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Original Article

# Validating scapular motion measurements using an optical motion analyzer and gravity magnetic resonance imaging

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**Abstract.** [Purpose] This study aimed to validate whether scapular motion measured using a pad with retroreflective markers and optical motion analyzer (VICON MX) can reflect the motion calculated by images using multi-posture (gravity) magnetic resonance imaging. [Participants and Methods] The participants were 12 healthy males (12 dominant-side shoulders). The measurement items were the scapular angle at shoulder flexion 140° and 160° and abduction 100°, 120°, 140°, and 160°. The scapular angle changes were extracted from the upward/downward and internal/external rotations. Angular changes were calculated by subtracting the scapular angle in static position (drooped upper limb and external shoulder rotation) during resting chair sitting from the scapular angle in each of the six limb positions and subtracting it at shoulder abduction 100° from the scapular angle at shoulder abduction 120°, 140°, and 160°. [Results] The results showed no agreement in most cases and no consistent bias. [Conclusion] The result questions the validity of scapular motion analysis using pads with optical markers. However, the facility environment imposes many study limitations, and this method requires further validation eventually.

**Key words:** Gravity magnetic resonance imaging (MRI), Optical motion analyzer, Scapula motion

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## INTRODUCTION

The shoulder joint has the largest range of motion of all joints in the human body[1)]. In the clinical setting, dysfunction such as pain and limited range of motion caused by shoulder joint diseases affect daily life activities[2)]. In addition, in overhead sports such as baseball and handball, shoulder joint dysfunction decreases in the level of athletic play and limits athletic participation. Therefore, preventing shoulder joint diseases is important for all generations.

The shoulder joint is classified into scapulothoracic, glenohumeral, sternoclavicular, and acromioclavicular portions that move cooperatively to enable smooth movement. Scapulothoracic joint movement is mechanically linked to that of the sternoclavicular and acromioclavicular joints, and the position of the scapula on the thorax provides the basis for glenohumeral joint movement[3)]. Furthermore, a well-known phenomenon around the shoulder joint, scapulohumeral rhythm[4, 5)], demonstrates that the shoulder joint and scapula are closely related. Therefore, to understand the shoulder joint and associated diseases, it is necessary to focus on the scapulothoracic joint.

Analyses of scapular motion associated with shoulder joint motion have been attempted by various researchers. Various methods have been developed and proposed to date[6)], one of which uses an optical motion analyzer. However, the scapula moves along the dorsal aspect of the thorax as the shoulder joint is raised, and the bone features corresponding to the fixed

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*Corresponding author. Yushin Mizuno (E-mail: mizuno@med.kanazawa-u.ac.jp) area of the retroreflective markers in an optical motion analyzer move significantly as if sliding under the body's surface[7]. Thus, consensus is lacking on the methodology for scapular motion analysis using an optical motion analyzer.

The distal end of the acromion undergoes less subcutaneous movement during shoulder motion than the rest of the scapula[8]. One study reported analyzing the movement of the scapula in the pitching motion using an optical motion analyzer with a pad and attached retroreflective markers[9]. However, the accuracy of this methodology has not been verified using images due to ethical considerations related to radiation exposure and technical limitations[10]. Therefore, it is necessary to verify its accuracy by using imaging data.

When acquiring imaging data in a clinical setting, X-ray imaging and computed tomography involve radiation exposure, whereas magnetic resonance imaging (MRI) is characterized by the fact that it does not involve radiation exposure. Therefore, ethical problems caused by radiation exposure can be resolved using MRI. Some studies have analyzed scapular motion using MRI[11–13].

However, on MRI, the limitation of imaging limb position is a problem. Most daily living and overhead sports activities are performed in the standing or sitting position; thus, it can be inferred that the gravitational load on the scapula and surrounding muscles in these postures differs from that in the supine position. Because optical motion analyses are also performed in the standing and sitting positions, it is necessary to compare the scapula in the same positions to validate its motion assuming daily life and overhead sports activities. However, imaging in the standing or sitting position is difficult because of the structure of conventional MRI systems.

In 2016, a new MRI system was developed to address this problem[14]. Because of the structural characteristics of gravity MRI, it can be used with the body in any position, making it possible to monitor the *in vivo* environment non-invasively considering the effects of gravity that we are exposed to in our daily lives. This enables imaging of the movement of the scapula in the standing and sitting positions. If it is possible to analyze the scapular motion associated with shoulder joint motion using an optical motion analyzer, it can be applied to various motions, such as daily and sports activities, so it is extremely important to clarify its validity. Therefore, this study aimed to verify whether the scapular motion measured using a pad with retroreflective markers and an optical motion analyzer could reflect the scapular motion calculated using gravity MRI and to clarify its validity.

## PARTICIPANTS AND METHODS

The participants of this study were 12 healthy males (12 dominant-side shoulders, defined as the side used to sign the consent form). The mean participant age (± standard deviation) was 21.3 ± 1.1 years, height was 173.2 ± 6.3 cm, and weight was 65.0 ± 10.9 kg. Of the 12, 11 were right-handed and 1 was left-handed. The inclusion criteria were as follows: 1) no history of orthopaedic or neurological disease of the shoulder joint; 2) willingness and ability to provide written consent for participation; and 3) age 20 years or older at the time of consent. The exclusion criteria were as follows: 1) shoulder pain or limited range of motion; 2) orthopaedic or neurological diseases of the shoulder joint; and 3) judged by the examiner as inappropriate for the study. This study was approved by the Medical Ethics Review Committee of Kanazawa University (approval number: 1013). The participants were fully informed and provided written and oral consent.

The measurements were performed using an optical motion analyzer and gravity MRI to examine the angular changes of the scapula associated with shoulder joint motion. Six movements of the shoulder joint were performed: 140° and 160° of flexion; and 100°, 120°, 140°, and 160° of abduction. The angles of upward/downward rotation and internal/external rotation of the scapula were calculated for each movement (Fig. 1). The angles of flexion and abduction of the shoulder joint were measured with a goniometer using the measurement method proposed by the Japanese Orthopaedic Association (2-40-8, Hongo, Bunkyo-ku, Tokyo, Japan) and the Japanese Society of Rehabilitation Medicine (1-18-12, Uchikanda, Chiyoda-ku, Tokyo, Japan). In addition to the six movements described above, we calculated the scapula angle in the chair sitting position, with the shoulder joint in the drooping position and the forearm in the external rotation position (static position). Two datasets were included in the data analysis: amount of scapular angle change, which is the scapular angle in each limb position minus the scapular angle in the static position; and amount of scapular angle change, which is the scapular angle in the three movements of shoulder abduction at 120°, 140°, and 160° minus the scapular angle at 100° of shoulder abduction.

An optical motion analyzer (VICON MX; Vicon Motion Systems, Oxford, UK) with a sampling frequency of 250 Hz was used. For the measurement, 22 retroreflective markers and a taping pad (Nitoms, Inc., Tokyo, Japan) molded into a T-shape with retroreflective markers placed at its edges (T-shaped pad) were used according to the method described by Miyashita et al[9]. The T-shaped pad was 200 mm long, 100 mm deep, and 10 mm wide and positioned at the distal end of the dominant acromion with the marker in the center of T-shaped pad positioned directly above the acromion (Fig. 2). The T-shaped pad was very lightweight and was visually confirmed not to move or flex during measurement. The markers were applied to the suprasternal notch, xiphoid process, spinous process of the third thoracic vertebra (Th3 spinous process), spinous process of the eighth thoracic vertebra (Th8 spinous process), both anterior superior iliac spines, both posterior superior iliac spines, the distal ends of both acromion, both lateral epicondyles of the elbows, both medial epicondyles of the elbows, both ulnar stapes, both radial stapes, any point on the line of the acromion, the lateral epicondyles of the elbows on both sides, any point on the line of the lateral epicondyles of the elbows, and the radial stapes on both sides. The scapular angle in the static position was measured once, while that at each shoulder joint angle was measured three times. The participants were asked to

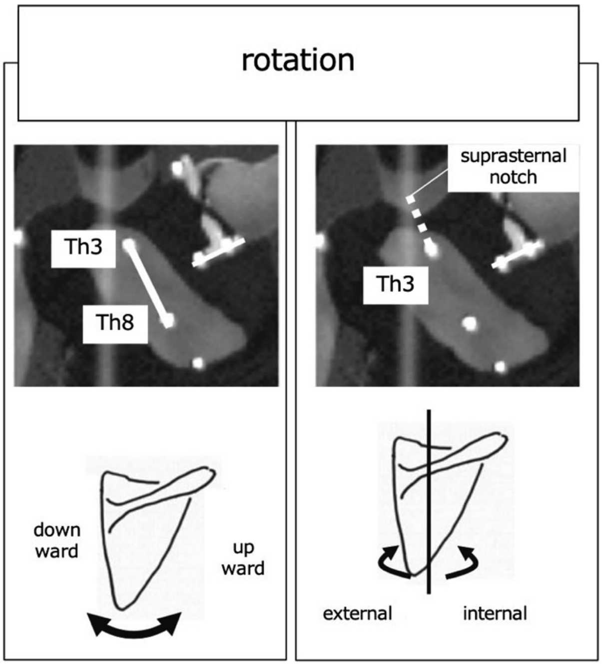

**Fig. 1.** Upward/downward rotation and internal/external rotation of the scapula[9].
The direction of scapular rotation in this study is shown in the figure.

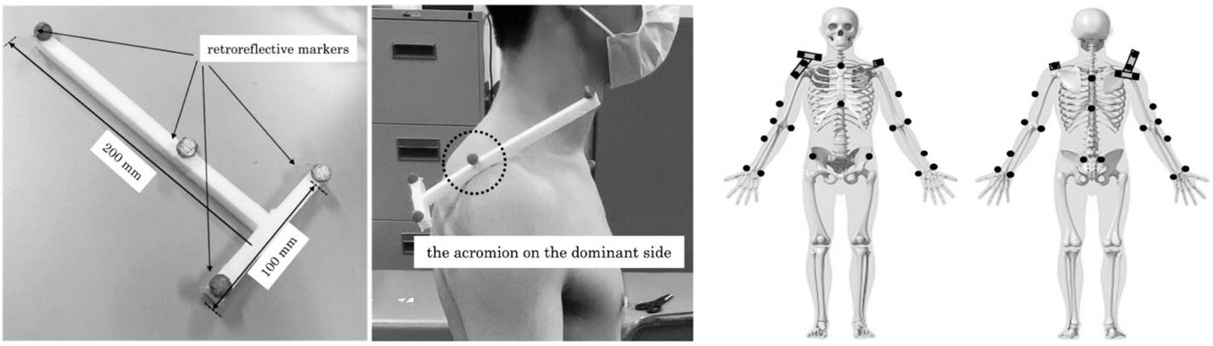

**Fig. 2.** Details of T-shaped pad and locations of retroreflective markers.
Retroreflective markers were attached to three ends of the T-shaped pad. A marker positioned at the distal part of the acromion was placed on the pad, which was positioned on the acromion of the dominant side. The T-shaped pad was positioned so its short side faced the back of the body. The pads were placed on the flat part of the acromion without consideration of the inclination of the pad. Twenty-two retroreflective markers were affixed to the bony landmarks[9]. The marker on the acromion of the participant's non-dominant side was placed on a pad of the same thickness to match the height of the markers on the acromion of the dominant side.

grasp a pole to hold their upper limb at each shoulder joint angle. Because the T-shaped pad may contact the head and neck with increased shoulder joint flexion and abduction angles, lateral bending of the neck was allowed to the extent that it would not interfere with the measurement.

The periarticular area of the shoulder joint was Imaged by a single radiological technologist using a quadrature body coil on gravity MRI (FUJIFILM Healthcare, Tokyo, Japan; Fig. 3) with a static magnetic field strength of 0.4 T. The imaging sequence was gradient-echo T1-weighted imaging with a repetition time of 200 ms, echo time of 4.1 ms, flip angle of 60°, field of view of 350 mm, matrix size of 128 × 128, slice thickness of 5 mm, average number of signals of 1, and receive bandwidth of 35.5 kHz. The imaging time under the conditions was 48 s. The imaging area was 200 mm, including the spinal column centered on the scapula, and the anterior forehead and horizontal (Fig. 4) sections of the scapula (scapular plane and coronal scapular plane, respectively) were imaged. MRI was performed once in each of the seven positions including the static and six shoulder joint positions. The gantry of the MRI system, pole, and cushions were used to maintain a stable posture during the MRI scanning. During imaging, the participants were checked for any mood discomfort or numbness in the upper limbs,

**Fig. 3.** Image of gravity magnetic resonance imaging apparatus.
The quadrature body coil was suspended above the seated participant by a wire and the height was adjusted to include the entire scapula in the measurements.

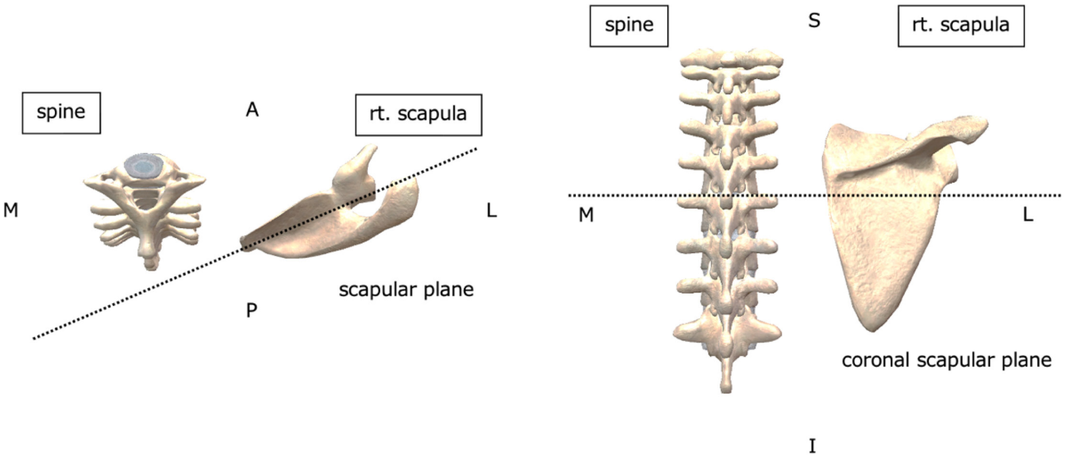

**Fig. 4.** Scapular plane and coronal scapular plane (Citation: Visible Body).
The definitions of the scapular plane and coronal scapular plane are shown in the figure.
A: anterior; L: lateral; M: medial; P: posterior; I: inferior; S: superior; rt.: right.

and imaging was performed with a break in between. When imaging was performed in the area around the thorax, image distortion due to respiration was allowed; when noise was detected, additional imaging was performed as necessary.

The data measured using the VICON MX were analyzed using Visual 3D (C-Motion, Inc., Boyds, MD, USA). Two parameters were calculated: 1) the amount of change in the angle of the scapula from the static position associated with shoulder joint motion; and 2) the change in the angle of upward/downward rotation of the scapula from 100° of shoulder joint abduction associated with shoulder joint motion defined as the angle formed between the straight line connecting the two markers at the posterior end of the T-shaped pad and the straight line connecting the Th3 and Th8 spinous processes. The angle between these two lines projected onto the scapular plane (defined by the three points of the Th3 spinous process, the Th8 spinous process, and the acromion on the dominant side) was calculated using Visual3D. The angle between the internal/external rotation of the scapula was defined as that formed between the straight line connecting the two markers at the posterior end of the T-shaped pad and the straight line connecting the Th3 spinous process and the suprasternal notch. The rotational angle projected onto the plane perpendicular to the scapular plane was calculated. The scapular angle at each shoulder position was averaged over a total of 2 s (500 frames) from 1 to 3 s after the start of the measurement, and the average of three trials was used as the representative value for each shoulder position. The scapular angle in the static position was similarly calculated. Based on these regulations, the scapular angles in the static position and the six shoulder joint positions were calculated.

The Image data obtained using gravity MRI were analyzed using Adobe Photoshop (Adobe Inc., San Jose, CA, USA). The angular change in scapular motion was calculated as described above. The angle between the vertical and horizontal lines on the PC monitor was set at 90°. The relative angles between the scapula and the line connecting the two vertebrae and between the scapula and the sternum were then calculated (Fig. 5). The angles of upward/downward rotation of the scapula were measured in the scapular plane. Upward rotation was defined as a positive value and the angle between the line connecting the Th3 vertebral body center and the Th8 vertebral body center and the scapular spine. The internal/external rotation angles of the scapula were measured in the coronal scapular plane. The internal rotation angle was defined as the positive value, the angle between the center of the suprasternal notch and the center of the thoracic vertebral body in the same section and the center of the humeral head and the most medial portion of the scapula. In addition to the analysis of the measurement results using the optical motion analyzer, the scapular angles in the static position and six shoulder joint positions were calculated based on these provisions.

SPSS version 27 (IBM SPSS Statistics; Japan IBM, Tokyo, Japan) was used for the statistical analysis, and the Shapiro–Wilk test was used to verify the normality of the analyzed data from the gravity MRI images. The intraclass correlation coefficient (ICC) (1,1) was calculated for the normally distributed data. A Bland–Altman analysis was performed between the scapular angle changes determined from the MRI images and the optical motion analyzer. The mean and difference of the two measurement methods were plotted on the graph, and if the difference was within the range of error (limits of agreement; LOA), the two methods agreed. LOA was calculated as “mean of difference ± 1.96 × standard deviation of difference”. Statistical significance was set at 5%.

## RESULTS

The reliability of the scapular angle changes obtained from the gravity MRI images was confirmed using a test-retest method performed at a 7-day interval randomly selected participants. The reliability of the amount of angular change in

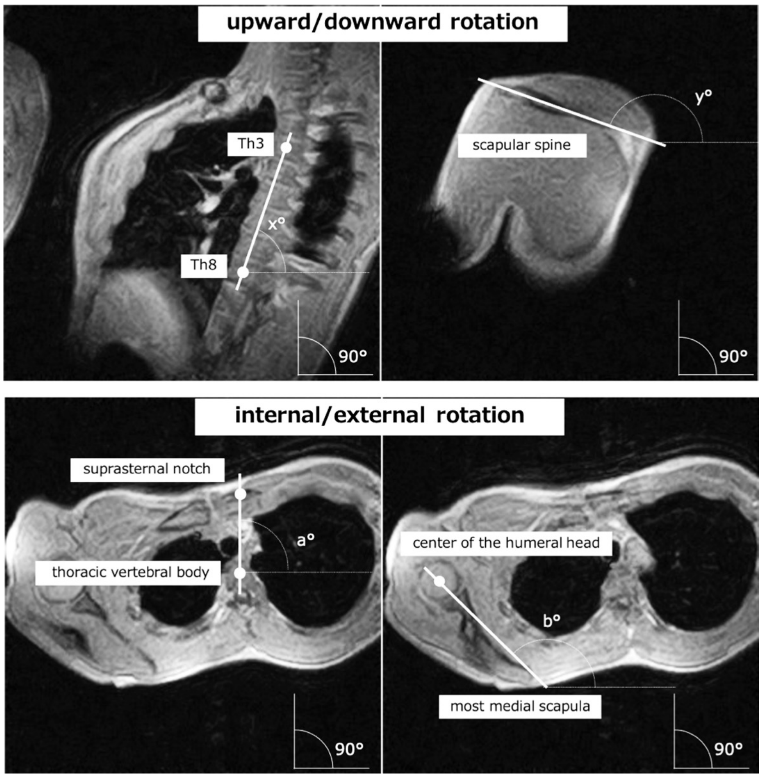

**Fig. 5.** Calculation of scapular upward/downward and internal/external rotation angles on magnetic resonance images.
About upward/downward rotation, appropriate images were extracted from the layer images, and the angles were calculated as follows: x + (180−y) degrees, where x is the angle of the spinal column and y is the angle of the scapula. About internal/external rotation, appropriate images were extracted from the layer images, and the angle was calculated as follows: 180 + (a−90) −b degrees, where x is the angle of the spinal column and y is the angle of the scapula.

scapular upward/downward rotation and internal/external rotation in the two shoulder joint positions (flexion, 140°; abduction, 140°) was confirmed. Normality was observed for all MRI analysis data, and the ICC (1,1) was >0.9.

The Bland-Altman analysis showed agreement between the values of the scapular upward/downward rotation at 140° of flexion, 160° of flexion, and 120° of abduction. Fixation errors were also observed in all three cases. No agreement was observed for 100°, 140°, or 160° of abduction. Concerning scapular internal/external rotation, agreement was found only at 140° of abduction, confirming a chance error; otherwise, agreement was lacking. Similarly, no agreement was found for the change from 100° of abduction in any of the three trials (Table 1).

# DISCUSSION

This study aimed to verify whether scapular motion measured using a T-shaped pad with retroreflective markers and an optical motion analyzer could reflect scapular motion calculated using gravity MRI images and clarify its validity.

Bland–Altman analysis was used to examine the concordance of the results. Concordance was noted between 140° and 160° of flexion and 120° of abduction during scapular upward/downward rotation. Agreement was noted in 140° of shoulder abduction during scapular internal/external rotation. However, many of the measurements were inconsistent, and we believe that the method used in this study did not reveal agreement between the two measurement devices. One reason for this result is that the orthotropic body coil used for MRI imaging was small, and it is possible that MRI images in the static position were not captured because of the correction for scapular elevation and other factors. Another reason for this result may be that scapular angle changes were scarce in the shoulder flexion position, as the measured limb positions were only 140° and 160°, relatively close to the maximum flexion angle. It was previously reported that the amount of change in the scapular upward rotation angle decreases as the shoulder joint flexion angle increases[13], and it is possible that the machine could not track small changes because the participants performed the motions at positions close to the final flexion range of the shoulder joint.

Internal/external rotation movements reportedly do not change in a constant direction of rotation with increasing shoulder flexion angle but rather irregularly with internal/external rotation[13, 15–19]. Given the small angular change in the same movement[12, 15] and the fact that the final limb position is the same in shoulder joint flexion and abduction, it is assumed that the same movement is performed in shoulder joint abduction, and the ambiguity of the movement may have affected the results.

**Table 1.** Results of Shapiro–Wilk tests, calculation of intraclass correlation coefficient, and Bland–Altman analysis (N=12)

| | | Shapiro–Wilk | ICC | | Bland–Altman analysis | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Statistics | (1,1) | 95% CI | MRI | Optical motion analyzer | Mean of difference | Standard deviation of difference | LOA |
| Flex 140° | Up/down | 0.904 | 0.902 | 0.709–0.971 | 43.2 ± 6.5 | 51.7 ± 9.7 | −8.43 | 10.9 | −29.8 to 12.9* |
| | In/ex | 0.972 | 0.956 | 0.860–0.987 | 4.9 ± 6.7 | −14.1 ± 17.9 | 19.0 | 20.1 | −20.4 to 58.4 |
| Flex 160° | Up/down | | | | 48.7 ± 6.5 | 58.0 ± 9.6 | −9.3 | 11.9 | −32.6 to 13.9* |
| | In/ex | | | | 3.3 ± 8.7 | −5.6 ± 15.9 | 8.9 | 18.5 | −27.3 to 45.1 |
| Abd 100° | Up/down | | | | 40.2 ± 6.3 | 27.2 ± 6.9 | 13.0 | 5.3 | 2.6 to 23.4 |
| | In/ex | | | | −2.5 ± 6.7 | 2.2 ± 9.6 | −4.7 | 11.6 | −27.5 to 18.0 |
| Abd 120° | Up/down | | | | 45.6 ± 7.2 | 33.0 ± 8.1 | 12.6 | 7.6 | −2.3 to 27.4* |
| | In/ex | | | | −1.7 ± 8.0 | −0.9 ± 10.4 | −0.8 | 11.7 | −23.8 to 22.2 |
| Abd 140° | Up/down | 0.956 | 0.958 | 0.866–0.988 | 49.0 ± 5.3 | 40.0 ± 7.8 | 9.1 | 6.3 | −3.3 to 21.4 |
| | In/ex | 0.946 | 0.978 | 0.928–0.993 | −1.3 ± 8.5 | −3.4 ± 11.6 | 2.1 | 11.3 | −20.0 to 24.1 |
| Abd 160° | Up/down | | | | 49.7 ± 5.4 | 50.4 ± 8.0 | −0.7 | 6.7 | −13.9 to 12.6 |
| | In/ex | | | | −1.4 ± 9.3 | −2.9 ± 12.7 | 1.5 | 13.8 | −25.4 to 28.5 |
| Abd 120° | Up/down (from abd 100°) | | | | 5.4 ± 5.0 | 5.8 ± 4.0 | −0.5 | 5.1 | −10.4 to 9.4 |
| Abd 140° | Up/down (from abd 100°) | | | | 8.8 ± 7.1 | 12.8 ± 6.0 | −4.0 | 6.0 | −15.8 to 7.8 |
| Abd 160° | Up/down (from abd 100°) | | | | 9.5 ± 6.4 | 23.2 ± 7.7 | −13.7 | 5.1 | −23.7 to −3.7 |

Flex: shoulder joint flexion; Abd: shoulder joint abduction; Up/down: upward/downward scapular rotation; In/ex: internal/external scapular rotation; ICC: intraclass correlation coefficient; 95% CI: 95% confidence interval; MRI: magnetic resonance imaging; LOA: limit of agreement.

*: the concordance of the two methods was acknowledged.

The scapula moves along the dorsal aspect of the rib cage as the upper arm Is raised[7)], and the bony landmarks corresponding to the fixed part of the retroreflective markers in the optical motion analysis move significantly as if sliding under the body's surface. Displacement of the distal end of the acromion reportedly differs only slightly[8)], but this error is said to cause the skin movement artifact[20)], and it cannot be denied that this may have affected the present study's results. Therefore, interpretation of the motion analysis of the scapula using an optical motion analyzer with retroreflective markers requires careful judgment.

The limitations of this study include the fact that the experimental environment was limited by the structure of gravity MRI, which limited the shoulder motion angles and types and the measurement positions, and that only a single quadrature body coil was used. In this study, no data analysis was performed of the anterior and posterior tilt angles of the scapula. Scapular motion, which is primarily three-dimensional, was evaluated only two-dimensionally, and we were unable to determine the angle itself. Furthermore, the measurements were not taken simultaneously by the two instruments; therefore, they may not be strictly comparable.

As increasingly more complicated shoulder joint motions and associated scapular motions occur in daily life and sports activities, future studies of various motions will be necessary. Moreover, the validity of tracking scapular motion using an optical motion analyzer can be clarified by expanding the number of participants and improving the experimental methods to determine whether the system applies to them. The resolution of the limitations of this study will require the use of 3D MRI images and the development of special coils to enable image acquisition of shoulder joint motion and associated scapular motion over a wider range.

In conclusion, our results suggest that scapular motion measurements of the optical motion analyzer are poorly consistent with the angular change measurements of gravity MRI. However, skin motion artifacts and other factors may have influenced the results, and careful judgment is needed to interpret the results of the scapular motion analysis using this device. Further studies of the validity of this method are required to confirm its usefulness.

## *Funding and Conflict of interest*

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