RELATIONSHIP BETWEEN THE SHEAR ELASTIC MODULUS AND PASSIVE FORCE IN POSTERIOR SHOULDER CAPSULES: A CADAVERIC STUDY

Naoya Iida[1], Keigo Taniguchi[2], Kota Watanabe[2], Hiroki Miyamoto[1], Tatsuya Taniguchi[1], Toshiki Jumonji[1], Mineko Fujimiya[3], Masaki Katayose[2]

[1]Graduate School of Health Science, Sapporo Medical University, Sapporo, Japan.
[2]Second Division of Physical Therapy, School of Health Science, Sapporo Medical University, Sapporo, Japan.
[3]Second Division of Anatomy, School of Medicine, Sapporo Medical University, Sapporo, Japan.

Although shear wave elastography (SWE) has been used to indirectly measure passive force in muscle tissues, it is unknown whether SWE can be utilized to evaluate passive force in capsule tissues. This study investigated the relationship between the shear elastic modulus and passive force in posterior shoulder capsules using SWE. Four middle and four inferior posterior shoulder capsules were dissected from four fresh-frozen cadavers. Passive force (0-400 g in 25-g increments) was applied to each capsule, and elasticity was measured simultaneously using SWE. The relationship between elasticity and passive capsule force was highly linear for all tested capsules (coefficients of determination range: 0.853-0.963). SWE is a valid and useful method of evaluating indirectly and noninvasively the passive force of the posterior shoulder capsules.

KEYWORDS: shear wave elastography, posterior shoulder tightness, quantification

INTRODUCTION: Quantification of mechanical stress in soft tissue in vivo is important to understand the clinical conditions and to develop treatment methods in orthopedic diseases. Recently, shear wave elastography (SWE) has proven useful for measuring noninvasively and indirectly the passive force of muscle tissues based on evidence that the shear elastic modulus is almost perfectly correlated to passive force in muscle tissues (Koo, Guo, Cohen, & Parker, 2013). However, it is unknown whether this innovative tool can be used to evaluate passive force in capsule tissues. The purpose of the current study was to investigate the relationship between the shear elastic modulus and passive force in the posterior shoulder capsules that are intimately related to shoulder injuries in overhead athletes, such as baseball players (Muraki et al., 2010 and Mihata, Gates, McGarry, Neo, & Lee, 2015).

METHODS: Four fresh-frozen glenohumeral joints were used for this study. The sample included 4 right shoulders without osteoarthritis or rotator cuff tears. The age of the specimens at death ranged from 74 to 91 years (mean, 83.5 years). All specimens were thawed at room temperature for approximately 24 hours before preparation. After thawing, the specimens were harvested by disarticulating the scapula from the thorax. Subsequently, all remaining soft tissues, except the posterior capsule, were removed. The humerus was cut at the surgical neck, and the glenoid was transected at the base of the scapular neck. Subsequently, the posterior capsule was divided into the superior posterior capsule (Sup-PC), middle posterior capsule (Mid-PC), and inferior posterior capsule (Inf-PC) parts. Then, the glenoid was cut according to the incisions between the Sup-PC and Mid-PC and between the Mid-PC and Inf-PC to create bone-capsule-bone specimens with a width of approximately 10 mm (Fig. 1(a)). We did not use the Sup-PC because the stiffness of the Mid-PC and Inf-PC is a typical finding of overhead athletes.

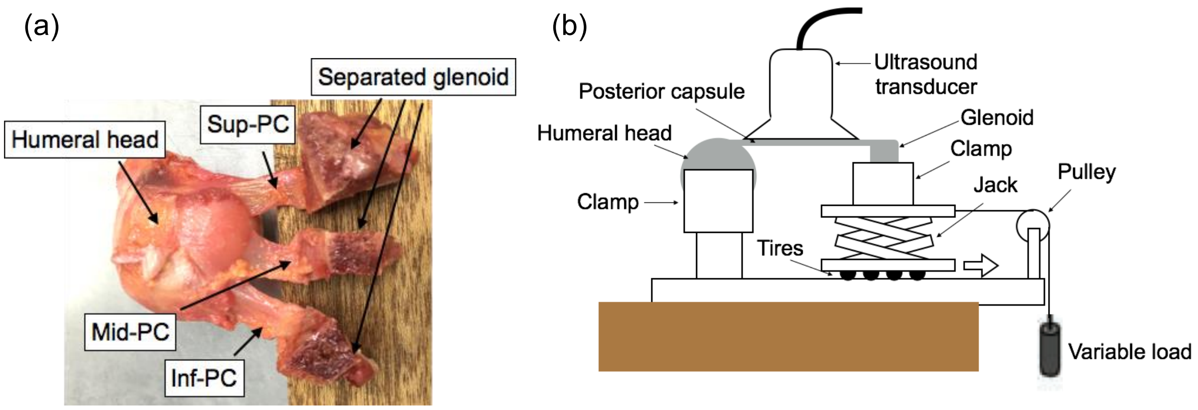

Figure 1: (a) Posterior capsules specimens of the right shoulder. (b) Experimental setup. The humeral head and the glenoid were fixed. Passive force for the capsules was applied to the glenoid through a pulley system.

Experimental setup: We used a custom-built device that was composed of two clamps, a pulley, and a cable to provide a passive load to the capsule (Figure 1(b)). The humeral head and glenoid were each immobilized with different clamps. So that the long axis of the capsule was horizontal to the floor, a height-adjustable jack was attached under the base of the clamp immobilizing the glenoid. In addition, there were very smooth tires under the jack. The base of the clamp immobilizing the glenoid was connected to the cable that provided a passive load to the capsule via a pulley. The passive load was increased stepwise from 0 to 400 g in 25-g increments (Koo et al., 2013).

Elasticity measurement: To measure the shear elastic modulus of the capsule, we used SWE with a 14-5 MHz linear ultrasound transducer (Aixplorer; Supersonic Imagine, Aix-en-Provence, France). The transducer was placed on the capsule along its longitudinal axis. The region of interest, which had a width of 3 mm and a height of 0.5 mm, was set at 5 mm lateral to the edge of the labrum. With each load, we measured the shear elastic modulus three times. To minimize creep or hysteresis effects, the elasticity measurement in each load was finished within 10 seconds. After measuring the elasticity in each load, the load was once removed from the glenoid, and the next load was applied to the glenoid after enough rest time.

Data analysis: The mean value of the three trials was used for statistical analysis. The elasticity-load relationship of each tested capsule for each loading was analyzed by fitting a least-squares regression line to the data using statistical software. Moreover, the intraclass correlation coefficient (ICC) was evaluated at each load to confirm the intra-observer reliability of the SWE measurement. The level of significance was set at $p < 0.05$.

RESULTS: Our data revealed that the relationships between the shear elastic modulus and passive capsule force were highly linear for all eight tested capsules ($p < 0.01$). The mean (±standard deviation) coefficient of determination (R^2) was 0.898 (±0.022; range 0.853 and 0.963). All data and an example are shown in Table 1 and Figure 2, respectively. The intra-observer reliability of SWE measurements was excellent at all loads (mean ICC = 0.90).

Table 1: Regression coefficient (R^2) for shear elastic modulus.

Specimen ID	Mid-PC	p value	Inf-PC	p value
1	0.861	< 0.01	0.925	< 0.01
2	0.892	< 0.01	0.853	< 0.01
3	0.931	< 0.01	0.865	< 0.01
4	0.890	< 0.01	0.963	< 0.01

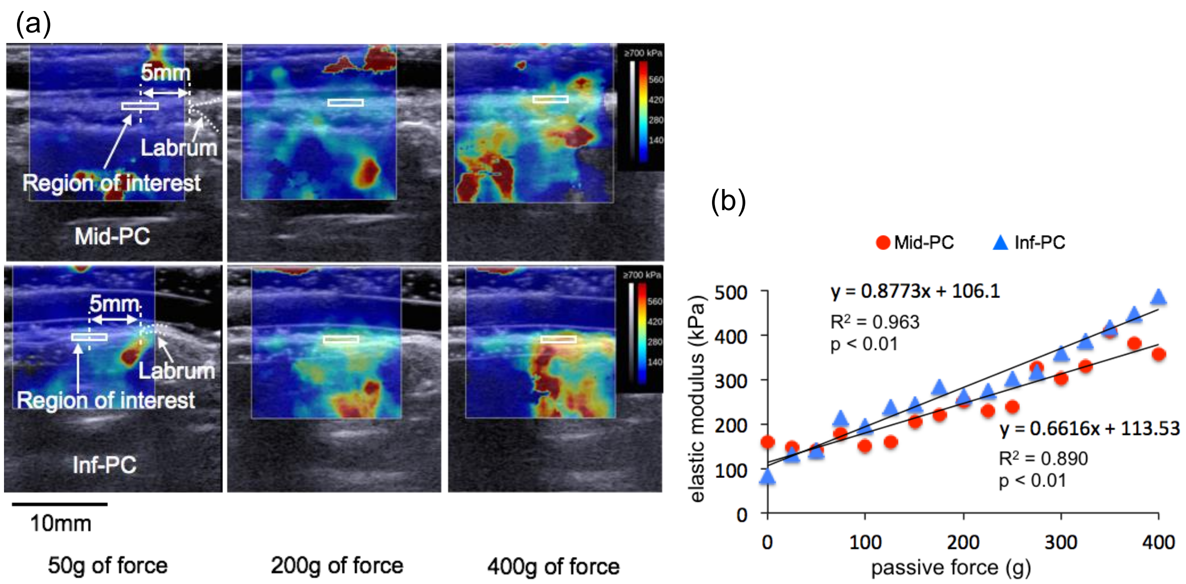

Figure 2: (a) A typical example of a SWE image. Red indicates tissue is stiff and blue indicates tissue is soft. (b) A typical elasticity–load plot.

DISCUSSION: Maisetti, Hug, Bouillard, & Nordez (2012) demonstrated that the elasticity–length relationship was highly correlated with the force–length curve in the gastrocnemius muscle during passive ankle dorsiflexion. Similarly, Koo et al. (2013) showed that the shear elastic modulus was almost perfectly correlated with passive force in the gastrocnemius and tibialis anterior muscles of fresh chickens. These previous studies indicated that the shear elastic modulus reflected the force of stretching in the muscle tissue. Therefore, SWE is a valid tool for investigating treatment methods, such as stretching maneuvers, for human muscles. The results of the current study also indicated that the shear elastic modulus was highly correlated with passive force in both Mid-PC and Inf-PC. To our knowledge, our results represent the first findings on capsule tissues. Furthermore, the ICC of the SWE measurements was excellent. Although the property of soft tissue is similar between fresh frozen cadaver and living bodies, there may be some differences in the property of capsule tissue between aged cadavers and young living bodies. However, we believed that our results could be applied to young living bodies because this study did not focus on the inherent elasticity in static condition but the change in elasticity when load was applied.

CONCLUSION: Our results showed that the shear elastic modulus measured by the SWE was highly correlated with passive force in posterior shoulder capsules. Utilizing the SWE is applicable in future studies to understand the clinical conditions and develop treatment methods, such as stretching maneuvers, for orthopedic diseases.

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