Cervical spine motion during swallowing

Kojiro Mekata · Tomoyuki Takigawa · Jun Matsubayashi ·
Yasuhiro Hasegawa · Yasuo Ito

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Abstract

Purpose There have been several studies regarding the relationship between deglutition and the cervical spine; however, the movement of the cervical spine during deglutition has not been specifically studied. The purpose of the present study was to clarify how the cervical spine moves during normal deglutition.

Methods We conducted videofluorography in 39 healthy individuals (23 men; 16 women; mean age, 34.3 years) with no evidence of cervical spine disease and analyzed images of the oral and pharyngeal phases of swallowing using an image analysis technique. Analyzed sections included the occiput (C0) and the first to seventh cervical vertebrae (C1–C7). The degrees of change in angle and position were quantified in the oral and pharyngeal phases.

Results In the pharyngeal phase, C1, C2, and C3 were flexed (the angle change in C2 was the most significant with a mean flexion angle of 1.42°), while C5 and C6 were extended (the angle change in C5 was the most significant with a mean extension angle of 0.74°) in reference to the oral phase. Angle changes in C0, C4, and C7 were not statistically significant. C3, C4, C5, and C6 moved posteriorly (the movement in C4 was the most significant, mean = 1.04 mm). C1, C2, and C3 moved superiorly (the movement in C2 was the largest, mean = 0.55 mm), and C5 and C6 moved inferiorly. Movements in C0 and C7 were not statistically significant.

Conclusions These findings suggest that the cervical spine moves to reduce physiological lordosis during deglutition.

Keywords Cervical spine · Deglutition · Swallowing · Dysphagia · Videofluorographic study · Manuscript text

K. Mekata
Department of Rehabilitation, Kobe Red Cross Hospital,
1-3-1 Wakinohamakaigandori, Chuo-ku, Kobe City,
Hyogo 651-0073, Japan

T. Takigawa · Y. Hasegawa · Y. Ito (✉)
Department of Orthopaedic Surgery, Kobe Red Cross Hospital,
1-3-1 Wakinohamakaigandori, Chuo-ku, Kobe City,
Hyogo 651-0073, Japan
e-mail: y-ito@kobe.jrc.or.jp

T. Takigawa
Department of Orthopaedic Surgery, Okayama University
Hospital, 2-5-1 Shikata-cho, Kita-ku, Okayama City,
Okayama 700-8558, Japan

J. Matsubayashi
Laboratory of Neurorehabilitation, Department of Human Health
Sciences, Graduate School of Medicine, Kyoto University,
53 Shogoin Kawara-cho, Sakyo-ku, Kyoto City,
Kyoto 606-8507, Japan

Introduction

There are many patients with dysphagia in all age groups ranging from the newborn to the elderly [1, 2]. Sequelae of dysphagia, such as undernutrition, dehydration, and pneumonia, can result in prolonged hospitalization or treatment [3, 4]. Disadvantages of dysphagia affect patients and society through the escalation of medical costs; therefore, it is important to clarify the causes of dysphagia and to establish its treatment methods. To this end, a broad array of studies on deglutition and dysphagia have been conducted, including anatomical and physiological studies of deglutition, clarification of causes of dysphagia, and the treatment and rehabilitation of patients with dysphagia [5].

Several studies have examined the relationship between deglutition and the cervical spine in several contexts including dysphagia in patients with cervical spine lesions [6–8], postoperative dysphagia after cervical spinal surgery [9, 10], and cervical spinal positioning during deglutition [11]. Major risk factors of postoperative dysphagia include a decrease of C0–C2 angle with reduction of the pharyngeal space [12, 13] and intraoperative retraction of esophagus with decrease of mucosal perfusion [14]. Interestingly, cervical total disc replacement surgery has a low incidence of dysphagia compared with anterior discectomy and fusion surgery [15, 16]. Although dysphagia is a multifactorial problem, literature analysis of dysphagia after cervical spine surgery suggests that a decrease of cervical spine motion itself can be a risk factor of dysphagia. However, specific cervical spine movements during deglutition have not been evaluated. To fully understand dysphagia, specific measurements of cervical spine movements need to be quantified during normal deglutition.

We hypothesized that cervical spine moves during swallowing and its motion is too small to be precisely measured by existing techniques. To overcome this technical limitation, we utilized an image analysis technique to determine angular and positional changes in the cervical spine. The purpose of this study was to clarify how the cervical spine moves during normal deglutition.

Methods

Subjects

Subjects included 39 healthy individuals [23 men, 16 women, 34.3 ± 8.2 years (mean $\pm$ SD)] with no history of cervical diseases. Written informed consent including a risk of radiation was obtained from all participants prior to initiation of the study. Participants could leave the study at any time by their own free will. The study was approved by the institutional ethical committee.

Videofluorography

Videofluorography was conducted by referencing the Manual for the Videofluorographic Study of Swallowing [17]. X-ray images were captured laterally with CUREVISTA software (Hitachi Medical Corporation, Tokyo, Japan) and recorded with DMCAT-2000HL (Panasonic, Osaka, Japan) at 30 frames per second. Subjects sat in a chair so that both the truncal tilt angle and cervical spine were 90° with respect to the ground. Subjects' heads were not stabilized but their motions were monitored. Oral contrast agents were ingested, consisting of 10 ml of 40 % barium sulfate diluted in water. A 1 cm reference marker was placed when capturing images.

An estimate of the total radiation dosage per videofluorographic examination was about 0.5 mGy.

Image analysis

Thirty still images per second were extracted from video images of deglutition and saved in a bitmap format. The oral phase was defined when the subject takes and holds barium sulfate in the mouth. The pharyngeal phase was defined when the hyoid bone elevates and takes the highest position. Because the subject was asked to hold barium sulfate in the mouth before swallowing, the oral phase was a stable and static phase. On the other hand, the pharyngeal phase was a dynamic phase. The hyoid bone height was directly compared among consecutive frames, which enabled consistent extraction of the pharyngeal phase frame. The phase extraction was performed using Windows Media Player (Microsoft Corp, WA). Extracted still images were analyzed by an ImageJ image analysis software (National Institute of Health, MD) [18].

When setting a reference point, calculating the center of gravity of an arbitrary closed area extracted from each image is approximately 10 times more accurate than visually obtaining the coordinates of a distinctive object such as an apical end [19–21]. In the present study, the coordinates of the center of gravity of the vertebral body and those of the spinous process were used as reference points, which increased the measurement precision to a sub-pixel level.

The borders of the vertebral body and spinous process were specified by adjusting the contrast and brightness of an extracted still image from a section of the cervical spine to be analyzed and magnified by 800 %. In the next step, a closed area was defined by manually drawing a line along the border of the vertebral body, and the coordinate of the center of gravity of this closed area was automatically determined by the ImageJ software (Fig. 1a, b). The same procedure was repeated to determine the coordinates of the center of gravity for each spinous process. An angle between a straight line that passed through these two points (the center of gravity of the vertebral body and that of the spinous process) and a horizontal line in the image was defined as an angle of the target cervical spine (Fig. 1c). In addition, the midpoint coordinates between these two centers of gravity were determined as the target position in the cervical spine (Fig. 1d). This was repeated for each level of the cervical spine three times, and the average values of these three measurements were used in the following analysis. When any borders of C0 or C7 was not identified, two visually identifiable closed areas were defined by manually drawing lines, and these two coordinates of the center of gravity were set as the reference coordinates.

The aforementioned procedure was performed on both oral and pharyngeal phase images, and changes in the angle

Fig. 1 **a** Lateral radiogram of the cervical spine. **b** Reference points in the vertebral body and spinous process. The *white square* in **a** is clarified by magnifying by 800 % and changing the *contrast* and *brightness*. The *lines* are the margins of the vertebral body and spinous process. The two *white dots* are the center of gravity of the vertebral body and spinous process. **c** Angle α . The *white dotted line* connects the two *white points* in **b**. The *white solid line* is a *horizontal line*. The angle α is defined by these two *lines*. **d** Reference point of the position. The midpoint of the *line* connecting the center of gravity of the vertebral body and spinous process is shown as a *white dot* and *white arrow*. The anterior-posterior coordinate is *x*, and the superior-inferior coordinate is *y*

and position of each vertebra, C0 through C7, were determined in the pharyngeal phase with respect to the oral phase.

Repeatability analysis

Interclass correlation coefficient (ICC) was calculated as an intra-observer repeatability analysis for our three times repetitive measurement method. ICC was measured at both *x* and *y* coordinates, at both vertebral body and spinous process, at each level (C0–7), and in both oral and pharyngeal phases, resulting in a total of 64 items.

Statistical analysis

A one-sample *t* test was used to perform a statistical analysis assuming the null hypothesis, “The change in the angle of each cervical vertebra is zero”, or “The movement of each cervical vertebra is zero”. The significance level was set to 5 % ($p < 0.05$).

Results

C7 was not visible in 4 subjects. Therefore, C0–C6 data were analyzed in 39 subjects and C7 data were analyzed in

35 subjects. Each ICC for 64 coordinates was >0.99 meaning almost perfect.

Angle change

Results of average angular changes of the cervical spine in the pharyngeal phase with respect to the oral phase are shown in Fig. 2 and Table 1. C1, C2, and C3 were flexed by 0.98° ($p = 0.002$), 1.42° ($p = 0.0001$), and 0.85° ($p = 0.003$), respectively. C5 and C6 were extended by 0.74° ($p = 0.002$) and 0.71° ($p = 0.0007$), respectively. C0, C4, and C7 were extended by 0.22° ($p = 0.452$), 0.28° ($p = 0.088$), and 0.03° ($p = 0.921$), respectively; however, they were not statistically significant. Average total lordosis angle ranging from C0 to C6 was 25.12 degrees in the oral phase and 23.89 in the pharyngeal phase, resulting in a decrease of cervical lordosis by 1.23° .

Movement

Results of the average movement of the cervical spine in the pharyngeal phase with respect to the oral phase are summarized in Fig. 3 and Table 1. C3, C4, C5, and C6 moved posteriorly by 0.85 mm ($p = 0.002$), 1.04 mm ($p = 0.0001$), 0.84 mm ($p = 0.001$), and 0.55 mm ($p = 0.007$), respectively. C1, C2, and C3 moved

Fig. 2 Changes in the angle of the cervical spine. C1, C2, and C3 are flexed. C5 and C6 are extended. C0, C4, and C7 show little change. Bar mean $\pm$ SEM, * $p < 0.05$, ** $p < 0.01$

Table 1 α change, movement x, movement y

	α change (°)	Movement x (mm)	Movement y (mm)
C0	0.22 $\pm$ 0.29	-0.42 $\pm$ 1.00	0.15 $\pm$ 0.30
C1	-0.98 $\pm$ 0.29**	-0.35 $\pm$ 0.80	0.30 $\pm$ 0.21**
C2	-1.42 $\pm$ 0.33**	0.32 $\pm$ 0.57	0.55 $\pm$ 0.29**
C3	-0.85 $\pm$ 0.27**	0.85 $\pm$ 0.51**	0.31 $\pm$ 0.20**
C4	0.28 $\pm$ 0.16	1.04 $\pm$ 0.49**	0.08 $\pm$ 0.14
C5	0.74 $\pm$ 0.22**	0.84 $\pm$ 0.47**	-0.15 $\pm$ 0.10**
C6	0.71 $\pm$ 0.19**	0.55 $\pm$ 0.41**	-0.19 $\pm$ 0.13*
C7	0.03 $\pm$ 0.29	0.25 $\pm$ 0.44	-0.03 $\pm$ 0.13

Positive values represent extension, posterior movement, and superior movement in α change, movement x, and movement y, respectively. Value: mean $\pm$ SEM, * $p < 0.05$, ** $p < 0.01$

superiorly by 0.31 mm ($p = 0.005$), 0.55 mm ($p = 0.0005$), and 0.31 mm ($p = 0.004$), respectively. C5 and C6 moved inferiorly by 0.15 mm ($p = 0.005$) and 0.19 mm ($p = 0.033$), respectively. C0 moved anteriorly by 0.42 mm ($p = 0.406$) and superiorly by 0.15 mm ($p = 0.328$), and C7 moved posteriorly by 0.25 mm ($p = 0.261$) and inferiorly by 0.03 mm ($p = 0.699$); however, none were statistically significant.

Discussion

Figure 4 depicts the schema of movement of the cervical spine during deglutition. In the pharyngeal phase, C1–C3 were flexed and C5–C6 were extended, which resulted in decrease of C0–C6 cervical lordosis angle. C3–C6 moved posteriorly, C1–C3 moved superiorly, and C5 and C6

moved inferiorly. These findings revealed that the cervical spine moves to reduce physiological lordosis during deglutition. Because the magnitude of subaxial posteroanterior translation per degree of rotation is less than 0.01 mm in flexion–extension motion [22], the posterior displacement of the mid-cervical spine in our study might depend on angular mobility of the upper cervical segments.

It is not clear why the physiological lordosis of the cervical spine reduces during deglutition. Muscular movements directly related to deglutition have been extensively studied [5]. However, there have been no studies regarding the relationship between these muscles and muscles related to cervical spine movements during deglutition [23]. We speculate that the relationship between muscles directly related to deglutition and muscles related to the movements of C0 and the cervical spine is similar to those between dynamic and static muscles. Muscles related to C0 and the cervical spine can work to stabilize these bones so as to smoothly execute dynamic movements required in deglutition, causing a decrease in physiological lordosis of the cervical spine.

Cervical spine antelexion [24] and chin down posture [25] are known as postures facilitating swallowing. These postures not only expand the pharyngeal cavity but also reduce the physiological lordosis of the cervical spine. It is, therefore, thought that cervical spine antelexion and chin down postures are preferable for deglutition in terms of the joint movement of C0 and the alignment of the cervical spine.

Dysphagia is a multifactorial pathology. Cervical osteophytes >10 mm have been reported to cause dysphagia by impinging on the pharynx or upper esophagus [26]. Patient age has been recognized as a risk of dysphagia due to anatomic and physiologic changes associated with aging [27]. Based on our results, decrease of cervical motion in elderly population may have negative influence on swallowing. Regarding the spinal surgical intervention, occipitocervical fusion surgery and anterior cervical discectomy and fusion surgery are well recognized risks for postoperative dysphagia. It has been reported that decrease of C0–C2 angle induces reduction of the pharyngeal space [12] and can be a predictor of postoperative dysphagia [13]. The largest angular motion during swallowing was detected at C2 followed by C1 in our study, which shows the importance of the mobility of these levels during swallowing. On the other hand, dysphagia after posterior subaxial cervical fusion has been also reported [28]. Results of the present study describe movement of the entire cervical spine during normal deglutition. This suggests that normal deglutition would be disturbed when the cervical spinal movements are restricted. Actually, cervical total disc replacement surgery that preserves cervical spinal motion has been reported to have lower incidence of dysphagia

Fig. 3 **a** Changes in the position of the cervical spine (antero-posterior direction). C3, C4, C5, and C6 move posteriorly. C0, C1, C2, and C7 show little change in position. **b** Changes in the position of the cervical spine (*vertical direction*). C1, C2, and C3 move superiorly. C5 and C6 move inferiorly. Movements of C0, C4, and C7 are slight. Bar mean $\pm$ SEM, * $p < 0.05$, ** $p < 0.01$

Fig. 4 Schema showing movements of the cervical spine during swallowing. The *gray* schema shows the oral phase, and the *black* schema shows the pharyngeal phase. Physiologic lordosis decreases in the pharyngeal phase

compared with anterior cervical fusion surgery that stabilizes cervical spinal segments [15, 16]. Our data are helpful for understanding one aspect of complex mechanism of dysphagia.

To the best of our knowledge, this paper is the first study showing the cervical spine motion during deglutition quantitatively. However, there are some limitations to this

study. The aim of this study was to analyze the movement of the cervical spine during normal deglutition. Therefore, subjects were relatively young, excluding data representing the elderly population. More research is needed in the future to compare the revealed findings of the present study on different age groups and ultimately correlate with outcome data. Evaluation of the deglutition of a liquid contrast agent was conducted in the sitting position to analyze movements during normal deglutition; however, evaluation in the decubitus position or using thickened food was not performed. In this study, only a comparison between the oral and pharyngeal phases was performed to evaluate the particular movements of the cervical spine during deglutition.

In conclusion, the present study revealed that the cervical spine moves to reduce physiological lordosis during deglutition. Further studies are needed to clarify its functional significance.

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Conflict of interest None.

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