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## The functional role of the supraspinatus and infraspinatus muscle subregions during forward flexion: a shear wave elastography study



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**Background:** Knowledge of the morphological and functional differences in the anatomic subregions of the supraspinatus (SSP) and infraspinatus (ISP) muscles during forward flexion will provide useful information in the management of shoulder joint disorders. The purpose of this study was to investigate whether the SSP and ISP muscle subregions exhibit independent roles during forward flexion of the shoulder joint.

**Methods:** Eight healthy male volunteers without any restriction in their shoulder joints were recruited for this study. Participants were instructed to sit on a chair with their back against the backrest. Shear modulus (kPa) was measured as a surrogate for muscle stiffness using shear wave elastography on the SSP and ISP muscle subregions. Active measurements of the nondominant arm were obtained during isometric contraction at a neutral position and every 15° intervals from 30° to 150° during forward flexion. Friedman test and Dunn's post hoc test were used to evaluate differences in measurement outcomes among angles during forward flexion in each muscle subregion.

**Results:** Active stiffness outcomes of the anterior-middle subregion of the SSP muscle during forward flexion increased from 30° up to 45°, reaching a value of  $182.4 \pm 32.1$  kPa ( $P < .001$ ). Stiffness of the anterior-superficial subregion of the SSP muscle was highest at 30° ( $125.0 \pm 20.6$  kPa;  $P < .019$ ) and linearly decreased up to 105° with increasing shoulder angle position. Stiffness of the superior, middle, and inferior subregions of ISP muscle presented a mountain-shaped trend, with peaks of  $99.9 \pm 23.5$  kPa at 90° ( $P < .013$ ),  $144.2 \pm 11.2$  kPa at 90° ( $P < .013$ ), and  $122.9 \pm 27.9$  kPa at 105° ( $P < .007$ ), respectively. Finally, the stiffness outcomes of the pectoralis major and anterior region of the deltoid muscles showed a mountain-shaped trend with peaks of  $89.4 \pm 23.5$  kPa at 60° ( $P < .007$ ) and  $176.7 \pm 22.9$  kPa at 90° ( $P < .026$ ), respectively.

**Conclusions:** The SSP and ISP muscle subregions play a significant role during active forward flexion motion. While closely overlapped, the activity of the muscle subregions changed during the forward flexion motion range, starting with an active anterior-superficial subregion of the SSP muscle at the initial range of motion and an active inferior subregion of the ISP muscle toward midrange of motion. The SSP and ISP subregions did not demonstrate independent functional behavior during forward flexion.

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Recent morphological studies have shown that the supraspinatus (SSP) and infraspinatus (ISP) muscles can be divided into subregions.<sup>2,3,9,12,14,21,25</sup> Roh et al divided the SSP muscle into anterior and posterior regions, suggesting that the anterior region

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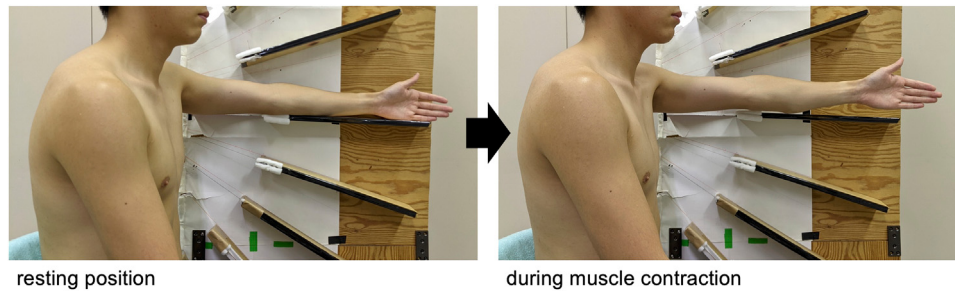
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is responsible for force production, whereas the posterior region is responsible for adjusting tension.<sup>21</sup> Kim et al further subdivided the anterior and posterior regions into superficial, middle, and deep subregions based on fiber bundle arrangement.<sup>14</sup> Similarly, Bacle et al divided the ISP muscle into superior, middle, and inferior subregions based on differences in muscle fiber orientation and intramuscular innervation.<sup>2</sup> Kato et al suggested the functional role of the superior subregion to be related to abduction, whereas the other subregions were associated with external rotation.<sup>12</sup>

Ultrasound shear wave elastography (SWE) has been used to estimate muscle function because of the linear relationship



**Figure 1** A resting position was attained by having the participants place their arm at specific intervals on the fixture; active isometric contraction measurements were obtained by moving the fixture back from the resting position and instructing the participants to hold their arm against gravity in the air, at every 15° intervals from 30° to 150° during forward flexion.

observed between muscle properties (ie, modulus) obtained with SWE and tetanic muscular force produced by electrical stimulation.<sup>22</sup> Kim et al demonstrated that the SWE-measured modulus was correlated with both joint torque and electromyography (EMG) root mean square values in the shoulder girdle muscles.<sup>13</sup> During scapular plane abduction (scaption) and rotation, individual SSP and ISP subregions have been shown to present specific activation timing and play specific roles during motion.<sup>10,11,18,26,27</sup> We have previously suggested that the middle subregion of the ISP muscle has the potential to compensate for the insufficient activity of the SSP muscle during scaption typically observed with rotator cuff tears.<sup>10</sup> Forward flexion is a common functional motion of the shoulder joint. While elevating the arm forward is more frequent than scapular plane elevation in daily life activities, there have been few studies investigating the functional role of the shoulder girdle muscles during forward flexion.<sup>8,17,23,24</sup> Higher activity of the pectoralis major and anterior region of the deltoid muscles as a prime mover during forward flexion has been consistently reported,<sup>8,17,23,24</sup> and higher activity of the ISP muscle and moderate activity of the SSP muscle as a stabilizer of the shoulder joint have been described.<sup>8,17,23,24</sup> Knowledge of the behavior of the individual SSP and ISP subregions during forward flexion will provide useful information for the management of shoulder joint disorders. We hypothesized that the SSP and ISP subregions have independent activation timing during forward flexion. The purpose of the present study was to investigate whether the SSP and ISP muscle subregions exhibit independent roles during shoulder forward flexion.

## Materials and methods

### Participants

Eight male volunteers were recruited for this study after approval by our institutional ethics review board. A priori sample size calculation using G\*Power statistical software (version 3.1, Germany) resulted in 8 individuals (effect size = 0.4,  $\alpha$  error = 0.05) for a one-way analysis of variance with repeated measures and a power greater than 95%.<sup>4</sup> Participants had no history of orthopedic disease, trauma, nor any abnormalities, evaluated by physical examinations, in their nondominant shoulder. Neer's sign was positive in the dominant arm of 1 participant. Thus, nondominant shoulders were evaluated in this study. Participants were requested not to exercise the upper body the day before the study. Written informed consent was obtained from all participants.

### Experimental protocol

An Aixplorer ultrasound scanner (Supersonic Imagine, Aix-en-Provence, France) and a 15–4 MHz linear array probe were used

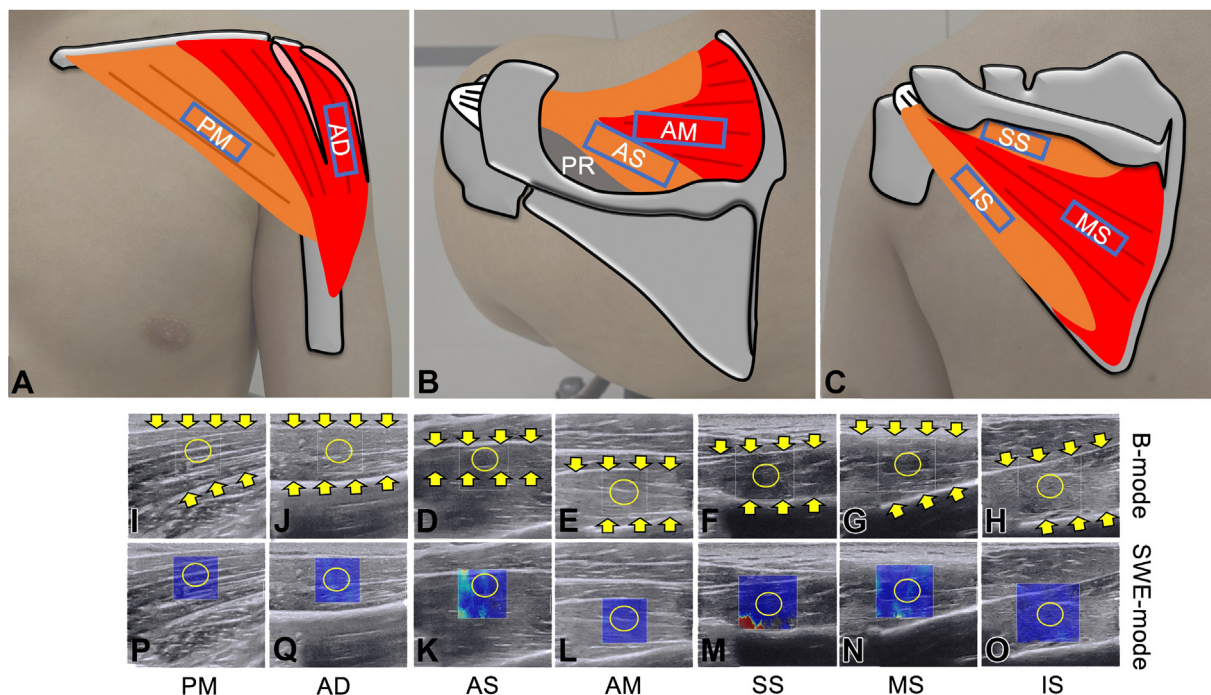
to measure muscle shear modulus (kPa) as a surrogate for stiffness. The stiffness of 2 subregions (anterior-superficial and anterior-middle) of the SSP muscle and 3 subregions (superior, middle, and inferior) of the ISP muscle were obtained in the nondominant arm of the participants. In addition, the stiffness of the sternoclavicular region of the pectoralis major and anterior region of the deltoid muscles were also obtained to compare with their activation timing reported in previous EMG studies. The participants were instructed to sit on a chair and asked to rest their arms on a hand-made semicircular protractor at 15° intervals from 30° to 150° in forward flexion and neutral rotation. At each position, the active stiffness, that is, during muscle contraction, was measured while the tester moved the fixture back from the resting positions, allowing the participants to hold their arms against gravity while maintaining the same position for approximately 10 s (Fig. 1). The ultrasound probe was gently placed on the skin over the mentioned muscles and subregions (Fig. 2) using previously described methods.<sup>6,10,11,19,27</sup> These probe orientations were verified through B-mode ultrasound imaging. To measure muscle stiffness, 3 random SWE images were chosen from a continuous recording obtained during the measurements. Three regions of interest (3 mm in diameter) were placed at the center of each specific muscle subregion to obtain stiffness outcomes; this process was repeated for each shoulder position. The measurements were conducted by a single sonographer (K.H.) and supervised by Y.K.

### Statistical analysis

IBM SPSS Statistics, version 24.0 (IBM Corp., Armonk, NY, USA), was used for all statistical analyses. Intraclass correlation coefficient (ICC<sub>1,3</sub>; one-way random effects, absolute agreement, multiple measurements) was implemented to evaluate the intratester reliability of the 3 SWE images obtained from each muscle subregion for all shoulder positions during muscle contraction on all 8 participants.<sup>16</sup> Reliability was classified as poor (<0.50), moderate (0.50–0.75), good (0.75–0.90), and excellent (>0.90). Data evaluation using the Shapiro-Wilk test did not indicate a normal distribution. For this reason, nonparametric tests were conducted for further analyses. Friedman test and Dunn's post hoc test were used to evaluate differences in measurement outcomes among angles during forward flexion in each muscle subregion. Statistical significance was set at  $P < .05$ .

## Results

Participant demographics are presented in Table I. The participants' mean (standard deviation) age, body weight, and height were 21.0 (0.7) years, 60.1 (2.2) kg, and 171.0 (4.9) cm, respectively. ICC<sub>1,3</sub> analyses showed good to excellent reliability (0.86–0.99). The mean (SD) SWE-measured stiffness values during muscle



**Figure 2** (A-C) Schematic probe orientation and ultrasound imaging of the sternoclavicular region of the pectoralis major (PM) muscle, anterior region of the deltoid (AD) muscle, 2 subregions (anterior-superficial [AS], anterior-middle [AM]) of the SSP muscle, and 3 subregions (superior subregion [SS], middle subregion [MS], and inferior subregion [IS]) of the infraspinatus (ISP) muscle. (probe orientation) represented blue line boxes of PM, AD, AS, AM, SS, MS and IS in A-C. PR, posterior region of the supraspinatus muscle. (D-J) B-mode images for each subregion. indicated the border of each subregions. (K-Q) SWE images for each subregion.

**Table I**  
Participant demographics.

Participant number	Age (y)	Body weight (kg)	Height (cm)	Hand dominance	Sport (experience)
1	22	60	170	R	Truck and field (13 ~ 18 y)
2	22	64	172	R (Neer's sign +)	Baseball (13 ~ 18 y)
3	20	56	161	R	Table tennis (16 ~ 18 y)
4	21	61	168	R	Truck and field (16 ~ 18 y)
5	21	61	170	R	Basketball (13 ~ 18 y)
6	21	61	178	R	Tennis (16 ~ 18 y)
7	21	58	176	R	Truck and field (16 ~ 18 y)
8	20	60	173	L	Baseball (13 ~ 18 y)

**Table II**  
Mean (SD) values for SWE-measured stiffness during muscle contraction for each muscle subregion at various forward flexion angles.

Muscle subregion	Angle									
	30°	45°	60°	75°	90°	105°	120°	135°	150°	
AS	125.0 (20.6)	106.4 (18.8)	80.5 (21.1)	59.9 (17.4)	52.8 (12.2)	35.4* (5.3)	41.8* (9.7)	46.6* (11.6)	52.4* (12.4)	
AM	162.2 (29.7)	182.4 (32.1)	172.5 (34.6)	119.1 (24.4)	94.7 (20.6)	61.8 (20.3)	50.0* (19.0)	47.0* (17.5)	44.6* (14.2)	
SS	64.0* (13.9)	77.5 (9.4)	88.5 (16.7)	93.9 (19.0)	99.9 (23.5)	86.4 (21.3)	72.9* (19.7)	63.1* (16.5)	56.4* (14.2)	
MS	75.0* (16.4)	93.4* (14.6)	113.8 (13.2)	128.9 (8.4)	144.2 (11.2)	124.7 (15.1)	99.9 (19.4)	79.4* (17.2)	62.2* (12.4)	
IS	68.4* (16.8)	81.4* (15.1)	89.1 (15.5)	100.2 (20.0)	113.1 (19.4)	122.9 (27.9)	99.4 (35.9)	85.4* (36.3)	71.8* (35.6)	
PM	50.5* (24.3)	75.7 (19.7)	89.4 (23.5)	84.4 (19.1)	71.7 (19.2)	55.5 (19.1)	43.9* (18.1)	23.2* (11.1)	14.4* (7.5)	
AD	102.8* (32.2)	141.6 (34.4)	152.9 (29.8)	166.1 (27.2)	176.7 (22.9)	174.8 (28.6)	140.0 (25.1)	128.5* (25.0)	113.9* (28.3)	

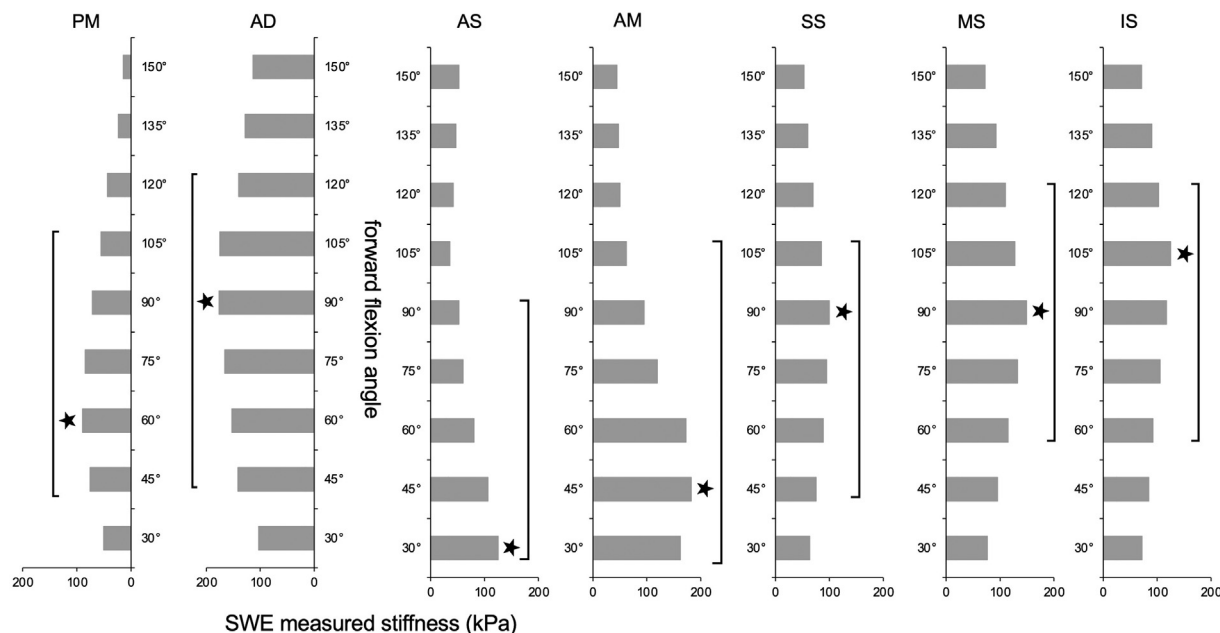
SD, standard deviation; SWE, shear wave elastography; AS, anterior-superficial subregion of the supraspinatus muscle; AM, anterior-middle subregion of the supraspinatus muscle; SS, superior subregion of the infraspinatus muscle; MS, middle subregion of the infraspinatus muscle; IS, inferior subregion of the infraspinatus muscle; PM, sternoclavicular region of the pectoralis major muscle; AD, anterior region of the deltoid muscle.

Peak stiffness values are shaded in gray.

\*Significantly smaller mean value when compared with the peak stiffness outcome.

contraction for each muscle subregion at various forward flexion angles are shown in Table II. Stiffness values from the anterior-middle subregion of the SSP muscle increased from 30° to 45° of forward flexion, reaching a value of 182.4 ± 32.1 kPa ( $P < .001$ ). The stiffness of this muscle subregion linearly decreased after 45° with

increasing elevation angles, resulting in a stiffness value of 44.6 ± 14.2 kPa at 150°. On the other hand, muscle stiffness outcomes of the anterior-superficial subregion of the SSP muscle were highest at 30° (125.0 ± 20.6 kPa;  $P < .019$ ) and linearly decreased up to 105° (35.4 ± 5.3 kPa) with increasing shoulder angle position.



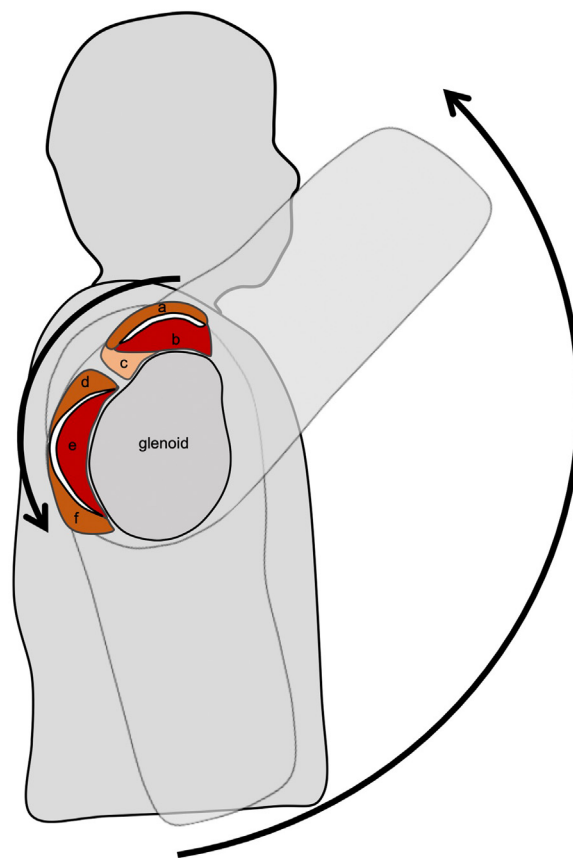
**Figure 3** SWE-measured stiffness during muscle contraction for each subregion during forward flexion at various shoulder positions. ★ indicates the elevation angle for peak stiffness during muscle contraction. [ ] indicate the active ranges for each muscle subregions. PM, sternoclavicular region of the pectoralis major muscle; AD, anterior region of the deltoid muscle; AS, anterior-superficial subregion of the SSP muscle; AM, anterior-middle subregion of the SSP muscle; SS, superior subregion of the ISP muscle; MS, middle subregion of the ISP muscle; IS, inferior subregion of the ISP muscle; SWE, shear wave elastography; SSP, supraspinatus; ISP, infraspinatus.

The stiffness of this muscle subregion increased from 105° to 150°. Finally, the stiffness outcomes of the superior, middle, and inferior subregions of ISP muscle presented a mountain-shaped trend, with peaks of 99.9 ± 23.5 kPa at 90° ( $P < .013$ ), 144.2 ± 11.2 kPa at 90° ( $P < .013$ ), and 122.9 ± 27.9 kPa at 105° ( $P < .007$ ), respectively. The stiffness outcomes of the pectoralis major muscle and the anterior region of the deltoid muscle showed a mountain-shaped trend with peaks of 89.4 ± 23.5 kPa at 60° ( $P < .007$ ) and 176.7 ± 22.9 kPa at 90° ( $P < .026$ ), respectively.

The range of angles that were not significantly different from the peak stiffness values during muscle contraction was defined as the active range (Fig. 3). The active ranges of the anterior-middle and anterior-superficial subregions of the SSP muscle ranged from 30°-90° and 30°-105°, respectively. The active ranges of the superior, middle, and inferior subregions of the ISP muscle were 45°-105°, 60°-120°, and 60°-120°, respectively. The active ranges of the pectoralis major and anterior region of the deltoid muscle ranged from 45°-105° and 45°-120°, respectively.

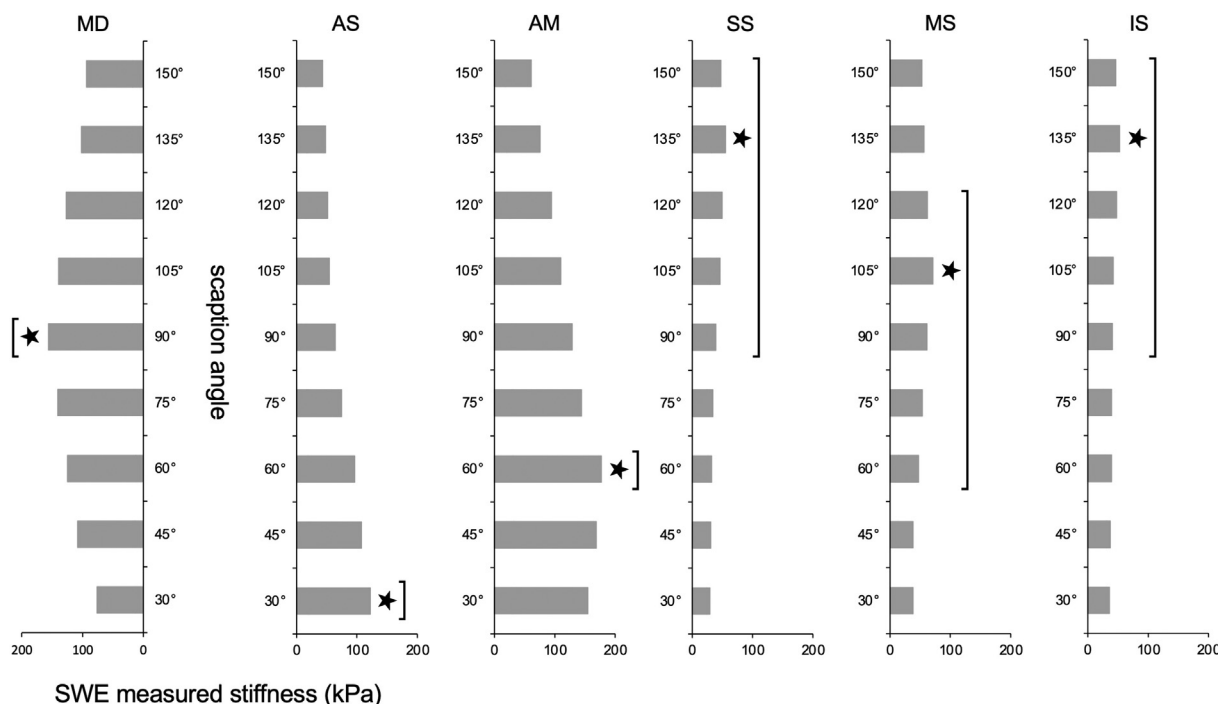
**Discussion**

The purpose of the present study was to investigate whether the SSP and ISP muscle subregions exhibit independent behavior during forward flexion of the shoulder. Our results showed that during the initiation of active range of motion, the activity of the anterior-superficial and anterior-middle subregions of the SSP muscle predominates, then transitioning to the superior, middle, and inferior subregions of the ISP muscle with increasing elevation angles. The active range of the muscle subregions changed in line with the relative position of the muscle subregions from the anterior-superficial subregion of the SSP muscle to the inferior subregion of the ISP muscle (Fig. 4). However, muscle activity from these muscles and subregions overlapped, and while all are active to various extents (Fig. 3), it cannot be said which muscle or subregion dominates motion. The SSP and ISP muscles do not seem to function independently during forward flexion.



**Figure 4** The active range of the muscle subregions changed in line with the relative position of the muscle subregions, from the anterior-superficial subregion of the SSP muscle to inferior subregion of the ISP muscle. (a) Anterior-superficial subregion of the SSP muscle, (b) anterior-middle and deep subregion of the SSP muscle, (c) posterior region of the SSP muscle, (d) superior subregion of the ISP muscle, (e) middle subregion of the ISP muscle, (f) inferior subregion of the ISP muscle. SSP, supraspinatus; ISP, infraspinatus.





**Figure 5** SWE outcomes during muscle contraction for the middle region of the deltoid muscle, SSP, and ISP muscle subregions during scapular plane abduction. ★ indicates the elevation angle for peak stiffness during muscle contraction. [ ] indicate the active ranges for each muscle subregions. MD, middle region of the deltoid muscle; AS, anterior-superficial subregion of the SSP muscle; AM, anterior-middle subregion of the SSP muscle; SS, superior subregion of the ISP muscle; MS, middle subregion of the ISP muscle; IS, inferior subregion of the ISP muscle; SWE, shear wave elastography; SSP, supraspinatus; ISP, infraspinatus.

The pectoralis major and anterior region of the deltoid muscle are defined as prime movers during forward flexion. A peak SWE outcome of the pectoralis major muscle was observed at 60°, with decreasing outcomes thereafter. SWE values from the anterior region of the deltoid muscle presented a mountain-shaped pattern with peaks at 90° and 105°. These outcomes resemble previous EMG studies of these muscles during forward flexion showing a mountain-shaped activation pattern with peaks at 60° and 90°, respectively.<sup>8,17,23,24</sup> The SSP and ISP muscles presented very interesting outcomes, with the subregions of the SSP presenting an initial activation (ie, larger SWE values with muscle contraction during flexion), and an eventual take over by the ISP muscle subregions with increasing elevation angles (Figs. 3 and 4). These results indicate that there exists individual subregion activation timing when each subregion acts as a shoulder stabilizer, which is dependent on the shoulder position and forward flexion angle. On the same note, the presence of a close overlap in the active ranges from the muscles and subregions suggests that during forward flexion, these subregions could compensate for an insufficiency present in a specific muscle subregion. As the active ranges of the ISP subregions coincided with those of the pectoralis major and anterior region of the deltoid muscles, the ISP subregions play a substantial role as a joint stabilizer during forward flexion. These relationships have been previously examined using EMG.<sup>17,24</sup> Kronberg et al reported higher activity of the ISP muscle during forward flexion and a similar activity pattern of the pectoralis major muscle.<sup>17</sup> Wattanaprakornkul et al demonstrated that the activation patterns of the ISP, SSP, and pectoralis major muscles were similar under high loads during forward flexion.<sup>24</sup> On the other hand, SWE values of the SSP subregions showed higher values in the initial and early midranges of forward flexion. We have previously demonstrated higher activity of the anterior-superficial and anterior-middle subregions of the SSP muscle at the initial range

and early midrange of scaption, respectively.<sup>11</sup> Therefore, the SSP subregions play an essential role during the initial range of motion as joint stabilizers.

Figure 5 shows SWE outcomes of the middle region of the deltoid muscle, SSP, and ISP muscle subregions previously obtained during scaption.<sup>10,11</sup> Contrary to the outcomes observed during forward flexion, the activity of the ISP and SSP muscle subregions do not show significant overlap, and the ISP muscle seems to present much lower active outcomes. Alpert et al demonstrated that EMG activation peak of the shoulder girdle muscles shifted to the initial range of scaption with increasing loads on the arm.<sup>1</sup> On a similar note, Wattanaprakornkul et al reported that EMG activation patterns of the SSP, ISP, and pectoralis major muscles are statistically correlated to load values.<sup>24</sup> These studies suggest that an intact ISP tendon and subregions are required to produce higher forces in compensation for a torn SSP tendon, whose active ranges are at the initial ranges of motion. These outcomes might provide an explanation as to why patients with rotator cuff tears rarely elevate their arm in the scapular plane but can easily elevate in the sagittal plane.<sup>15,20</sup>

This study has several limitations. First, we measured only 2 subregions of the SSP muscle, as determined by Kim et al.<sup>14</sup> Although there are studies further compartmentalizing the SSP muscle into additional subregions,<sup>5,7</sup> the selection of these regions was based on the anterior subregion being responsible for force production and the posterior subregion for an adjustment of tension on the tendon.<sup>14,21</sup> Hatta et al demonstrated that the deep region of the anterior compartment of the SSP muscle, beneath the internal tendon, presented different stiffness outcomes compared with the superior region.<sup>5</sup> We have already revealed that the anterior-superficial and anterior-middle subregions showed independent behaviors during scaption.<sup>11</sup> Therefore, measuring the anterior-superficial and anterior-middle subregions of the SSP muscle, regions superficial and deep to the internal tendon, allowed

for information of the muscle to be obtained reliably. Second, although participants included only young and healthy men, it allowed for a complete description of the SSP, ISP, deltoid, and pectoralis major muscles activation and functional roles during forward flexion. Further studies are needed to extrapolate our findings to an older population with different pathologies in the clinical setting.

## Conclusions

Active SSP and ISP muscle subregion outcomes were observed throughout the active range of motion with increasing forward flexion angles. While closely overlapped, the activity of the muscle subregions changed during the forward flexion motion range, starting with an active anterior-superficial subregion of the SSP muscle at the initial range of motion to an active inferior subregion of the ISP muscle toward midrange of motion. The SSP and ISP subregions did not demonstrate independent functional behavior during forward flexion. A close overlap in the active ranges from the muscle subregions suggests that during forward flexion these subregions could compensate for an insufficiency present in a specific muscle subregion. Our findings can provide some guidance for establishing appropriate rehabilitation protocols for shoulder related injuries.

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**Conflicts of interest:** The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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