INTRODUCTION

Tightness of the posterior shoulder capsule is common in overhead athletes, such as baseball and handball players. Previous biomechanical studies using fresh-frozen cadavers reported that posterior shoulder capsule tightness induced abnormal translation of the humeral head during shoulder flexion, and external rotation at shoulder abduction. Thus, posterior shoulder capsule tightness is a factor for subacromial and internal impingement, which may lead to rotator cuff tears and labrum lesions.

Stretching is often used to both prevent and treat tightness of soft tissues during rehabilitation. Although many previous studies targeting overhead athletes...
indicated that sleeper (ie, internal rotation at 90 degrees of shoulder flexion) and cross-body (ie, horizontal adduction at 90 degrees of shoulder elevation) stretching were effective to treat tightness of the posterior shoulder tissues,\textsuperscript{11-17} it is unclear whether passive tension develops in the posterior shoulder capsule during stretching. Conversely, previous studies quantified passive tension or strain in the posterior capsule and identified stretching positions that created the greatest amount of passive tension or strain in the posterior capsule of fresh-frozen cadavers.\textsuperscript{18-20} One of these positions was shoulder internal rotation at 30 degrees of scapular plane elevation (scaption)\textsuperscript{18,19}; however, it is unknown whether passive tension also develops in the posterior capsules of overhead athletes using this stretching position. There may be a difference in response to stretching in the posterior capsules of old cadavers versus young overhead athletes who commonly experience tightness of the posterior capsule.\textsuperscript{1-5}

Shear wave elastography (SWE) is an ultrasound-based imaging modality that provides a noninvasive estimate of tissue mechanical properties; it measures the speed of shear wave propagation through soft tissues. SWE is recognized as a useful tool for noninvasively estimating passive capsule\textsuperscript{21} and muscle\textsuperscript{22} tension.

Prior to evaluating the passive tension of posterior shoulder capsules during stretching, we needed to clarify that the stretching position identified in previous cadaveric studies could be simulated in baseball players. Therefore, the first experiment aimed to investigate whether the stretching position as identified in cadaveric studies could be simulated in baseball players. The second experiment aimed to investigate whether passive tension develops in the posterior shoulder capsules of baseball players during this stretching position using the SWE. We hypothesized that the stretching position identified in cadaveric studies could be simulated in baseball players in experiment 1 and that passive tension would develop in the posterior shoulder capsules of baseball players during this stretching position in experiment 2.

## MATERIALS AND METHODS

### 2.1 Experimental design

The study design was a laboratory-based cross-sectional study. First, we measured the glenohumeral joint angles during stretching exercises in baseball players in experiment 1. Second, we measured the shear moduli of posterior shoulder capsules of baseball players in stretching positions in experiment 2.

### 2.2 Ethics

Ethics Committee of the Sapporo Medical University reviewed and approved the study protocol (29-2-30). Written informed consent was obtained from each subject.

### 2.3 Experiment 1

#### 2.3.1 Subjects

Four male baseball players participated in experiment 1 during the off-season. Subjects with a history of significant shoulder injuries or surgeries (such as fractures or dislocations), or those presenting with significant injuries at the time of examination, were excluded.
2.3.2 Stretching maneuver

Subjects were seated upright on a chair with their trunks immobilized using belts. Based on previous cadaveric studies, a shoulder internal rotation at 30 degrees of scaption was indicated to be the effective stretching position for the posterior capsule.\textsuperscript{18,19} To simulate this position, the first investigator held the subject’s shoulder at 30 degrees of scaption with 90 degrees of elbow flexion, while a second investigator immobilized the subject’s scapula. The first investigator then proceeded to internally rotate the subject’s shoulder until the subject’s palm touched their stomach; this was defined as the start position. In the start position, the first investigator held the subject’s palm to their stomach, while pulling their distal humerus anterior and medial in 10 N increments; subjects’ shoulders were internally rotated until they felt pain or discomfort (Figure 1), and the pulling direction was perpendicular to the long axis of the subject’s humerus in the horizontal plane. The point of force application was 20 cm from the estimated center of the humeral head. The pulling force was quantified using a digital push-pull gauge (RX-50, Aiko Engineering Co., Ltd, Osaka, Japan). The second investigator immobilized the subject’s scapula as much as possible during force application.

2.3.3 Joint angle measurement

We used a 6-degree-of-freedom electromagnetic tracking device (3Space Fastrak, Polhemus, Colchester, Vermont, USA) to measure the glenohumeral joint angles during stretching exercises. First, we set a transmitter—a generational source of the magnetic field—in front of the subject. We then attached sensors (Micro Sensor 1.8, Polhemus) to the subject’s acromion and humeral shaft (via a thermoplastic cuff at the midpoint of the humerus\textsuperscript{23}) for the scapular and humeral segments, respectively (Figure 2). We subsequently recorded the position of the bony landmark’s three-dimensional coordinates at 0 degrees of shoulder elevation with 0 degrees of shoulder rotation. The positions of all bony landmarks were based on the International Society of Biomechanics recommendations\textsuperscript{24}; the acromial angle (AA), base of the spine (BS), and inferior angle (IA) were the scapular landmarks; and the medial (ME) and lateral epicondyles (LE) were the humeral landmarks (Figure 2). We also recorded the three-dimensional coordinates of both acromioclavicular joints to calculate the center of the glenohumeral joint. With a 750-mm range from the source, the positional accuracy was 0.8 mm root mean square (RMS); the angular accuracy was 0.5 degrees RMS.

2.3.4 Data analysis

The local three-dimensional coordinates—obtained by two sensors—were transferred to a global three-dimensional coordinate system, generated by the transmitter using numerical software (MATLAB R2020a, MathWorks, Natick, Massachusetts, USA). The coordinate system was defined as shown in Table 1\textsuperscript{24} using motion analysis software (Visual 3D, C-motion, Germantown, Maryland, USA):

The glenohumeral joint angle was defined as the change in position of the humeral coordinate system with respect to the scapular coordinate system by the Euler angle. Motion of the glenohumeral joint included flexion/extension, horizontal adduction/abduction, and internal/external rotation. We calculated the amount of change of internal rotation angle from the start position to the stretching position.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{The location of sensors (A) and bony landmarks (B). (A) Sensors were attached on the subject’s acromion and the shaft of the humerus (using a thermoplastic cuff at the midpoint of the humerus) as the segment of scapular and humerus, respectively. (B) The AA, BS, and IA were the scapular landmarks. The ME and LE were the humeral landmarks. AA, acromial angle; BS, base of the spine; IA, inferior angle; GH, center of the glenohumeral joint; ME, medial epicondyles; LE, lateral epicondyles} \end{figure}
2.4 | **Experiment 2**

2.4.1 | **Subjects**

Fifteen male baseball players were examined during the off-season. The exclusion criteria were based on experiment 1.

2.4.2 | **Measurement position**

We measured elasticity on the subject's dominant side in both the resting and stretching positions. In the resting position, subjects were seated upright on a chair with their forearm set on a stand to maintain 30 degrees of shoulder flexion with 0 degrees of shoulder rotation (Figure 3). Stretching maneuvers were based on experiment 1. We pulled the subject’s distal humerus anterior and medial to internally rotate the shoulder until subjects felt pain or discomfort; this was defined as the stretching position.

2.4.3 | **Elasticity measurement**

An SL10-2 linear array transducer (AixPlover Ver. 6, SuperSonic Imagine, Aix-en-Provence, France) was used to measure elasticity using SWE. We measured the shear moduli of the middle and inferior posterior capsules (MPC and IPC, respectively), superior and inferior infraspinatus (SISP and IISP, respectively), teres minor (TM), and posterior deltoid (PD) in random order; the location of the probe was based on previous studies.\(^2,18,25\) For the MPC, the probe was placed on the posterior aspect of the shoulder, and a long-axis scan of the SISP was obtained. The location of the probe was then adjusted to clearly visualize the humeral head, glenoid rim, labrum, and SISP, and the elasticity of the MPC beneath the SISP was measured. For the IPC, the probe was placed on the postero-inferior aspect of the shoulder to visualize the IPC beneath the TM. The location of the probe was adjusted to clearly visualize the humeral head, glenoid rim, labrum, and TM, and the elasticity of the IPC was measured.

We defined the measurement site of the SISP as the intersection of the line connecting the greater tubercle to the quarter point between the trigonum scapulae and IA and the line connecting the IA to the halfway point between the trigonum scapulae and AA. The measurement site of the IISP was defined as the intersection of the line connecting the greater tubercle to the three-quarter point between the trigonum scapulae and IA, and the line connecting the IA to the halfway point between the trigonum scapulae and AA. The measurement site of the TM was defined as the halfway point between the IA and the greater tubercle, and

| TABLE 1 | Coordinate system definitions |
|---------|-----------------------------|
| **Origin** | X-axis |
| The AA | The line perpendicular to the plane formed by the IA, AA, and BS |
| **Y-axis** | Z-axis |
| The GH | The common line perpendicular to the Y- and Z-axes |
| **Z-axis** | The line connecting the GH and the midpoint of the ME and LE |

Abbreviations: AA, acromial angle; BS, base of the spine; GH, center of the glenohumeral joint; IA, inferior angle; LE, lateral epicondyle; ME, medial epicondyle; TM, teres minor; IPC, inferior posterior capsule; MPC, middle posterior capsule; SISP, superior infraspinatus; IISP, inferior infraspinatus; PD, posterior deltoid.
the measurement site of the PD was defined as the point 4 cm below the AA. We positioned the probe at the measurement sites parallel to the capsule or muscle fibers; to minimize measurement error, we measured the shear moduli of capsules and muscles for each position in duplicate.

2.4.4 | Data analysis

The elasticity analysis software embedded in the SWE was not sufficient for analyzing capsules in this study, as it did not allow for a circular region of interest (ROI) with a diameter <1 mm. Capsules often have a thickness <1 mm; thus, we exported the elasticity images in JPEG format and analyzed the elasticity using custom analysis software (S-14133 Ver.1.2, Takei Scientific Instrument Co., Ltd.). Using this software, the ROI can be arbitrary in size and shape, and can be located anywhere on the elasticity image; additionally, the elastic modulus calculation is based on the color map scale. In this study, a rectangular ROI (width: 3 mm; height: 0.5 mm) was set 5 mm lateral to the edge of the labrum (Figure 4). The center

FIGURE 3 Resting position. The subjects were seated upright in a chair with their forearm set on a stand to maintain 30 degrees of shoulder flexion with 0 degrees of shoulder rotation.

FIGURE 4 Location of the regions of interest (ROI) for the capsule (A) and muscle (B). (A) For capsules, a rectangular ROI (width, 3 mm; height, 0.5 mm) was set 5 mm lateral to the edge of the labrum. (B) For muscles, three adjacent circular ROIs were set at the midpoint of the muscle belly.
The height of the ROI was aligned with the center thickness of the capsule, and the mean value of Young's modulus in the ROI was the representing value of each image.

The software program embedded in the SWE was used for the elasticity analysis of the muscles. Three adjacent circular ROIs with a 5-mm diameter were set at the midpoint of the muscle belly (Figure 4). The mean value of Young's modulus in the three ROIs was the representing value of each image. In the SWE software, Young's modulus was quantified in kilopascals (kPa) based on the shear wave propagation speed ($c$). For each ROI, Young's modulus ($E$) was deduced from $E = 3\rho c^2$, where $\rho$ (density) is assumed to be constant (1000kg/m$^3$) in human soft tissues. The SWE software calculated Young's modulus based on the supposition that biological tissue is an isotropic material; however, muscles and capsules are not isotropic. Therefore, we determined the shear modulus by dividing Young's modulus by 3. For each image, the ensemble mean across the two images was regarded as the shear modulus of the tested capsule and muscle at that position.

All shear moduli data were analyzed using SPSS Statistics Ver.25.0 for Windows (IBM). The stress-strain relationship was markedly different between the capsule and muscle, indicating a large difference in mechanical characteristics between the two. To test the difference in shear moduli between tissues in the resting or stretching position, we first compared the shear moduli using one-way repeated-measures analysis of variance (ANOVA), with tissues as a within-subject factor; a Tukey's post hoc test was used if significant main effects were observed. If there was a great effect in tissues, each tissue was separately compared using a paired $t$-test to determine whether stretching significantly affected the shear modulus. The level of significance was set at $P < .05$. In addition, we conducted a priori power analysis to determine the required sample size using G*Power 3.1 (Heinrich Heine University, Dusseldorf, Germany). We estimated that a sample size of 15 participants was required based on a 0.8 effect size, 0.05 alpha-level, and 0.8 desired power level to detect the difference of mean between two dependent variables in a paired $t$-test.

### TABLE 2 Demographic data

|                          | Experiment 1 ($n = 4$) | Experiment 2 ($n = 15$) |
|--------------------------|------------------------|-------------------------|
| Age (y)                  | 21.3 ± 0.5             | 22.6 ± 3.7              |
| Height (cm)              | 171.5 ± 4.7            | 171.2 ± 5.9             |
| Weight (kg)              | 59.4 ± 5.3             | 67.0 ± 8.8              |
| Dominant side (Right:Left) (n) | 4:0                  | 13:2                    |
| Position (Pitcher:Fielder) (n) | 0:4                | 1:14                    |
| Career length (y)        | 9.0 ± 0.0              | 11.9 ± 2.2              |

**FIGURE 5** Amount of internal rotational angle change in the glenohumeral joint. Increasing values represent increasing internal rotation angle. The glenohumeral joint was gradually internally rotated in response to the stretching force in all subjects.
3 | RESULTS

3.1 | Demographic data

Demographic data of experiments 1 and 2 were shown in Table 2.

3.2 | Experiment 1

Two subjects experienced pain or discomfort at 100 N of force, while the other two subjects experienced it at 70 N. The glenohumeral joint was gradually internally rotated in response to the stretching force in all subjects (Figure 5); on average, the increase in internal rotational angle from the starting to stretching positions was 27.8 ± 9.9 degrees.

3.3 | Experiment 2

Results of the one-way ANOVA indicated significant main effects in the resting (P < .001) and stretching positions (P < .001) (Figure 6). In the resting position, Tukey’s test indicated that the shear modulus of the MPC was significantly higher than those of the SISP (P < .001), IISP (P < .001), and TM (P < .001); the shear modulus of the IPC was significantly higher than those of the SISP (P < .001), IISP (P < .001), TM (P < .001), and PD (P = .035); and the shear modulus of the PD was significantly higher than those of the SISP (P = .014) and IISP (P = .002). In the stretching position, Tukey’s test indicated that the shear modulus of the MPC was significantly higher than those of the SISP (P < .001), IISP (P < .001), TM (P < .001), and PD (P = .002); the shear modulus of the IPC was significantly higher than those of the SISP (P = .008), IISP (P < .001), and TM (P = .003); and the shear modulus of the PD was significantly higher than that of the IISP (P = .011).

This study aimed to investigate whether passive tension was generated within the posterior shoulder capsules of baseball players during shoulder internal rotation stretching at 30 degrees of scaption. To the best of our knowledge, this is the first study to measure the passive tension of the posterior shoulder capsule during stretching in baseball players. Previous cadaveric studies reported that one of the stretching positions that causes the greatest amount of passive tension or strain in the posterior shoulder capsule was shoulder internal rotation at 30 degrees of scaption.18,19 We modified the stretching position from previous in vitro studies18,19; thus, it could be implemented in vivo. The resultant kinematic data confirmed that the glenohumeral joint was internally rotated in the stretching position, as expected.

The shear modulus reflects the passive tension in the muscle22 and capsule21 tissues. Our results revealed passive tension in the MPC to be significant in the stretching position, consistent with the findings of previous cadaveric studies18,19; this result supported our hypothesis.

Tissues had a great effect (ie, the shear modulus was four times greater in the IPC than in the IISP in the resting position); thus, each tissue was separately compared using a paired t test. Results of the paired t-test indicated that the shear moduli of the MPC (resting vs stretching: 20.9 kPa vs 34.6 kPa, P < .001), SISP (7.2 kPa vs 17.6 kPa, P < .001), TM (8.8 kPa vs 16.4 kPa, P = .001), and PD (15.2 kPa vs 21.3 kPa, P = .001) were significantly higher in the stretching position than in the resting position (Figure 7); however, there was no significant difference in the shear moduli between the resting and stretching positions in the IPC (22.3 kPa vs 29.5 kPa, P = .120) and IISP (5.6 kPa vs 9.7 kPa, P = .089) (Figure 7).

4 | DISCUSSION

FIGURE 6 Comparison of the shear moduli among tissues. The shear moduli of the capsules were higher than those of most muscles in the resting and stretching positions. MPC, middle posterior capsule; IPC, inferior posterior capsule; SISP, superior infraspinatus; IISP, inferior infraspinatus; TM, teres minor; PD, posterior deltoid. * P < .05 for comparison with the SISP; † P < .05 for comparison with the IISP; ‡ P < .05 for comparison with the TM; § P < .05 for comparison with the PD
Unexpectedly, passive tension in the SISP, TM, and PD also increased during stretching; however, the increase was smaller than that in the MPC (the shear moduli of the MPC, SISP, TM, and PD increased by 13.7 kPa, 10.4 kPa, 7.6 kPa, and 6.1 kPa in the stretching position, respectively). According to previous studies using cadavers, the stretching positions that caused the greatest amount of passive tension or strain on the SISP, TM, and PD were shoulder internal rotation at 30 degrees of extension,29 shoulder internal rotation at 90 degrees of flexion,18 and shoulder horizontal adduction at 90 degrees of elevation,18,29 respectively. It is difficult to explain the reason for the difference between previous and current results; however, the difference between cadavers and living humans may cause this inconsistency. The neuromuscular system, such as muscle spindle and Golgi tendon organ reflex may generate muscle tension and increase shear moduli during stretching in vivo. Nevertheless, this stretching position may be useful to treat and prevent tightness of the posterior capsules—as well as muscles—in baseball players. Conversely, our results showed that insufficient passive tension was created in the IPC in this stretching position. According to a recent cadaveric study, the stretching position found to create significant passive tension in the IPC was shoulder internal rotation at 30 degrees of shoulder flexion18; therefore, passive tension in the IPC may have increased further if the shoulder horizontal adduction angle was larger during stretching.

The present study has some limitations. First, we could not simulate the exact stretching position reported in previous cadaveric studies; however, we confirmed that the stretching position used was kinematically similar to those recommended. Moreover, it is clinically useful, as this stretching method allows overhead athletes to exercise by themselves. Second, we recruited only asymptomatic baseball players in this study. It is unclear whether the same results would be observed in symptomatic baseball players, as they may have severely thicker and shorter posterior shoulder capsules than asymptomatic players30,31; therefore, future studies are required to investigate whether these results translate to symptomatic overhead athletes. In conclusion, passive tension of the MPC increased during shoulder internal rotation stretching at 30 degrees of scaption in baseball players.

FIGURE 7 Comparison of the shear moduli between the resting and stretching positions. The shear moduli of the middle posterior capsule, superior infraspinatus, teres minor, and posterior deltoid were higher in the stretching position than in the resting position. There was no difference observed in shear moduli between the stretching and resting positions in the inferior posterior capsule and inferior infraspinatus. *P < .05 for comparison with the resting position

5 | PERSPECTIVE

To the best of our knowledge, this is the first study to investigate passive tension of the posterior capsule during
stretching in overhead athletes. The results of this study suggest that shoulder internal rotation stretching at 30 degrees of scaption can relieve tightness of the posterior capsule. Future studies should investigate whether this position decreases stiffness of the posterior capsule and reduces the incidence of shoulder injuries in overhead athletes.

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CONFLICT OF INTEREST
The authors have no conflict of interest to declare.

ETHICAL APPROVAL
This study has been approved by the Ethics Committee of the Sapporo Medical University (No 29-2-30).

PATIENT CONSENT
Written informed consent was obtained from each subject.

DATA AVAILABILITY STATEMENT
Research data are not shared.

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