Characteristics of the scapula movement during shoulder elevation depend on posture

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Abstract. [Purpose] This study aimed to clarify the differences in scapular movement during flexion and abduction of the shoulder joint with different postures. [Participants and Methods] This study included 15 male participants. Their shoulder flexion and abduction and angles of the scapular upward rotation, scapular anterior tilt, scapular external rotation, and thoracic spine flexion were measured. Measurements were taken in three positions: the control, thoracic spine flexion, and thoracic spine extension positions using a three-dimensional motion capture system. [Results] In the shoulder flexion, the amount of change in the scapular external rotation was significantly greater in the thoracic flexion than in the thoracic extension. In shoulder abduction, the amount of change in the scapular anterior tilt and external rotation was significantly greater in the thoracic flexion than in the thoracic extension. A comparison of the scapular angles in shoulder flexion and abduction showed that the upward rotation, posterior tilt, and external rotation were significantly greater in abduction than flexion. [Conclusion] To avoid posture-induced incoordination of the scapula and thorax movement during shoulder elevation, postural adjustment of the thoracic spine based on the movements is necessary for the shoulder joint exercises.

Key words: Thoracic posture, Scapulothoracic movement, Glenohumeral movement

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INTRODUCTION

Shoulder joint elevation [flexion and abduction] movements have been reported in the past; Codman proposed the scapulohumeral rhythm11). It is a coordinated motion of the glenohumeral and scapulothoracic joints. Notably, decreased coordination and malalignment can increase mechanical stress on the tissues and cause pain and numbness2–5).

Additionally, the glenohumeral, the scapulothoracic joint, and the spinal column movement during shoulder elevation, including the lumbar and thoracic extension, are necessary for maximum elevation6 7). In this way, shoulder elevation is a coordinated and complicated motion of the thorax, the humerus, and the scapula8). The thoracic extension movement is not seen in the first half of shoulder flexion [0–90°] but seen in the second half [90–180°]. Conversely, the thoracic extension continues from the beginning to the end of shoulder abduction9). Therefore, the thoracic spine movement for the shoulder elevation depends on the direction of motion.

During normal shoulder elevation, the scapular moves in the direction of upward rotation, posterior tilt, and external rotation10). These movements were examined by the coordinated shift analysis during both flexion and abduction. Miura11) showed that the scapula abducted and upward rotated from 30° to 120° and adducted and upward rotated from 120° to 180° in shoulder flexion, whereas the scapula adducted and upward rotated from 0° to 90° and abducted and upward rotated from 90° to 180° in shoulder abduction. Therefore, scapulohumeral rhythm during elevation depends on the plane and elevation angle. Consequently, it is necessary to investigate the scapulohumeral rhythm in sagittal flexion and abduction in the coronal plane, respectively.
There have been several reports on the scapulothoracic joint with poor posture. Notably, there was a decrease in the scapula’s upward rotation and posterior tilt and an increase in internal rotation with the upright posture\textsuperscript{12}. Another article showed that there was no difference in scapular upward rotation but decreased posterior tilt and external rotation in the stooped posture\textsuperscript{13}. Additionally, there was an article on increased scapular upward rotation in the scapular plane and decreased scapular posterior tilt. Harada\textsuperscript{14} reported that subjects with thoracic flexion posture exhibited decreased external rotation of the scapula.

Therefore, the difference between flexion and abduction of the shoulder joint has not been unclear with reference to the posture. The purpose of this study was to examine the differences in scapular movement during shoulder flexion and abduction, depending on posture differences. We hypothesized that scapular upward rotation, posterior tilt, and external rotation would decrease except for the neutral spine position because the thorax could not move properly according to the direction of humeral movement. We also hypothesized that shoulder flexion would decrease in the thoracic extension and shoulder abduction would reduce in the thoracic flexion.

**PARTICIPANTS AND METHODS**

A total of 15 males participated in the study. None of the patients had undergone upper limb or spinal surgery and did not have any orthopedic diseases or pain of the upper limb or spinal column within the past year. The mean (± standard deviation) age, height, and weight of the participants were 30.1 ± 5.9 years, 171.7 ± 4.4 cm, and 65.6 ± 8.1 kg, respectively. The Bunkyo Gakuin University ethics committee approved this study (No. 2020-0009), and all the participants provided written informed consent prior to participation.

The relationship between the scapular angle and the posture during shoulder elevation was analyzed. Participants were asked to sit with their knees and hips at 90° flexion, and their feet placed flat on the floor throughout the measurement. The starting position of the shoulder joint was at 0°. The shoulder elevation speed was set to be 6 sec with a metronome. The measurement conditions were as follows: Condition 1 (control: thoracic neutral position); Condition 2 (thoracic flexion: the participants were instructed to hold their thoracic spine in the maximum flexion position); and Condition 3 (thoracic extension: the participants were asked to hold their spine in the maximum extension). The examiner checked the participant’s thoracic position and gave them feedback if necessary. After several trials and familiarization, the participant’s movements were captured with randomized sequences. The data in which the thoracic spine angle changed over 3° during the measurement were excluded.

Kinematic data were collected using a three-dimensional motion analysis system (VICON Nexus; Vicon Motion Systems Ltd., Oxford, UK) with a 100 Hz sampling time by 11 cameras. Infrared-reflective markers were attached to 45 points, including the incisura jugularis (IJ), xiphoid process (PX), sternoclavicular joints, acromioclavicular joints, coracoid processes, inferior angles (IA), trigonum spine (TS), acromial angle (AA), medial and lateral epicondyles (EM and EL), medial and lateral of wrist joints, dorsum of the head of the second metacarpal bone, spinous process of the seventh cervical vertebra (C7), spinous process of the eighth thoracic (T8), spinous process of the first lumbar (L1), anterior-superior iliac spines, and posterior-superior iliac spines on both sides, according to the recommendations of the International Society of Biomechanics (ISB)\textsuperscript{15}. Moreover, the acromion cluster markers (AC1, AC2, and AC3) were placed on the acromion as in previous studies\textsuperscript{16–19} (Figs. 1, 2). The shoulder, scapula, and thorax angles were calculated from the marker coordinates obtained by the measurement using an analyzing software (Body Builder; Vicon Motion Systems Ltd., Oxford, UK).

For the analysis, we defined the three segments; the thorax, the humerus, and the scapula. In the thorax segment, the superiorly directed axis (Yt) extended from the midpoint between T8 and PX to the midpoint between C7 and IJ; the laterally directed axis (Zt) was perpendicular to the plane defined by C7, IJ, and T8, PX; and the anteriorly directed axis (Xt) was defined as a rectangular coordinate system of the Yt and Zt\textsuperscript{15,20}. The humeral segment was defined as follows: the superiorly directed axis (Yh) extended from the midpoint between the EM and EL to the midpoint between the coracoid process and
acromial angle; the anteriorly directed axis (Xh) was perpendicular to the plane defined by the coracoid process, acromial angle, EM and EL; and the laterally directed axis (Zh) was determined as a rectangular coordinate system of the Xh and Yh. The shoulder flexion and abduction angles of the three conditions were calculated by the humerus segment. The scapular segment was defined as follows: the laterally directed axis (Zs) extended from TS to AA; the anteriorly directed axis (Xs) was perpendicular to the plane defined by the TS, AA, and IA; and the superiorly directed axis (Ys) was defined as a rectangular coordinate system. Moreover, the three acromion cluster markers segment were defined as follows: the superiorly directed axis (Yh) extended from AC1 to AC2; and the laterally directed axis (Zh) was perpendicular to the plane defined by AC1, AC2, and AC3; the anteriorly directed axis (Xh) was determined as a rectangular coordinate system. The scapular anterior tilt angle was measured by the acromion cluster marker. The scapula variables were the angles of the scapular upward rotation, scapular anterior tilt, and scapular external rotation. Thoracic spine flexion was calculated by the thorax segment. As absolute angles at the moments of 0°, 30°, 60°, 90°, and 120° and the angle changes during each moment. The scapular upward and external rotation angles were measured by the AA, TS, and IA. The measurement of the scapular angle is less affected by skin motion artifacts in the case of the movement from 0° to 120° of shoulder elevation11). For that reason, we selected this range in our study. Data were normalized by time. All variables were exhibited by absolute angles concerning the laboratory space, not relative angles.

Repeated measures of analysis of variance were used for each angle of shoulder elevation. One-way analysis of variance was used for the scapular angle among the conditions. Tukey’s test was used as multiple comparison tests. The corresponding t-test compared the scapular angles between flexion and abduction angles. Statistical analyses were performed using SPSS Statistics version 25 (IBM Inc., Chicago, IL, USA). A significance level of p<0.05 was used.

RESULTS

The thoracic angle for each condition was within 3°. The scapular upward rotation angle was not significant difference in all thoracic conditions of shoulder flexion. The scapular anterior tilt angle was more significant in the thoracic flexion than in the extension from 0° to 90° of shoulder flexion (p<0.01). Moreover, the scapular anterior tilt angle was significantly larger in the thoracic flexion than in the control at 60° of shoulder flexion (p<0.05). The scapular external rotation angle was substantially larger in the control and thoracic extension than in the thoracic flexion in all flexion angles (0°–90° of shoulder flexion, p<0.01; 120° of shoulder flexion, p<0.05). The amount of change in the external rotation was significantly greater in the thoracic flexion than in the extension from 90° to 120° shoulder flexion (p<0.01; Tables 1 and 2).

The scapular upward rotation angle was not significantly difference in all thoracic conditions in shoulder abduction. The scapular anterior tilt angle was significantly larger in the thoracic flexion than in the thoracic extension from 0° to 90° of shoulder abduction (0–60°, p<0.01; 90°, p<0.05). And the scapular anterior tilt angle was significantly larger in the thoracic flexion than in the control from 0° to 60° of shoulder abduction (p<0.05). The amount of change of this angle was considerably smaller in the thoracic flexion than in the extension from 60° to 120° (p<0.01).

The scapular external rotation angle was significantly greater in the control and thoracic extension than in the flexion from 0° to 120° (0–90°, p<0.01; 120°, p<0.05). External rotation change was significantly greater in the thoracic flexion than in the extension between 60° and 120° (p<0.01; Tables 3 and 4).

In the comparison between shoulder flexion and abduction, the amount of change of the scapula upward angle during abduction was significantly greater than that during flexion between 30° and 120° (p<0.01) postures. The amount of change in the scapular anterior tilt angle was significantly smaller during abduction than during flexion in all shoulder range (p<0.01), in all postures. The amount of change in scapular external rotation angle was significantly larger during abduction than flexion in all shoulder range (p<0.01).

DISCUSSION

There was no significant difference of the scapular upward rotation angle during flexion in all spinal condition. However, the scapular anterior tilt in the thoracic flexion was significantly larger than in the thoracic extension from 0° to 60° of shoulder flexion. Moreover, the scapular external rotation angle in the thoracic flexion was significantly smaller than that in the control and extension positions in any flexion angle, supporting the hypothesis. Furthermore, the amount of change in external rotation was significantly greater in the thoracic flexion from 0° to 60° than in the other conditions, which was different from the hypothesis. Chiba9) showed that the scapulothoracic joint changed its plane of motion according to the thorax’s shape. Furthermore, the amount of change in the external rotation was significantly greater in the thoracic flexion from 90° to 120° than in the other conditions, which was different from the hypothesis. And it has been reported that the scapular abduction and posterior tilt occur in the first half of flexion and thoracic spine extension hardly occurs in this range8,11). Therefore, the results may be due to the scapula anterior tilt and internal rotation, based on the shape of the posterior surface of the thorax between the start of the movement and 90° of flexion. Kebaetse(12) and Finley(13) reported that the scapular external rotation angle was significantly decreased in the poor posture compared with the upright posture during flexion and shoulder abduction. However, the results of our study were different from those of the reports mentioned above. There is reported that the scapula is internally rotated and posteriorly tilted in the second half of shoulder flexion, and the thoracic
### Table 1. Scapula angle during shoulder flexion

| Humeral flexion angle | Upward rotation angle (°) | Anterior tilt angle (°) | External rotation angle (°) |
|-----------------------|---------------------------|-------------------------|-----------------------------|
| Control               | Thorax flexion | Thorax extension | Control | Thorax flexion | Thorax extension | Control | Thorax flexion | Thorax extension |
| 0°                    | 8.20 ± 10.22 | 9.96 ± 9.04 | 9.97 ± 12.26 | 16.48 ± 13.12 | 27.60 ± 15.82 | 11.24 ± 13.81 | -31.26 ± 5.27 | -40.13 ± 6.67 | -27.05 ± 6.09 |
| 30°                   | 9.75 ± 8.59  | 12.25 ± 8.16 | 10.55 ± 10.45 | 18.30 ± 12.81 | 29.51 ± 14.08 | 13.99 ± 12.71 | -32.39 ± 5.97 | -41.13 ± 6.66 | -28.43 ± 6.16 |
| 60°                   | 17.35 ± 7.56 | 19.10 ± 8.81 | 17.64 ± 9.01 | 16.56 ± 12.24 | 27.70 ± 12.00 | 12.27 ± 11.63 | -33.18 ± 6.08 | -41.88 ± 6.50 | -29.94 ± 5.60 |
| 90°                   | 23.23 ± 7.81 | 24.47 ± 7.81 | 24.57 ± 9.50 | 12.68 ± 11.97 | 22.95 ± 12.42 | 8.53 ± 12.58 | -33.20 ± 5.73 | -41.01 ± 6.42 | -30.75 ± 5.74 |
| 120°                  | 34.55 ± 7.49 | 34.80 ± 9.18 | 32.81 ± 10.08 | 5.32 ± 11.09  | 12.61 ± 10.81 | 4.49 ± 11.71 | -31.04 ± 5.36 | -36.52 ± 5.64 | -32.69 ± 6.14 |

*Positive and negative values indicate upward rotation and downward rotation respectively.
*Positive and negative values indicate posterior and anterior tilting respectively.
*Positive and negative values indicate external and internal rotation respectively.
*Significantly larger than in the thoracic extension position (p<0.01).
*Significantly larger than in the control position (p<0.01).
*Significantly larger than in the thoracic extension position (p<0.05).
*Significantly larger than in the control position (p<0.01).

### Table 2. Difference amount of change in scapula angle during shoulder flexion

| Humeral flexion angle | Upward rotation angle (°) | Anterior tilt angle (°) | External rotation angle (°) |
|-----------------------|---------------------------|-------------------------|-----------------------------|
| Control               | Thorax flexion | Thorax extension | Control | Thorax flexion | Thorax extension | Control | Thorax flexion | Thorax extension |
| 0°–30°                | 1.55 ± 2.52  | 2.29 ± 2.55 | 0.83 ± 3.15 | 1.82 ± 2.38 | 1.91 ± 3.48 | 2.75 ± 2.68 | -1.13 ± 1.52 | -1.00 ± 1.76 | -1.38 ± 1.07 |
| 30°–60°               | 9.14 ± 5.03  | 9.14 ± 5.33 | 7.91 ± 6.98 | 0.08 ± 6.01 | 0.09 ± 8.65 | 1.01 ± 6.38 | -1.93 ± 1.76 | -1.75 ± 3.09 | -2.89 ± 2.97 |
| 60°–90°               | 15.03 ± 5.60 | 14.50 ± 5.62 | 14.85 ± 8.01 | -3.80 ± 9.15 | -4.65 ± 12.99 | -2.71 ± 9.61 | -1.95 ± 3.69 | -1.95 ± 3.69 | -3.71 ± 4.27 |
| 90°–120°              | 26.35 ± 7.02 | 24.84 ± 5.99 | 23.09 ± 8.62 | -11.16 ± 13.45 | -14.99 ± 16.86 | -6.74 ± 13.52 | 0.22 ± 4.49 | 3.61 ± 5.64 | -3.47 ± 5.88 |

*Positive and negative values indicate upward rotation and downward rotation respectively.
*Positive and negative values indicate posterior and anterior tilting respectively.
*Positive and negative values indicate external and internal rotation respectively.
*Significantly larger than in the thoracic extension position (p<0.01).
### Table 3. Scapula angle during shoulder abduction

| Humeral abduction angle | Upward rotation angle (°) | Anterior tilt angle (°) | External rotation angle (°) |
|-------------------------|---------------------------|-------------------------|-----------------------------|
|                         | Control | Thorax flexion | Thorax extension | Control | Thorax flexion | Thorax extension | Control | Thorax flexion | Thorax extension |
| 0°                      | 7.12 ± 11.35 | 9.44 ± 11.48 | 15.54 ± 17.05 | 14.83 ± 15.16 | 28.35 ± 14.14 | 6.83 ± 13.93 | -29.26 ± 6.82 | -39.75 ± 6.17 | -24.71 ± 6.42 |
| 30°                     | 10.53 ± 11.52 | 11.04 ± 10.64 | 17.34 ± 14.77 | 8.79 ± 13.97 | 23.40 ± 13.70 | 1.17 ± 12.11 | -27.97 ± 7.06 | -38.82 ± 6.78 | -23.52 ± 6.32 |
| 60°                     | 33.48 ± 15.95 | 27.33 ± 12.93 | 37.67 ± 13.89 | -7.44 ± 10.93 | 4.22 ± 13.25 | -12.48 ± 9.21 | -23.33 ± 6.81 | -33.30 ± 7.68 | -20.20 ± 5.22 |
| 90°                     | 48.39 ± 12.37 | 43.53 ± 11.39 | 50.50 ± 13.66 | -16.62 ± 8.56 | -10.90 ± 9.75 | -19.64 ± 7.99 | -20.34 ± 5.36 | -28.34 ± 6.87 | -18.61 ± 4.56 |
| 120°                    | 57.99 ± 10.57 | 55.24 ± 9.04  | 57.87 ± 11.95 | -18.65 ± 9.96 | -17.89 ± 10.41 | -20.14 ± 9.82 | -18.55 ± 5.66 | -24.06 ± 6.70 | -20.29 ± 6.27 |

*Positive and negative values indicate upward rotation and downward rotation respectively.*

*Significantly larger than in the thoracic extension position (p<0.01).*

*Significantly larger than in the control position (p<0.01).*

*Significantly larger than in the thoracic extension position (p<0.05).*

*Significantly larger than in the control position (p<0.01).*

### Table 4. Difference amount of change in scapula angle during shoulder abduction

| Humeral abduction angle | Upward rotation angle (°) | Anterior tilt angle (°) | External rotation angle (°) |
|-------------------------|---------------------------|-------------------------|-----------------------------|
|                         | Control | Thorax flexion | Thorax extension | Control | Thorax flexion | Thorax extension | Control | Thorax flexion | Thorax extension |
| 0°–30°                  | 3.39 ± 4.23 | 1.60 ± 3.23 | 2.05 ± 3.53 | -6.04 ± 2.55 | -4.95 ± 3.11 | -5.55 ± 3.28 | 1.29 ± 1.65 | 0.93 ± 1.50 | 1.19 ± 1.72 |
| 30°–60°                 | 26.34 ± 11.94 | 17.89 ± 8.98 | 22.38 ± 14.78 | -22.28 ± 7.55 | -24.13 ± 7.66 | -19.31 ± 7.57 | 5.93 ± 2.90 | 6.45 ± 3.66 | 4.51 ± 3.63 |
| 60°–90°                 | 41.25 ± 9.22 | 34.69 ± 9.32 | 35.20 ± 15.45 | -31.45 ± 11.47 | -39.25 ± 12.99 | -26.47 ± 10.80 | 8.92 ± 4.52 | 8.92 ± 4.52 | 6.09 ± 5.15 |
| 90°–120°                | 50.85 ± 11.20 | 45.80 ± 10.60 | 42.58 ± 16.34 | 33.49 ± 16.02 | -46.24 ± 17.61 | -26.97 ± 14.55 | 10.71 ± 6.08 | 15.69 ± 4.95 | 6.46 ± 5.94 |

*Positive and negative values indicate upward rotation and downward rotation respectively.*

*Significantly larger than in the thoracic extension position (p<0.01).*

*Significantly larger than in the control position (p<0.01).*

*Significantly larger than in the external and internal rotation respectively.*

*Significantly larger than in the thoracic extension position (p<0.01).*
spine is extended as it approaches the final range\textsuperscript{9, 11}. However, the shoulder flexion in the thoracic spine flexion position couldn’t change the posterior thoracic shape. Thus, the posterior thoracic surface couldn’t be flattened, making scapular external rotation difficult. If the shoulder flexion continues with pack of scapula external rotation, then the glenohumeral joint will lead to relative horizontal abduction position. This may cause impingement of the soft tissue between the greater tubercle of the humerus under the coracoacromial arch. Therefore, a large external rotation of the scapula during the coordination of the scapula and the thorax loss is considered a reaction to avoid such impingement.

There was no significant difference of the scapular upward rotation angle during abduction. The scapular anterior tilt angle in the thoracic flexion was significantly greater than in the thoracic extension from 0° to 90° of shoulder abduction. Additionally, the scapular external rotation angle in the thoracic flexion was significantly smaller than in the control and thoracic extension positions from 0° to 120° of shoulder abduction, supporting the hypothesis. However, the amount of change in posterior tilt and external rotation was greater in the thoracic flexion from 60° to 120° of shoulder abduction, which was different from the hypothesis. It has been reported that the thoracic spine continues to extend from the start of the movement to the final range in shoulder abduction\textsuperscript{9, 11}. The results showed that the scapula took an angle opposite to that required for abduction motion. Therefore, we considered the scapula’s influence, being anteriorly tilted and internally rotated in the thoracic flexion position, according to the shape of the posterior surface of the thorax at the beginning of the movement, was significant. A previous study reported that in shoulder abduction, the thoracic spine continued to extend immediately after the beginning, and the magnitude of the extension was greater than that of the flexion\textsuperscript{9}. Therefore, we presume that the scapula moves posteriorly tilted and externally rotated during the abduction. The abduction in the thoracic flexion position couldn’t change the shape of the posterior surface of the thorax. It is considered that shoulder abduction with insufficient scapular posterior tilt and external rotation resulted in the glenohumeral joint being relatively extended, and horizontal abduction may transpire. Impingement may occur in the soft tissues between the humeral greater tuberosity under the acromial arch of the coracoid, as in the flexion. Therefore, the scapula may be posteriorly tilted and externally rotated significantly to avoid impingement.

The scapula’s upward rotation occurred in all postures, but the amount of change in shoulder abduction was greater than in flexion after 30°. The scapular anterior tilt occurred in all postures. Nonetheless, the scapula moved in the anterior tilt direction in shoulder flexion and switched to the posterior tilt from 60°. The scapula continued to the posterior tilt during shoulder abduction up to 120°. During shoulder flexion, the scapula rotation moved in the direction of internal rotation in the control and thoracic flexion positions and switched to external rotation from around 60°. However, its rotation in the internal rotation direction in the thoracic extension and switched to the external rotation direction after 90°. During shoulder abduction, the scapula external rotation continued from 0° to 120°. The scapular upward rotation in our study was consistent with those reported by Inman\textsuperscript{2}. The scapula upward rotation was greater after 30°, after the setting phase, which is the incoincidence between the humerus and the scapula movement. According to McClure\textsuperscript{22}, the mean scapulohumeral rhythm in shoulder flexion was 2.0:1, whereas that in the abduction was 1.7:1, suggesting that the proportion of scapular motion increased as the humeral plane approached abduction. Our study’s scapular anterior tilt and external rotation showed differences in the scapular movement between flexion and abduction, as reported by Miura\textsuperscript{11}. Our study showed that the scapula’s upward rotation was more considerable in the shoulder abduction than in the shoulder flexion after 30°, which shoulder abduction may require upward rotation of the scapula from an early stage of the elevation movement.

Our study’s scapular anterior tilt and external rotation showed differences in the scapular movement between flexion and abduction, as reported by Miura\textsuperscript{11}. However, the scapula external rotation in the shoulder flexion in the thoracic extension position was slower to switch to external rotation compared to the others. In the second half of shoulder flexion, the scapula was internally rotated and posteriorly tilted, and the thoracic spine was extended\textsuperscript{9, 11}. However, in the thoracic extension position, the angle of scapula external rotation was greater due to the flattening of the thorax’s posterior surface. When the scapula switches from the internal to the external rotation after 90° of shoulder flexion, the scapula can’t be directed toward the humerus. Therefore, we thought that compensatory scapular motion, contrary to the thorax’s movement, occurred to reduce the mechanical stress on the glenohumeral joint. Additionally, the scapula posterior tilt and external rotation were earlier in shoulder abduction than in flexion. We infer that this is due to the scapula posterior tilt and external rotation, seen earlier in shoulder abduction than in shoulder flexion. Therefore, postural adjustment of the thoracic spine according to the movements are necessary during shoulder elevation. One of the limitations of this study is that owing to the influence of the skin, shoulder movement was only able to be examined up to 120°.

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\textbf{Conflict of interest}

The authors do not have any conflicts of interest to declare.
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