset latency of laryngeal elevation was defined as the time from the initiation of the pharyngeal phase to the initiation of laryngeal elevation (Choi et al., 2011). The peak laryngeal elevation was defined by measuring the point of maximal anterior and superior excursions of the larynx during a swallow Choi et al., 2011; Leonard et al., 2000). The onset latency of pharyngeal constriction is defined as the time from the initiation of the pharyngeal phase to the initiation of constriction of the pharyngeal wall and soft palate (Choi et al., 2011). As the bolus is propelled into the upper esophagus, the pharynx is typically completely obliterated by the tongue, which pushes against the contracting posterior pharyngeal wall (Choi et al., 2011). The peak pharyngeal constriction is the narrowest anterior-posterior diameter, as measured in a lateral view (Choi et al., 2011; Kendall and Leonard, 2001). The upper esophageal sphincter (UES) opening was identified as the moment at which the narrowest part of the upper esophagus between C4 and C6 opened, because this opening is functionally the most significant (Choi et al., 2011; Kendall et al., 2000). The duration of UES opening is defined as the interval between the opening and closing of UES opening (Choi et al., 2011; Kendall et al., 2000).

To analyze the motion of the hyoid bone, an automated kinematic analysis program (AKAP) developed by our group was used (Software Registration Number: C-2015-019815) (Lee et al., 2017). By using the MATLAB® program, VFSS images were divided as each frame in the program, and then one of the authors marked a point on the anterior border of the hyoid bone, antero-inferior edge of the C3 vertebral body, and C4 antero-superior edge of the C4 vertebral body of first frame. Then, the MATLAB® program automatically analyzed the position of the hyoid bone based on C3 and C4 vertebral bodies of all remaining frames (Fig. 1A).

By using the analytic technique of AKAP, we analyzed the timing parameters of the hyoid bone's trajectory (Fig. 1B). In kinematic studies about the trajectory of the hyoid bone in normal subjects, the hyoid bone initially moves anteriorly and superiorly, then moves inferiorly and posteriorly (Chi-Fishman and Sonies, 2002). The A point was defined as the initial position of the hyoid bone. The hyoid bone arrives at the maximal superior position, which was defined as point B. Then, the hyoid bone moves anteriorly when it arrives at the maximal anterior position, which was defined as point C. Last, the hyoid bone arrives at the maximal inferior position, which was defined as point D (Fig. 1B). We measured the timing parameters of onset of each point from A-D. In addition, we measured the time where the distance was 2 mm or less from point C (duration of C state). We synchronized these timing parameters with other studies based on epiglottis tiling of VFSS images.