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Original Article

Effects of simulated kyphosis posture on swallowing and respiratory functions

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Abstract. [Purpose] To evaluate the effects of kyphosis on swallowing and respiratory functions. [Participants and Methods] In 94 healthy adult volunteers, the respiratory (vital capacity, percentage of vital capacity, and cough peak flow and swallowing (hyoid amplitude and tongue pressure) functions, were evaluated under the following conditions: vertical, moderate kyphosis, and severe kyphosis postures defined by the round-back index. [Results] The mean vital capacity and percentage of vital capacity were significantly lower in severe kyphosis than in the vertical posture. The suprahyoid muscle amplitudes, tongue pressure, and cough peak flow was significantly lower in severe kyphosis than in moderate kyphosis or the vertical positions. [Conclusion] The swallowing and breathing functions were significantly lower in volunteers with severe kyphosis than in those with moderate kyphosis or the vertical positions. Although strengthening of the suprahyoid muscles is a typical example of rehabilitation for dysphagia, but it may also be necessary to consider postural adjustment for patients with kyphosis. A comprehensive evaluation of swallowing function that takes both posture and respiratory function into consideration is necessary.
Key words: Kyphosis, Swallowing function, Respiratory function

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INTRODUCTION

Aspiration pneumonia accounts for more than half of all elderly patients (aged 60 and older) admitted to hospitals with pneumonia[1)]. Although swallowing function is directly affected by aspiration pneumonia, attention should be paid to the individual characteristics of the elderly patient. The kyphosis posture is a common postural change associated with aging, but studies examining the relationship between this structural change and swallowing function have received little attention. Although swallowing function in response to postural changes has been studied[2)], comprehensive studies examining respiratory and swallowing functions have not been conducted. Studies on respiratory function have shown that unlike the muscles of the extremities, trunk muscles (e.g., intercostal muscles) and diaphragm atrophy of both white and red muscles as a function of age[3)]. Because the round-back posture is associated with kyphosis, the erector spinae and other antigravity muscles are constantly active, and their functions differ from those of the trunk held vertically. In particular, the visual field necessary for daily living is compensated for by the extension of the cervical spine; the greater the degree of rounding of the spinal column, the greater the extension of the cervical spine. Such postural changes that compensate for kyphosis may also produce structural changes in the swallowing function, including the swallowing muscles of the anterior cervical, pharyngeal,

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and laryngeal surfaces. Since these structures are motor organs necessary for swallowing, we hypothesized that changes in these structures would limit swallowing and breathing movements. This study aimed to quantify kyphotic posture and simultaneously assess respiratory and swallowing functions under various postural conditions to elucidate their relationship with posture. We hypothesized that a kyphosis posture increases the posterior pelvic tilt and spinal kyphosis, leading to neck position changes and structural changes in the pharynx and larynx, causing functional limitations. The outcomes of this study could mediate the development of a wide range of interventions in addition to the current interventions in swallowing rehabilitation.

PARTICIPANTS AND METHODS

The study protocol and materials were evaluated and approved by the ethics committees of the University of Tokyo Health Sciences (21-8H) and the Tokyo Medical and Dental University (D2021-089). Participants were recruited by posting posters on the university campus to recruit applicants. The study participants were 94 healthy adults (49 males and 45 females) without dorsal column and thorax deformations. The participants' baseline characteristics (mean ± SD and range) were as follows: age, 25.3 ± 4.2 years (range, 20–45); height, 164.4 ± 8.2 cm (range, 143–180); and body weight, 61.2 ± 8.4 kg (42–84). Table 1 shows the participants' baseline characteristics by gender. Before the study commenced, written consent was obtained from the participants.

This study is an analytical observational study measuring factors and outcomes. Based on previous studies[4)], three conditions of pseudo kyphosis were specified: vertical position (round-back index 9.2 ± 2.5), moderate kyphosis (17.9 ± 0.7), and severe kyphosis (20.2 ± 1.3). To maintain the participants' kyphosis posture during the measurement, thoracolumbar spine movement was restricted using an elder experience suit (front bending experience material; Kyoiku Tosho Co., Ltd., Tokyo, Japan) (Fig. 1). Their neck position under each condition was perpendicular to the ground.

In the measurement of the round-back index, the curvature of the back from the seventh cervical spinous process (hereafter "C7") to the fourth lumbar vertebra (hereafter "L4") was measured using a flexible curve ruler. The sitting posture and the shape of the kyphosis posture of the Participants were captured with a digital camera. The images were captured on a personal computer (hereafter "PC") and measured on the PC screen using image analysis software (Scion Image; Scion Corporation, Frederick, MD, USA). The straight-line distance between C7 and L4 was denoted as L and that from the center of L to the apex of the kyphosis was denoted as H. The round-back index was calculated using the formula (H/L × 100), described by Milne et al[5)].

Table 1. Patients' baseline characteristics

Item	Male (n=49)	Female (n=45)	p-value*
Age (years)	23.5 ± 4.2 (19–36)	24.7 ± 5.8 (19–42)	
Height (cm)	173.7 ± 4.6 (164–181)	155.6 ± 3.6 (149–168)	<0.02

Mean ± standard deviation (range), *t-test.

Fig. 1. Simulating degrees of kyphosis using the front bending experience material (Kyoiku Tosho Co., Ltd., Tokyo, Japan).

The measurements included the mean amplitude of the suprahyoid muscles (root mean square, RMS) and maximum tongue pressure using surface electromyographic analysis as swallowing function, and they included pulmonary capacity (vital capacity, VC), %VC, and maximal coughing force (cough peak flow, CPF) as respiratory function.

Suprahyoid muscle amplitudes were measured using the Myo Motion^{TM} (Noraxon USA, Inc.; Scottsdale, AZ, USA) with a sampling frequency of 1 kHz. An electrode (Blue Sensor M, Metz Inc., Tokyo, Japan) was applied to the suprahyoid muscle following adequate skin treatment (skin impedance of 5 kilo-ohms or less). The electrode application site was based on previous studies[6]. Potential changes in the geniohyoid muscle while swallowing 3 mL of cold water was measured according to the modified water swallowing test (MWST) method[7]. The obtained signals were AD-converted and imported into a PC and analyzed with a data processing device (myoMuscle Master^{TM}, Noraxon Inc.).

For tongue pressure measurements, participants were instructed to rest in an end-sitting position. A probe—JMS tongue pressure measuring device (TPM-02, JMS Corp., Hiroshima, Japan)—was inserted into the oral cavity. The balloon attached to the probe's tip was placed between the tongue and palate, and the participants was instructed to raise the tongue and press it down for 5 seconds. Since the task was fatiguing, measurements were taken three times with a one-minute rest in between, and the average value was used as the representative value[8].

Respiratory function was measured using a spirometer (HI-801 multifunction spirometer, Chest Inc., Tokyo, Japan). VC and %VC were measured three times with the nostrils closed with a nose clip and a mouthpiece attached, and the mean of each was used as the representative value. CPF was measured by connecting a face mask to a filter attached to the spirometer. The Participants was instructed to hold the face mask with both hands and cough with maximum force following maximum inhalation with the face mask held tightly to the mouth.

The data were analyzed by one-way analysis of variance (ANOVA). When the main effects of these three conditions were significant, a multiple comparison test (Bonferroni method) was then performed. All statistical analyses were performed with SPSS statistical software (version 24: SPSS Inc., Chicago, IL, USA) at α=0.05.

RESULTS

Summary statistics (mean ± SD) of swallowing and respiratory function data of the three conditions are shown in Table 2. A significant main effect ($p<0.05$) was observed in the amplitude of the suprahyoid muscles, with mean ± SD of 0.44 ± 0.09 µV, 0.38 ± 0.08 µV, and 0.21 ± 0.07 µV for vertical position, moderate kyphosis, and severe kyphosis, respectively. The results of multiple comparison test revealed that the mean amplitude in severe kyphosis posture was significantly lower than that of vertical or moderate kyphosis. The mean values of tongue pressure were 43.3 ± 6.4 kPa, 41.1 ± 6.7 kPa, and 35.5 ± 6.9 kPa for vertical position, moderate kyphosis posture, and severe kyphosis posture, respectively, showing a significant difference ($p<0.05$). Results of multiple comparison test indicated that tongue pressure in the severe kyphosis posture was significantly lower than in the vertical or moderate kyphosis posture. The mean values of VC were 3.6 ± 0.7 L, 3.3 ± 0.8 L, and 2.7 ± 0.8 L for vertical position, moderate kyphosis posture, and severe kyphosis posture, respectively ($p<0.05$). Multiple comparison test showed that VC in the severe kyphosis posture was significantly lower than that in the vertical position. The mean values of %VC were 95.5 ± 13.5%, 89.4 ± 11.9%, and 79.3 ± 12.7% for vertical position, moderate kyphosis posture, and severe kyphosis posture, respectively ($p<0.05$). Multiple comparison test demonstrated significantly lower %VC in the severe kyphosis posture than in the vertical position. The mean values of CPF were 358.4 ± 42.1 L/min, 291.1 ± 34.7 L/min, and 260.5 ± 38.5 L/min for vertical, moderate, and severe kyphosis postures, respectively ($p<0.05$). Results of multiple comparison test revealed significantly lower CPF in the severe kyphosis posture than that in the vertical or moderate kyphosis posture.

DISCUSSION

These results demonstrated that severe kyphosis posture resulted in limited swallowing and respiratory functions compared to vertical and moderate kyphosis. The swallowing function was significantly different in participants with moderate

Table 2. Results of one-way analysis of variance (ANOVA) on main outcomes (n=94)

Outcome	A: Vertical position	B: Moderate kyphosis	C: Severe kyphosis	F value	p-value	Multiple comparison
Amplitude (µV)	0.44 ± 0.09	0.38 ± 0.08	0.21 ± 0.07	5.90	<0.05	A>B>C
Tongue pressure (kPa)	43.3 ± 6.4	41.1 ± 6.7	35.5 ± 6.9	4.88	<0.05	A>B>C
VC (L)	3.6 ± 0.7	3.3 ± 0.8	2.7 ± 0.8	2.27	<0.05	A>B, C
%VC (%)	95.5 ± 13.5	89.4 ± 11.9	79.3 ± 12.7	1.95	<0.05	A>B, C
CPF (L/min)	358.4 ± 42.1	291.1 ± 34.7	260.5 ± 38.5	5.16	<0.05	A>B>C

Mean ± Standard Deviation, Multiple comparison=Bonferroni method. VC: vital capacity; CPF: cough peak flow.

and severe kyphosis postures compared to those with vertical positions. Additionally, the respiratory function of those with severe kyphosis was significantly different, supporting this hypothesis.

Swallowing functions are normally controlled by the cooperative actions of the suprahyoid and infrahyoid muscles via the hyoid bone. The suprasellar muscle connects the mandible to the hyoid bone and is important for lifting the larynx during swallowing[9]. On the other hand, the infrahyoid muscle connects the sternal scape to the hyoid bone and presses down on it. These two muscles connect the sternum to the mandible; thus, if the kyphosis condition worsens, the spine will become more circular as the pelvis tilts backwards, and the rib cage will also be pulled back. Unlike the suprasellar muscle, which lifts the larynx during swallowing, abnormal posture turns into a pulling-down force on the sublingual muscle, hyoid bone, and larynx. This abnormal posture is suspected to be responsible for the reduced amplitude of the suprasellar muscle in moderate and severe kyphosis postures compared to the vertical position. In this study, the neck position was maintained perpendicular to the ground. These conditions reproduce a head-forward posture in which the center of gravity is displaced backwards due to kyphosis, and the neck remains forward[10]. Anterior head posture has been reported to affect the activity of the supraorbital muscles[11]; therefore, it is necessary to consider structural changes in the neck, in addition to the kyphosis condition. Tamai et al.[12] reported that the cross-sectional area and transverse diameter of the geniohyoid muscles decreased with an anterior head posture, and this posture was also associated with an opening force proportional to the action of the suprasellar muscles.

Similar results were obtained for tongue pressure and amplitude. Tongue pressure is related to mastication, swallowing function, and food morphology[13]. In the present study, tongue pressure decreased according to the degree of kyphosis, suggesting that this change may be structural. In moderate and severe kyphosis postures, the hyoid bone can be pulled downward by the sublingual muscles, and the root of the tongue may also be moved posteriorly. This posterior movement reduces the contraction of the posterior pharynx wall and the contact with the root of the tongue, thereby lowering swallowing pressure[14].

Both swallowing functions—the amplitude of the supraspinatus muscle and tongue pressure—were significantly lower in the non-vertical positions. This suggested that the vertical position should be maintained for safer swallowing.

The kyphosis posture not only restricts trunk extension but also restricts the movement of the costovertebral joints, resulting in a reduction in thoracic expansion. Restricted thoracic expansion may result in decreased respiratory function and, in turn, restricted ventilation failure[15]. There is a close relationship between respiratory function and kyphosis, and it has been reported that VC and peak expiratory flow (PEF) are reduced in kyphosis posture[16]. The kyphosis posture changes the structures of the spine and thorax, affecting respiratory function. However, the effects should be classified according to the degree of kyphosis. This study examined respiratory function based on different degrees of kyphosis: vertical posture, moderate, and severe. The results indicated a significant difference between the vertical position and severe kyphosis posture in terms of VC and %VC, and CPF was significantly lower in kyphosis posture than in other conditions.

VC measures the ability of the diaphragm to descend upon maximal contraction, increasing intra-abdominal pressure and maximizing outward expansion of the abdominal wall and lower thorax. It is considered a respiratory function for the following reasons: (i) the rib portion of the diaphragm attached to the seventh to twelfth ribs contracts and lifts the lower ribs upward, and (ii) the lower diameter of the rib cage expands[17]. In severe kyphosis posture, the abdomen probably compresses against the thorax, inhibiting diaphragmatic movement. The kyphosis may also inhibit the diaphragmatic rib portion from elevating the lower ribs, limiting the ability of the diaphragm to expand outward in the abdomen. The VC, measuring the degree of thoracic dilation, showed no difference between the vertical position and the moderate kyphosis posture. This indicated that the range of motion that permits the diaphragm to descend was intact in moderate kyphosis. Maximal coughing force (cough peak flow, CPF) is a measure of the ability of the rectus abdominis muscle to contract and push up the diaphragm by increasing intra-abdominal pressure, facilitating expiration. A strong CPF level requires strength in the rectus abdominis muscles. The circular back of the spine due to kyphosis causes the pelvis to tilt backward and the thorax to be displaced downward, thereby narrowing the range of motion of the rectus abdominis muscle. Based on the muscle length-tension curve, the contractility of the rectus abdominis muscle decreases in the kyphosis posture as muscle length becomes shorter. Therefore, it was inferred that the force to compress the abdomen decreased. Moderate and severe kyphosis exhibited significantly lower CPF than vertical posture, indicating that kyphosis is a major limiting factor for CPF.

As a limitation of the study, the participants of this study were healthy adult volunteers. Participants in the study do not reflect the characteristics of dysphagia, which is common among elderly people. Future studies are required to elucidate the associations between dysphagia and secondary impairments in swallowing and respiratory functions.

The amplitudes of the suprahyoid muscles and tongue pressure were used as indices of the swallowing function. However, these indices are indirect assessments and did not directly reflect the relationship between the kyphotic posture and the position of the hyoid bone or the variation in the area of the pharyngeal cavity. The measurement should be performed using a swallowing endoscope to confirm direct structural changes.

Based on the results of this research, I will present a proposal to reflect this in future rehabilitation. The Shaker method[18] for strengthening the suprahyoid muscles is a typical example of rehabilitation for dysphagia, but it may also be necessary to consider postural adjustment for patients with kyphosis. A comprehensive evaluation of swallowing function that considers both posture and respiratory function is needed.

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Conflict of interest

None.

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