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Original Article

Relationship between the bilateral ratios of the thoracic shape and electromyographic activity of the thoracic and lumbar iliocostalis muscles during thoracic lateral translation

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Abstract. [Purpose] This study aimed to determine the relationship between thoracic lateral deviation, the bilateral ratio of the thoracic shape, and the bilateral ratio of the thoracic and lumbar iliocostalis muscles during resting sitting and thoracic lateral translation. [Participants and Methods] We included 23 healthy adult males in the study. The measurement tasks were resting sitting and thoracic lateral translation relative to the pelvis. The thoracic lateral deviation and bilateral ratio of the upper and lower thoracic shapes were measured using three-dimensional motion capture. The bilateral ratio of the thoracic and lumbar iliocostalis muscles were measured using the surface electromyographic recording. [Results] The bilateral ratio of the lower thoracic shape was significantly positively correlated with the thoracic translation distance and the bilateral ratio of the thoracic and iliocostalis muscles. In addition, the bilateral ratio of the thoracic iliocostalis muscles was significantly negatively correlated with the bilateral ratios of the lower thoracic shape and lumbar iliocostalis muscles. [Conclusion] Our findings showed that the asymmetry of the lower thoracic shape is associated with left lateral deviation of the thorax at rest and thoracic translation distance. In addition, the thoracic and lumbar iliocostalis muscle activity differed between the left and right translations.

Key words: Thoracic shape, Thoracic lateral translation, Iliocostalis muscle

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INTRODUCTION

The thorax plays an important role in respiration[1]. It consists of many ribs, joints, and trunk muscle attachments[2] and contains the upper body's center of mass[3]. Therefore, the rotation of the ribs resulting from the contraction of trunk muscles can efficiently move the upper body's center of mass by changing the thoracic shape. Thus, the thorax is considered playing an important role not only as a respiratory organ but also as a locomotor organ.

There have been recent studies on thoracic and rib motions associated with flexion-extension, lateral bending, and rotation of the spine[4–8], as well as studies on the asymmetry of thoracic shape showing rotational deviation of the ribs and lateral deviation of the thorax and breathing or posture[9–13]. In particular, thoracic lateral deviation and translation are used in many

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motions to move the upper body's center of mass on the frontal plane[14–18]. In healthy individuals, lateral deviation of the trunk occurs in a specific direction due to worsening asymmetry of the infrasternal angle[19]. In addition, there is a significant positive correlation between the bilateral difference in erector spinae muscle thickness and the amount of lateral deviation of the trunk[20].

As for the erector spinae muscles, flexion or rotation of the thoracic spine causes changes in rib alignment due to the pulling effect of the thoracic iliocostalis muscle (TIM)[21]. The TIM, which originates on ribs 7–12 and inserts on ribs 1–6, and the lumbar iliocostalis muscle (LIM), which inserts on ribs 6–12[2, 22], have many attachments across the thorax and are easily influenced by the shape of the thorax. However, the relationship between TIM or LIM and thoracic shape or lateral translation remains unclear. If there is a deviation in the thorax or an asymmetry in the thoracic shape at rest, a bilateral difference in lateral translation and TIM or LIM activity associated with deviation in the upper body's center of mass would be expected. Therefore, the relationship between asymmetry in the thoracic shape, thoracic shape change caused by thoracic lateral translation, and TIM or LIM attached across the thorax may be a valuable evaluation of the upper body's center of mass in the frontal plane in clinical rehabilitation.

Thus, this study aimed to investigate the relationship between the bilateral ratio of the thoracic shape and the bilateral ratio of the electromyographic activity of the thoracic and lumbar iliocostalis muscles during resting sitting and thoracic lateral translation relative to the pelvis in healthy adult participants.

PARTICIPANTS AND METHODS

This cross-sectional analytic study was conducted among healthy adult males[23]. A simple random sampling technique was used to recruit participants[24, 25]. Study participants were 23 healthy males (age: 25.9 ± 3.2 years, height: 170.8 ± 4.7 cm, body mass: 63.2 ± 8.3 kg, body mass index: 21.9 ± 2.4 kg/m^2 [mean ± SD]). The participants were recruited from the Bunkyo Gakuin University and Takashimadaira Chuo General Hospital. Since respiratory function begins to decline at age 35[26], the inclusion criteria for the study participants were adult males between the ages of 20 and 34. In addition, the exclusion criteria for the study participants were respiratory, spinal, or chest diseases or noticeable spinal or thoracic deformation. All participants were volunteers and informed of the scientific purpose and significance of the study and provided informed consent before participating in the study. This study was approved by the Ethics Committee of the Tokyo Medical University (approval No. T2020-0085) and the Ethics Committee of the Bunkyo Gakuin University (approval No. 2020-0017). The study was conducted according to the Declaration of Helsinki revised in October 2013.

In this study, the thoracic lateral deviation, thoracic translation distance, anteroposterior diameter of the upper thoracic shape (UTS), and anteroposterior diameter of the lower thoracic shape (LTS) were measured using an optical three-dimensional (3D) motion capture system (VICON MX; Vicon Motion Systems, Ltd., Oxford, UK). The system is composed of eight infrared cameras, and the sampling frequency was set to 100 Hz. The electromyographic (EMG) activity of the TIM and LIM was measured by a recording of surface EMG (TeleMyo2400, EM-401; NORAXON, Scottsdale, AZ, USA). The sampling frequency was set to 1,000 Hz and synchronized with an optical 3D motion capture system.

The measurement tasks were resting sitting and active thoracic lateral translation to the left and right sides from resting sitting (right lateral translation [right translation] and left lateral translation [left translation]). In resting sitting, the participants were seated in an upright position with an upper limb drooping position on a 40-cm platform. Similarly, in the right and left translations, the participants were seated in an upright position with an upper limb drooping position and maintained a constant speed without a resulting lateral tilt of the pelvis or lateral flexion of the trunk, and the tasks were limited to the extent that the movement could be performed in 5 s. In addition, the right translation and left translation analysis sections were set until the pelvic tilt angle reached 2 ° to define the motion within the range that did not cause angular changes in the trunk on the frontal plane. The pelvic tilt angle on the frontal plane during gait[27–29] was used as a reference for regulating the pelvic tilt angle during right translation and left translation. The participants held the resting expiratory position to exclude motion of the thorax with respiration in resting sitting, right translation, and left translation. Each task was measured three times and the average value of the measurements was used as a representative value for the participant.

In every task, 23 infrared reflective markers (9.5-mm diameter) were attached to the thorax, chest wall, and pelvis to track movement trajectories. The locations of the infrared reflective markers were determined based on methods described in previous studies[10, 11, 30–33] as follows: jugular notch, sternal angle (A), each of the three markers placed at regular intervals on the horizontal line from the marker of A to the left and right at the same level (Right; A1-3, Left; A4-6), the spinous process at the same level as A (B), xiphoid process (C), the spinous process at the same level as C (D), each of the three markers placed at regular intervals on the horizontal line from the marker of D to the left and right at the same level (Left; D1-3, Right; D4-6), T2 spinous process, T10 spinous process, anterior superior iliac spine (ASIS) of the left and right sides, and the posterior superior iliac spine (PSIS) of the left and right sides (Figs. 1, 2). The markers of A1-6 and D1-6 were placed at 13% of the distance between the left and right acromion and horizontally and regularly at intervals using a line laser and tape measure with reference to previous studies[9, 34]. The data obtained from each task were processed using Nexus 2.9.3 (Vicon Motion Systems). After the fill gap was processed, the data were smoothed using a Woltring low-pass filter (cut-off frequency: 6 Hz). Furthermore, the local coordinate system of the thoracic segment (created by the jugular notch, T2, xiphoid process, and T10) and pelvis segment (created by ASIS and PSIS of the left and right sides) were defined using programming software (Body

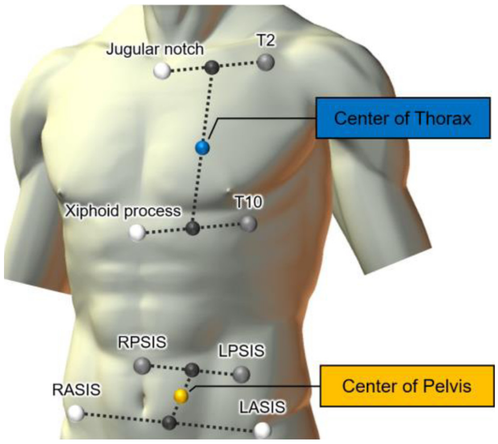

Fig. 1. Infrared reflective marker locations in the thorax and pelvis.
RPSIS: right posterior superior iliac spine; LPSIS: left posterior superior iliac spine; RASIS: right anterior superior iliac spine; LASIS: left anterior superior iliac spine.

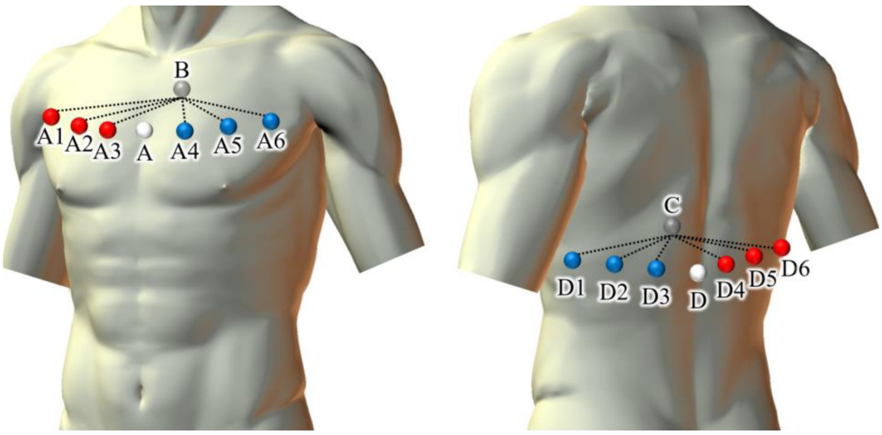

Fig. 2. Infrared reflective marker locations in the upper and lower thorax.

Builder; Vicon Motion Systems). The thoracic lateral deviation and thoracic translation distance were calculated using the distance between the middle point of the thoracic and pelvic segments (Fig. 1). The data were normalized by the height of the participants. In addition, the absolute values were calculated and used only for the data derived by adding values from each left and right translation.

The UTS bilateral ratio and LTS bilateral ratio were calculated using the anteroposterior diameter of the thorax on the left and right sides. In previous studies, the anteroposterior diameter of the UTS and LTS was indicated as an undulation of the chest wall or a forward rotation and backward rotation of the rib. The measurements of the UTS and LTS are described below. For the UTS, the anteroposterior diameters were calculated using the distance from marker B to A1, A2, A3, A4, A5, and A6, and the sum of BA1, BA2, and BA3 was defined as the anteroposterior diameter of the right UTS. Meanwhile, the sum of BA4, BA5, and BA6 was defined as the anteroposterior diameter of the left UTS (Fig. 2). For the LTS, the anteroposterior diameters were calculated using the distance from marker C to D1, D2, D3, D4, D5, and D6, and the sum of CD4, CD5, and CD6 was defined as the anteroposterior diameter of the right LTS. On the hand, the sum of CD1, CD2, and CD3 was defined as the anteroposterior diameter of the left LTS (Fig. 2). The right UTS and LTS values divided by the left values were defined as the bilateral ratio of UTS and LTS. Thus, if the bilateral ratio was near 1.0, it indicated that the UTS and LTS tended to be symmetrical. In contrast, if the bilateral ratio was away from 1.0, which indicated that the UTS and LTS tended to be asymmetrical.

The measurements of the surface EMG are described below. The amplified EMG signals were captured by a computer at 1,000 Hz with 12-bit via an analog digital converter and recorded with NORAXON MyoResearch XP (NORAXON). Surface electrodes (Bio-Load SDC-H 45352V, Sekisui Kasei Co., Ltd., Tokyo, Japan; discs, Ag/AgCl, 40-mm diameter [20 mm of gel diameter]) were attached after shaving the hair, skin abrasion, alcohol applied to cleanse the skin, and paste (skin pure YZ-0019, NIHON KOHDEN, Tokyo, Japan). The inter-electrode distance was set to 35 mm. In previous studies, the electrode location was parallel to the muscle fiber direction[35–38]. In the TIM, the electrode location was set 6 cm lateral to the T10 spinous process and inside the costal angle. In the LIM, the electrode location was set 6 cm lateral to the L3 spinous process and inside the costal angle. Furthermore, the earth electrode was inserted in the T11 spinous process. All electrodes were attached by the same examiner. Raw EMG data were processed as follows: reduction of ECG noise, bandpass filter (Butterworth: 20–500 Hz) processing, root mean square (100 msec) processing, and normalization processing. Normalization processing was based on maximal voluntary contraction (MVC), which is referred to as manual muscle testing[39]. Additionally, %MVC was obtained from each of the MVC data. The TIM and LIM bilateral ratios were obtained from the left and right data of each %MVC. The right value divided by the left value was defined as the bilateral ratio of TIM and LIM. Thus, if the bilateral ratio was near 1.0, it indicated that the TIM and LIM tended to be symmetrical; in contrast, if the bilateral ratio was away from 1.0, it indicated that the TIM and LIM tended to be asymmetrical.

Statistical analyses were conducted using SPSS 26.0 (IBM Japan, Tokyo, Japan). All parameters were assessed for normality using a Shapiro–Wilk test. Statistical data are presented as the mean value and standard error (SE).

The thoracic lateral deviation, UTS bilateral ratio, and LTS bilateral ratio in resting sitting were assessed using a 95% confidence intervals (95% CI). Multiple comparisons between the resting sitting, right translation, and left translation for UTS bilateral ratio in which normality has been confirmed were assessed using a Welch's t-test with adjusted p-value (Bonferroni method); LTS bilateral ratio in which normality could not be confirmed were assessed using a Wilcoxon rank-sum test with adjusted p-value (Bonferroni method). A comparison between right translation and left translation for thoracic translation distance and TIM and LIM bilateral ratios in which normality could not be confirmed were performed using the Wilcoxon rank-sum test. In addition, UTS, LTS, and TIM bilateral ratios in the data derived by adding values from each left and right translation; thoracic lateral deviation, and UTS and LTS bilateral ratios in resting sitting; UTS and LIM bilateral ratios in right translation; and thoracic translation distance and UTS, LTS, and TIM bilateral ratios in left translation in which normality has been confirmed were assessed using the Pearson correlation coefficient. Other data in which normality could not be confirmed were assessed using the Spearman rank correlation coefficient. Statistical significance was set at $p<0.05$.

RESULTS

The 95% CIs of the thoracic lateral deviation, UTS bilateral ratio, and LTS bilateral ratio in resting sitting were −5.0–2.5 mm/ m, 0.98–0.99, and 1.02–1.03, respectively.

The results for each parameter are shown in Table 1. A significant difference was observed between resting sitting, right translation, and left translation. The UTS bilateral ratio in the right translation was significantly greater than that in resting sitting and left translation ($p<0.01$); and in resting sitting, the UTS bilateral ratio was significantly greater than that in left translation ($p<0.01$). The LTS bilateral ratio was significantly greater in left translation than that in resting sitting and right translation ($p<0.01$); and in the resting sitting, the ratio was significantly greater than that in the right translation ($p<0.01$). There was no significant difference in thoracic translation distance between the right translation and the left translation. The TIM and LIM bilateral ratios were significantly greater for left translation than for right translation ($p<0.01$).

The results of the correlation coefficients for each dataset are shown below. In the data derived by adding values from each left and right translation left and right translations, the LTS bilateral ratio was significantly positively correlated with thoracic translation distance ($r=0.39$, $p<0.05$) and TIM bilateral ratio ($r=0.33$, $p<0.05$); and was significantly negatively correlated with the UTS bilateral ratio ($r=-0.64$, $p<0.01$) and LIM bilateral ratio ($r=-0.36$, $p<0.05$) (Table 2).

In resting sitting, the thoracic lateral deviation was significantly negatively correlated with the LTS bilateral ratio ($r=-0.68$, $p<0.01$) and was significantly positively correlated with the thoracic translation distance bilateral difference ($r=0.48$, $p<0.05$). The LTS bilateral ratio was significantly negatively correlated with the thoracic translation distance bilateral difference ($r=-0.54$, $p<0.01$) (Table 3).

Table 1. Mean value and 95% CI of each parameter in the resting sitting, right translation, and left translation

	Resting sitting	Right translation	Left translation
Thoracic lateral deviation (mm/m)	−6.4 ± 1.1 (−5.0–−2.5)	–	–
Thoracic translation distance (mm/m)	–	26.8 ± 1.1 (24.7–28.9)	27.2 ± 1.2 (24.9–29.4)
UTS bilateral ratio (Rt./Lt.)	0.98 ± 0.01 (0.98–0.99)**	0.99 ± 0.01 (0.98–1.00)††	0.98 ± 0.01 (0.97–0.99)
LTS bilateral ratio (Rt./Lt.)	1.02 ± 0.01 (1.02–1.03)**	1.01 ± 0.01 (1.00–1.02)††	1.03 ± 0.01 (1.03–1.04)
TIM bilateral ratio (Rt./Lt.)	–	0.5 ± 0.1 (0.4–0.6)**	2.8 ± 0.2 (2.4–3.2)
LIM bilateral ratio (Rt./Lt.)	–	0.4 ± 0.1 (0.4–0.5)**	2.4 ± 0.2 (2.0–2.8)

Mean ± SE (95% CI), **$p<0.01$ (vs. Left translation), ††$p<0.01$ (vs. Resting sitting and left translation).
CI: confidence interval; SE: standard error; UTS: upper thoracic shape; LTS: lower thoracic shape; TIM: thoracic iliocostalis muscle; LIM: lumbar iliocostalis muscle; Rt.: right; Lt.: left.

In the right translation, the thoracic translation distance was significantly negatively correlated with the LTS bilateral ratio ($r=-0.59$, $p<0.01$) and was significantly positively correlated with the LIM bilateral ratio ($r=0.44$, $p<0.05$). The LTS bilateral ratio was significantly negatively correlated with the LIM bilateral ratio ($r=-0.58$, $p<0.01$) (Table 4).

In left translation, thoracic translation distance was significantly negatively correlated with the LTS bilateral ratio ($r=-0.57$, $p<0.01$), and the LTS bilateral ratio was significantly positively correlated with the TIM bilateral ratio ($r=0.50$, $p<0.05$) (Table 5).

DISCUSSION

This study investigated the relationship between thoracic lateral deviation, thoracic shape, and electromyographic activity of the TIM and LIM during lateral translation of the thorax relative to the pelvis.

First, analysis of the thoracic lateral deviation, UTS, and LTS showed that the thorax deviated to the left relative to the pelvis in resting sitting, the left anteroposterior diameter was larger than the right anteroposterior diameter in UTS, and the right anteroposterior diameter was larger than the left anteroposterior diameter in LTS. Since an increase in the anteroposterior diameter of the thorax indicates a backward rotation of the ribs and a decrease in the anteroposterior diameter of the thorax

Table 2. The correlation coefficient of each parameter in the data derived by adding values from each left and right translation

	Thoracic translation distance (mm/m)	UTS bilateral ratio (Rt./Lt.)	LTS bilateral ratio (Rt./Lt.)	TIM bilateral ratio (Rt./Lt.)	LIM bilateral ratio (Rt./Lt.)
Thoracic translation distance (mm/m)	1	−0.18	0.39*	0.04	−0.22
UTS bilateral ratio (Rt./Lt.)	–	1	−0.64**	−0.25	0.24
LTS bilateral ratio (Rt./Lt.)	–	–	1	0.33*	−0.36*
TIM bilateral ratio (Rt./Lt.)	–	–	–	1	0.17
LIM bilateral ratio (Rt./Lt.)	–	–	–	–	1

*$p<0.05$, **$p<0.01$.
UTS: upper thoracic shape; LTS: lower thoracic shape; TIM: thoracic iliocostalis muscle; LIM: lumbar iliocostalis muscle; Rt.: right; Lt.: left.

Table 3. The correlation coefficient of each parameter in resting sitting

	Thoracic lateral deviation (mm/m)	UTS bilateral ratio (Rt./Lt.)	LTS bilateral ratio (Rt./Lt.)	Bilateral difference of the thoracic translation distance (Rt.–Lt.)
Thoracic lateral deviation (mm/m)	1	0.06	−0.68**	0.48*
UTS bilateral ratio (Rt./Lt.)	–	1	−0.19	0.19
LTS bilateral ratio (Rt./Lt.)	–	–	1	−0.54**
Bilateral difference of the thoracic translation distance (Rt.–Lt.)	–	–	–	1

*$p<0.05$, **$p<0.01$.
UTS: upper thoracic shape; LTS: lower thoracic shape; Rt.: right; Lt.: left.

Table 4. The correlation coefficient of each parameter in right translation

	Thoracic translation distance (mm/m)	UTS bilateral ratio (Rt./Lt.)	LTS bilateral ratio (Rt./Lt.)	TIM bilateral ratio (Rt./Lt.)	LIM bilateral ratio (Rt./Lt.)
Thoracic translation distance (mm/m)	1	0.21	−0.59**	0.06	0.44*
UTS bilateral ratio (Rt./Lt.)	–	1	−0.13	0.36	−0.10
LTS bilateral ratio (Rt./Lt.)	–	–	1	0.11	−0.58**
TIM bilateral ratio (Rt./Lt.)	–	–	–	1	0.33
LIM bilateral ratio (Rt./Lt.)	–	–	–	–	1

*$p<0.05$, **$p<0.01$.
UTS: upper thoracic shape; LTS: lower thoracic shape; TIM: thoracic iliocostalis muscle; LIM: lumbar iliocostalis muscle; Rt.: right; Lt.: left.

Table 5. The correlation coefficient of each parameter in left translation

	Thoracic translation distance (mm/m)	UTS bilateral ratio (Rt./Lt.)	LTS bilateral ratio (Rt./Lt.)	TIM bilateral ratio (Rt./Lt.)	LIM bilateral ratio (Rt./Lt.)
Thoracic translation distance (mm/m)	1	0.01	−0.57**	−0.19	0.00
UTS bilateral ratio (Rt./Lt.)	−	1	−0.18	−0.20	0.39
LTS bilateral ratio (Rt./Lt.)	−	−	1	0.50**	−0.11
TIM bilateral ratio (Rt./Lt.)	−	−	−	1	−0.18
LIM bilateral ratio (Rt./Lt.)	−	−	−	−	1

*$p<0.05$, **$p<0.01$.
UTS: upper thoracic shape; LTS: lower thoracic shape; TIM: thoracic iliocostalis muscle; LIM: lumbar iliocostalis muscle; Rt.: right; Lt.: left.

indicates a forward rotation of the ribs[4, 9, 40], the thoracic shape of the participants showed a relative forward rotation in the right upper and left lower ribs and a relative backward rotation in the left upper and right lower ribs. These results indicated that conflicting rotational deviations were observed in the ribs on the left and right sides.

Second, a correlation analysis of the data derived by adding values from each left and right translation showed a positive correlation between thoracic translation distance and LTS bilateral ratio. Thus, the results indicated that forward rotation on the translating side and backward rotation on the contralateral side occurred in the lower thorax with an increase in the thoracic lateral translation distance. A negative correlation was found between the UTS bilateral ratio and LTS bilateral ratio during the lateral translation of the thorax. These results indicated that the upper thorax had an ipsilateral backward rotation and a contralateral forward rotation, whereas the lower thorax had an ipsilateral forward rotation and a contralateral backward rotation during lateral translation of the thorax relative to the pelvis and opposing rotations in the upper and lower thorax. Regarding the thoracic lateral translation relative to the pelvis, the lateral translation of the thorax to the left or right relative to the pelvis leads to lateral flexion of the lumbar spine ipsilaterally and lateral flexion of the thoracic spine contralaterally[41]. Similarly, the leftward infrasternal angle tends to increase as the trunk side shifts distance to the right and the right infrasternal angle tends to increase as the trunk side shifts distance to the left[19]. In addition, the characteristics of thoracic lateral translation are mainly accompanied by alignment changes in the thoracolumbar transitional area or shape changes in the lower thoracic shape[18, 19]. However, unlike previous studies, the aim of this study did not allow for lateral flexion of the trunk or elevation of the pelvis. In other words, it is supposed that the change in the thoracic shape associated with lateral translation is not due to lateral flexion of the spinal column but rather slight shear stresses in the spine. However, because changes in thoracic and lumbar spine alignment were not the focus of this study, the details of the mechanism cannot be discussed, and examination of the entire spine is, therefore, needed. In conclusion, thoracic lateral translation involves opposing thoracic shape changes in the upper and lower thorax; in particular, the conditions in the lower thoracic area are responsible for thoracic lateral translation distance.

Next, the results of correlation analysis with muscle activity showed a significant positive correlation with TIM and a significant negative correlation with LIM in the bilateral ratio of LTS. Generally, it has been reported that %MVC is considered muscle recruitment and firing rather than muscle strength; in addition, a large EMG amplitude is considered strong muscle activity and produces a large muscle force[41]. Physiologically, EMG amplitude is affected by the length-tension relationship of the muscle, and it increases in muscles in the stretched position by reaching a critical length early[41]. As discussed above, since LTS during lateral translation relative to the pelvis is accompanied by an ipsilateral forward rotation and a contralateral backward rotation, the TIM attached to the 7th–12th ribs[22, 42] is shortened ipsilaterally and elongated contralaterally in the origin insertion, which is thought to increase muscle tension and the contralateral TIM %MVC. Similarly, the LIM attached to the 6th–12th ribs[22, 42] is elongated ipsilaterally and shortened contralaterally in the origin insertion, which is believed to result from muscle tension, and cannot easily increase and decrease the contralateral LIM %MVC. In other words, the TIM and LIM during lateral translation showed different muscle activities on the left and right sides due to the change in LTS.

In addition, the results of the correlation analysis of resting sitting showed a negative correlation between thoracic lateral deviation at resting sitting and LTS bilateral ratio. This indicates that the degree of asymmetry of bilateral rib rotation is increased by the amount of left lateral deviation of the thorax at rest associated with backward rotation of the right rib and forward rotation of the left rib in the lower thorax. Furthermore, a positive correlation was found between the leftward thoracic lateral deviation at resting sitting and the thoracic translation distance bilateral difference at right translation and left translation, indicating that the translation distance in left increases and right decreases correspondingly with the position or lateral deviation of the thorax relative to the pelvis at resting sitting.

Furthermore, a negative correlation was found between the LTS bilateral ratio and thoracic translation distance bilateral difference at right and left translation. This indicates that the left thoracic translation distance tends to extend while the right thoracic translation distance tends to shorten with the degree of asymmetry of the LTS in resting sitting, such that the right lower rib is in backward rotation and the left lower rib is in forward rotation. In other words, if the degree of asymmetry of the

LTS is small and symmetrical in resting sitting, equal translation can occur on the left and right sides. These results indicate that thoracic lateral translation is accompanied by changes in the shape of the lower thorax and that the position or shape of the thorax at rest is related to the translational distance and direction.

Moreover, the characteristics of the right translation and left translation are discussed below. In the right translation, there was a positive correlation between the LIM %MVC bilateral ratio and thoracic translation distance and a negative correlation between the LIM %MVC bilateral ratio and the LTS bilateral ratio. This indicates that the activity of the left LIM increases with an increase in the rightward thoracic translation distance and with increasing LTS asymmetry. When the asymmetry of the LTS is associated with rightward thoracic translation, left LIM contraction was necessary to move the left lower ribs in the backward rotation. In contrast, the left translation showed a positive correlation between the TIM %MVC bilateral and LTS bilateral ratios. This suggests that the asymmetry of the LTS increases more in leftward thoracic translation, and the contraction of the right TIM was necessary to control the backward rotation of the right lower ribs. In other words, left translation requires rib rotation in the same direction as the resting sitting thoracic shape, which facilitates relatively easy LTS change, and the right TIM activity is thought to control the increase in backward rotation of the right lower rib. In addition, right translation requires rib rotation in the contralateral direction from the resting sitting thoracic shape, and it is more difficult to facilitate LTS change than left translation; therefore, the left LIM is thought to be activated to facilitate backward rotation of the left lower ribs.

Finally, this study had some limitations. The misalignment between the skin and markers could not be excluded because the thoracic shape was measured using infrared reflective markers. Thus, the thorax may be accompanied by a spin or rotation instead of pure thoracic lateral translation relative to the pelvis. In addition, the crosstalk effect could not be excluded because surface EMG recording rather than needle EMG recording was used. Consequently, the activity of the other erector spinae muscles cannot be ruled out. Moreover, the origin insertion was not measured, and it is impossible to say if the change in thoracic shape causes the extension or shortening of the distance between the origin and insertion of TIM and LIM. It is necessary to investigate the cross-sectional area of the muscle and the function and kinetics of the origin insertion during thoracic lateral translation using ultrasound imaging.

In conclusion, this study implies that asymmetry of the lower thoracic shape associated with leftward deviation of the thorax at rest may produce bilateral differences in translation distance and TIM and LIM muscle activity. Furthermore, symmetry of the lower thoracic shape associated with decreased leftward deviation of the thorax at rest may produce an equal thoracic lateral translation and equal TIM and LIM activity on both sides.

Conflict of interest

None declared.

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