Supraspinatus tendon thickness and subacromial impingement characteristics in younger and older adults

Tomonobu Ishigaki1,2*, Koichiro Yoshino3, Motoki Hirokawa4, Makoto Sugawara3 and Masanori Yamanaka5

Abstract
Background: Subacromial impingement (SAI) may be a cause of age-related rotator cuff abnormalities; therefore, the purpose of this study was to compare SAI characteristics between younger and older adults. In addition to the fact that thickened supraspinatus tendon (SST) indicates tendon abnormalities, SAI characteristics have been recognized as follows: greater SST thickness, reduced acromiohumeral distance (AHD), greater reduction of AHD (∆AHD) with arm elevation, and a higher percentage of SST within AHD (i.e., occupation ratio: OcAHD). Furthermore, we investigated the relationships between SST thickness and AHD, as well as SST thickness and ∆AHD to clarify the effect of SAI on rotator cuff abnormalities.

Methods: Healthy younger (n = 18, 21–24-year-old) and older (n = 27, 45–80-year-old) adults without any shoulder symptoms participated in this study. We measured their SST thickness and AHD at rest and at arm elevation (30° and 60°) in the scapular plane using ultrasound, and calculated ∆AHD as the relative change expressed as a percentage of the baseline. OcAHD was expressed as the ratio of SST thickness at rest to AHD at rest and in elevated positions.

Results: The older subjects had approximately one mm thicker SST (P = 0.003, 95% Confidence interval [CI] = 0.410 to 1.895) and approximately 1.0 to 1.3 mm greater AHD than the younger subjects (P = 0.011, 95%CI = 0.284 to 2.068 at rest; P = 0.037, 95%CI = 0.082 to 2.609 for 30° of arm elevation; P = 0.032, 95%CI = 0.120 to 2.458 for 60° of arm elevation). However, there were no differences in ∆AHD and OcAHD between the groups.

Conclusion: This study demonstrated that, compared with the younger subjects, the older subjects showed thicker supraspinatus tendon but no other SAI characteristics including decreases in AHD and increases in OcAHD. Thus, this study suggests that older subjects showed age-related SST abnormalities without SAI, although the magnitude of the differences in SST thickness is notably small and the clinical significance of this difference is unclear.

Keywords: Acromiohumeral distance, Extrinsic factor, Intrinsic factor, Occupation ratio, Supraspinatus, Tendon abnormalities

Background
Aging has been recognized as a risk factor for rotator cuff tears [1–5]. For example, Yamamoto et al. reported that the prevalence of rotator cuff tear in general population was 25.6% in their 60s, 45.8% in their 70s, and 50.0% in their 80s [5]. Degenerative histopathological changes in rotator cuff tendons exist before the tear [6], hence the rotator cuff tear in older individuals may result from age-related rotator cuff abnormalities. Therefore, it is worth investigating the underlying mechanisms for the age-related rotator cuff abnormalities to establish preventive approaches for degenerative rotator cuff tears.
Tendon thickening seems to be associated with rotator cuff abnormalities [7–9]. It is known that patients with various tendinopathy show thicker tendons [10–14]. Moreover, several studies measured rotator cuff tendon thickness using ultrasound (US) and reported that patients with subacromial impingement (SAI) syndrome and rotator cuff tendinopathy showed thickened rotator cuff tendons [7, 8, 15]. In addition, our previous study reported that, even in healthy college baseball players, increases in supraspinatus tendon thickness are associated with greater glenohumeral internal rotation deficits, which have been recognized as a risk factor for throwing-related shoulder injuries [16]. These studies [7–12, 16] indicate that increases in tendon thickness are associated with tendon abnormalities. Further, older individuals also had thickened supraspinatus tendons, that are most frequently involved in rotator cuff tears [17], compared with healthy younger individuals [9]. Considering the results of this study and the fact that the prevalence of rotator cuff tears increases with age [1–5], increases in supraspinatus tendon thickness in older individuals imply age-related supraspinatus tendon abnormalities. However, the underlying mechanism for the increase in supraspinatus tendon thickness in older individuals remains unclear.

SAI is a result of mechanical compression of the rotator cuff tendon in the reduced subacromial space [18]. Although the relationship between SAI and rotator cuff tendon injuries is still controversial, SAI has long seemed to be the major extrinsic cause of rotator cuff tendinopathy [19, 20]. Patients with SAI presented specific characteristics in comparison with healthy controls, including decreased subacromial space [21] and greater reduction in subacromial space during arm elevation [22, 23]. Furthermore, those patients also showed greater occupation ratio (OcAHD) [7], that is the percentage of the supraspinatus tendon (SST) thickness within the subacromial space [7, 24]. The acromiohumeral distance (AHD), which is measured by US, has been used to evaluate the subacromial space [7, 25, 26]. To evaluate reduction in AHD, the changes in AHD (∆AHD) were calculated as the difference in AHD among different arm positions [22, 23, 27]. Besides that the SAI is believed to be the pathomechanism of rotator cuff abnormalities, older people showed similar scapular kinematics alterations to patients with SAI [28]; thus, there may be a relationship between SAI and age-related SST abnormalities. However, the effect of aging on SAI characteristics (i.e., smaller AHD, greater reduction in ∆AHD, and greater OcAHD) is poorly documented. If age-related SST abnormalities potentially develop with SAI, the SAI characteristics would be apparent in older individuals compared to younger individuals.

This study aimed to compare SST thickness and the following SAI characteristics between younger and older individuals: AHD, ∆AHD, and OcAHD. We hypothesized that older individuals would display thicker SST and SAI characteristics when compared with younger individuals. Furthermore, because SAI characteristics were thought to affect SST thickness, we investigated whether SST thickness relates to AHD, and SST thickness to ∆AHD with arm elevation. The results of the present study provide insights into the pathogenesis of rotator cuff abnormalities with advancing age.

Methods

Subjects

Eighteen younger adults (10 male and 8 female) and 27 older adults (7 male and 22 female) participated in this study (Table 1). Because a previous study found asymptomatic rotator cuff tears in people in their 40s [29], inclusion criteria for the older group included 40-year-olds or older. In contrast, no rotator cuff tears were found in people in their 20s [5]; thus, the inclusion criteria for the younger adults was people in their 20s. Exclusion criteria for both groups were: individuals with a history of orthopedic disease affecting the shoulder and spine: those with a history of neurological, metabolic, and cardiovascular diseases: and those presenting with shoulder pain at the time of measurement. We explained the purpose of this study and the procedures to be carried out to the subjects, and written informed consent was obtained from all participants before examination. The Institutional Review Board of Hokkaido University approved this study, and all procedures were carried out in accordance with relevant guidelines and regulations.

US measurement

For US imaging, MyLab 25 (Biosound Esaote, Indianapolis, IN, USA) and FAZONE CB (FUJIFILM Co., Tokyo, Japan) with 10–12 MHz linear array transducers in gray scale B-mode were used for the younger and older subjects, respectively. We adjusted imaging parameters to obtain clear images in each subject. We used a built-in

| Table 1 Anthropometrics data (mean ± standard deviation [SD]) |
|-----------------|-----------------|
|                 | Younger         | Older           |
| Age (year-old)  | 22.4 ± 0.8      | 63.0 ± 7.7*a    |
| Height (cm)     | 167.2 ± 9.9     | 157.8 ± 9.2*b   |
| Body mass (kg)  | 58.9 ± 8.2      | 60.4 ± 12.8*c   |

*a: Significant difference between groups  

P < 0.001; t (26.808) = 27.206; 95% confidence interval [CI] = 36.875 to 44.236  

b P = 0.002; t = −3.282; 95% CI = −15.218 to −3.634  

P = 0.632; t = 0.482; 95% CI = −4.810 to 7.828
caliper system in each US unit to perform digital measurements of the SST thickness and AHD. A single examiner (T.I.) with more than 3 years of experience using the US in orthopedic clinical and research fields acquired all images from the shoulder of the subjects’ dominant arm.

For the SST measure, the participants were seated in an upright position with their feet flat on the floor. They were asked to place their tested hand on the ipsilateral iliac crest with the elbow pointed posteriorly (the modified Crass position) [24, 30, 31]. We placed the US transducer on the anterior aspect of the acromion in the coronal plane at the position where the footprint at the greater tuberosity and superior facet of the greater tuberosity were visualized. We obtained two longitudinal tendon images at this point and measured SST thickness as the distance between the deep fibers of the tendon and the peribursal fat perpendicular to the tendon fibers at the footprint-cartilage junction on the humeral head (Fig. 1a) in each image [32]. The average of two images for each measurement was used for statistical analysis. In our preliminary study with 14 healthy young individuals, the test-retest reliability of the described procedure was good to excellent (ICCs (1,2) for AHD0, AHD30, and AHD60 were 0.87, 0.75, and 0.93, respectively).

The rate of changes in AHD (ΔAHD) were calculated as the relative change expressed in the percentage of AHD0 (ΔAHD0–30 and ΔAHD0–60) using the following equation.

\[ \text{ΔAHD} = \left( \frac{\text{AHD}_{	ext{rest}} - \text{AHD}_{30}}{\text{AHD}_{	ext{rest}}} \right) \times 100 \]

US images of AHD were captured with participants seated on a chair in an upright posture, elbows straight, and feet flat on the floor. We placed the transducer parallel to the flat superior aspect of the acromion at the middle portion of the acromion in the plane of the scapula. US images were obtained at three arm angles: at rest (AHD0) with the arm by their side, at 30° (AHD30), and at 60° (AHD60) actively elevated on the scapular plane. For the measurement at an elevated position, the participants actively elevated their arms until the desired angle on the scapular plane with a 1 kg dumbbell in their dominant hands, and were asked to hold the position while the US image was captured. Second examiners (K.Y. or M.H.) confirmed the desired angles with a goniometer and visually confirmed the plane of elevation. This was because an applied external load caused an apparent change in AHD during arm elevation [33]. The elevation angle was determined using a digital inclinometer. The order of the measurement positions was randomized to prevent the effect of fatigue. Participants were also well rested between trials. We acquired two clear images that visualized the acromion and humeral head in each examined position, and measured AHD as the shortest linear distance between the inferior edge of the acromion and the superior aspect of the humeral head (Fig. 1b). For each arm angle, the average AHD from two images was used for further analysis. In our preliminary study on 15 healthy young individuals, the test-retest reliability of the described procedure was good to excellent (ICCs (1,2) for AHD0, AHD30, and AHD60 were 0.87, 0.75, and 0.93, respectively).

Corresponding to previous studies [7, 24], the occupation ratio (OcAHD) was expressed as the ratio of the SST thickness to AHD at each arm position (OcAHD0, 30, and 60) using the following equation:

\[ \text{OcAHD} = \frac{\text{SST}}{\text{AHD}} \times 100 \]

Statistical analysis
IBM SPSS ver. 18 (IBM Corp., Armonk, NY, USA) was used for the statistical analysis. An alpha level was set at 0.05 to determine statistical significance. All descriptive statistics were reported as the mean and standard deviation (SD). Before statistical analysis, we performed the Shapiro-Wilk test to check the normality of SST thickness. Depending on the results of normality, an
independent t-test or a Mann-Whitney U test was used to compare SST thickness between young and older subjects. Additionally, we conducted power analysis for SST thickness using G*Power (University of Kiel, Germany). For AHD, ∆AHD, and OcAHD, two-way repeated-measures analysis of variance (ANOVA) was performed to test the effects of age and angle. If a significant interaction effect and main effects were identified, a post-hoc test was conducted with the Bonferroni correction for multiple pairwise comparisons. The effect size was reported using partial eta squared, with small, medium, and large effects classified as 0.01, 0.06, and 0.14, respectively [34]. Furthermore, relationships between SST thickness and AHD, along with ∆AHD, were examined with Pearson’s correlation coefficients in the three different categories: 1) the younger subjects, 2) the older subjects, and 3) all subjects.

**Results**

Table 2 summarizes all the descriptive data. Due to the normal distribution of SST thickness, we performed an independent t-test to compare group differences. Consequently, SST was approximately 1 mm thicker in the older subjects than their younger counterparts \( (P = 0.008; t = 3.135; 95\% \text{ confidence interval } [CI] = 0.410 \text{ to } 1.900). \) The power analysis showed 84% power for the detection of differences in SST thickness. For AHD, a two-way repeated ANOVA showed significant main effects of group \((d.f. = 1.0; F = 7.440; P = 0.009; \eta^2 = 0.148)\) and angle \((d.f. = 1.706; F = 94.478; P < 0.001; \eta^2 = 0.687)\) but no significant group-by-angle interaction \((d.f. = 1.706; F = 0.054; P = 0.925; \eta^2 = 0.001). \) Post hoc analysis revealed that the older subjects had greater AHD than the younger subjects at all elevation angles (Table 2). There was also a significant reduction in AHD between baseline and both elevated positions in both age groups (Table 2), but no significant difference was found between AHD30 and AHD60 \((d.f. = 1.0; F = 0.114; P = 0.214; \eta^2 = 0.003 \text{ for effect of group, } d.f. = 1.0; F = 0.818; P = 0.371; \eta^2 = 0.019 \text{ for effect of angle, and } d.f. = 1.0; F = 0.010; P = 0.920; \eta^2 = 0.000 \text{ for interaction}.)\). For OcAHD, there was a significant main effect of angle \((d.f. = 2.0; F = 59.576; P < 0.001; \eta^2 = 0.581)\), whereas no significant main effect of group \((d.f. = 1.0; F = 0.571; P = 0.454; \eta^2 = 0.013)\) or interaction \((d.f. = 2.0; F = 0.056; P = 0.946; \eta^2 = 0.001)\) was found. According to the post hoc analysis, OcAHD30 and OcAHD60 were significantly greater than in OcAHD0 (Table 2). However, there was no significant difference between OcAHD30 and OcAHD60 \((d.f. = 1.0; F = 0.946; P = 0.371; \eta^2 = 0.003 \text{ and } d.f. = 1.0; F = 1.930; P = 0.192; \eta^2 = 0.098)\).

The results of Pearson’s correlation coefficients are shown in Table 3. There was no relationship between SST thickness and AHD, as well as ∆AHD, in the younger, the older, and all subjects.

**Discussion**

There have long been controversies on the mechanism underlying age-related rotator cuff abnormalities. Because SAI is a possible extrinsic mechanism of rotator cuff abnormalities in older individuals, this study compared SAI characteristics between healthy younger and older subjects. This comparison showed that the older subjects had supraspinatus tendons that were significantly thicker than those of the younger subjects. This result supported our hypothesis; contrary to our expectations, the older subjects had greater AHD than the younger subjects, and no significant differences were found in ∆AHD and OcAHD between the two groups across all three arm positions.

**Table 2  Descriptive data (mean ± standard deviation [SD])**

|                | Younger | Older | Mean difference (95% CI) |
|----------------|---------|-------|------------------------|
| SST thickness (mm) | 5.2 ± 0.9 | 6.3 ± 1.6<sup>a</sup> | 1.153 (0.410 to 1.900) |
| AHD30 (mm) | 9.6 ± 1.0 | 10.8 ± 1.7<sup>b</sup> | 1.176 (0.284 to 2.068) |
| AHD60 (mm) | 6.6 ± 1.5<sup>c</sup> | 7.9 ± 2.4<sup>d</sup> | 1.345 (0.082 to 2.609) |
| ∆AHD60–30 (%) | 31.6 ± 14.0 | 26.5 ± 19.6 | 1.289 (0.120 to 2.458) |
| ∆AHD60–60 (%) | 34.3 ± 102 | 29.8 ± 13.6 | 4.445 (−12.184 to 3.295) |
| OcAHD (%) | 53.9 ± 9.0 | 59.6 ± 16.2 | 5.648 (−2.820 to 14.115) |
| OcAHD30 (%) | 82.0 ± 22.1<sup>e</sup> | 86.0 ± 28.5<sup>f</sup> | 4.010 (−12.090 to 20.111) |
| OcAHD60 (%) | 84.3 ± 20.9<sup>g</sup> | 88.2 ± 28.3<sup>h</sup> | 3.817 (−11.905 to 19.538) |

* CI: Confidence interval, SST: Supraspinatus tendon, AHD: Acromiohumeral distance, ∆AHD: Rate of change in acromiohumeral distance, OcAHD: Occupation ratio

<sup>a</sup>: Significant difference between groups
<sup>b</sup>: Significant difference from baseline (i.e. at rest)
<sup>c</sup>: \( P = 0.008; t = 3.135 \)
<sup>d</sup>: \( P = 0.011 \)
<sup>e</sup>: \( P = 0.037 \)
<sup>f</sup>: \( P = 0.032 \)
<sup>g</sup>: \( P < 0.001; 95\% CI = 1.930 \text{ to } 4.198 \)
<sup>h</sup>: \( P < 0.001; 95\% CI = 2.513 \text{ to } 4.064 \)
<sup>i</sup>: \( P < 0.001; 95\% CI = 1.968 \text{ to } 3.821 \)
<sup>j</sup>: \( P < 0.001; 95\% CI = 2.543 \text{ to } 3.809 \)
<sup>k</sup>: \( P < 0.001; 95\% CI = −35.089 \text{ to } −19.378 \)
<sup>l</sup>: \( P < 0.001; 95\% CI = −35.911 \text{ to } −23.106 \)
Consistent with a previous study [9], this study demonstrated that SST was thicker in healthy older subjects with no prior shoulder injuries than younger adults. Such thickened tendons have been observed in patients with various types of tendinopathies involving the rotator cuff, Achilles, and patellar tendons [7, 13–15]. Furthermore, in this study, SST thickness was approximately 6 mm in the older subjects. Although this value was in line with that of healthy control subjects in the study of Michener et al. [7], this seemed to be attributed to similar subjects’ age and different ultrasound techniques for measuring SST thickness. Whereas our older subjects were in their 40s or older, and the average age of the control subjects was 45-year-olds in this previous study by Michener et al.; thus, the results of their control subjects in the previous study might include age-related changes in SST thickness. Additionally, whereas Michener et al. obtained short-axis images at the just anterior to the anterior-lateral margin of the acromion to measure SST thickness, we measured SST thickness on long-axis images of SST at the footprint-cartilage junction on the humeral head where it might be more distant than that in the study by Michener et al. However, SST thickness in the present study met one of the diagnostic criteria for supraspinatus tendinopathy described by Arend et al. [15] who used similar ultrasound technique as we did. Due to the absence of shoulder symptoms in our subjects, this diagnostic criterion may need to be revised; however, the current result would imply that the healthy older subjects had asymptomatic age-related SST abnormalities.

Despite our expectations, AHD was significantly greater in the older subjects, with or without arm elevation, than in the younger subjects. Greater AHD was also observed in different studies in collegiate baseball players with increased SST thickness [35]. Furthermore, an observational study reported a positive correlation between SST thickness and AHD with the arm at rest [36]. Unfortunately, the present study found no significant relationships between SST thickness and AHD. However, the difference in AHD between the younger and the older subjects across all three arm positions was as much as the difference in SST thickness between the two age groups (approximately 1 mm). Thus, a reasonable explanation for this result is that AHD enlargement in older subjects may be a positive adaptation to protect thickened supraspinatus tendons from excessive compression within the subacromial space. However, AHD possibly changes with other factors, including joint laxity [24] and muscle dysfunction [25]. Although our participants had no recent history of shoulder injuries, we should have measured the shoulder range of motion, as well as the muscle strength. In the future, comprehensive studies with subjects of a diverse range of age groups are needed to clarify age-related changes in AHD.

AHD has been measured in patients with SAI, as well as in patients with rotator cuff tears, but limited data exist regarding the age-related changes in AHD. Contrary to the present study, Hufeland et al. found no difference in AHD between the different age groups [37]. One cause of the discrepancy is the difference in methods utilized. This study used US imaging, but Hufeland et al. used magnetic resonance imaging and roentgenography. Another explanation for this discrepancy was the difference in the inclusion criteria of the younger subjects. All younger subjects were in their 20s in this study, whereas the study by Hufeland et al. included subjects ranging in age from 21 to 40 years in their younger subjects group. According to a study by Yu et al., rotator cuff tendon thickness increased with age [9]. Therefore, the younger subjects in the study by Hufeland et al. may have age-related rotator cuff tendon thickening. Because the current study suggested that enlarged AHD in older subjects may be a positive adaptation to protect the thickened supraspinatus tendon against SAI, age-related changes in rotator cuff tendon thickness could have influenced the results of AHD in the study by Hufeland et al. Thus, the current study would have more appropriately clarified the effect of aging on AHD.

This study also attempted to find age-related differences in ΔAHD and OcAHD; however, there was no significant difference between the younger and the older subjects in terms of those two measurements. In contrast to the current findings in our healthy older subjects, patients with SAI showed not only a marked reduction of AHD with arm elevation (i.e., ΔAHD) [22], but also greater OcAHD [7]. Therefore, our results suggested that the older subjects did not show SAI characteristics which have been reported in previous studies. In addition to these findings in older subjects, the current study found no significant

### Table 3 The relationships between supraspinatus tendon thickness and each variable

|                  | Younger | Older | All participants |
|------------------|---------|-------|------------------|
| AHD0             | r=0.290, p=0.243 | r=0.061, P=0.763 | r=0.234, P=0.122 |
| AHD30            | r=0.079, p=0.756 | r=0.044, P=0.826 | r=0.167, P=0.274 |
| AHD60            | r=0.030, p=0.907 | r=0.029, P=0.887 | r=0.151, P=0.321 |
| ΔAHD0–30         | r=0.054, p=0.832 | r=−0.048, P=0.813 | r=−0.080, P=0.601 |
| ΔAHD0–60         | r=0.169, p=0.502 | r=−0.029, P=0.885 | r=−0.057, P=0.712 |

AHD Acromiohumeral distance, ΔAHD rate of change in acromiohumeral distance
relationships between SST thickness and AHD, as well as SST thickness and ∆AHD. As we have mentioned, the older subjects had thicker SST, presumably due to age-related tendon abnormalities; thus, our results suggest that age-related SST abnormalities occurred without SAI.

Up to now, little is known about the underlying mechanisms of age-related rotator cuff abnormalities. The underlying mechanism for rotator cuff abnormalities has been thought to include intrinsic and extrinsic factors. Whereas SAI has long been accepted as the major extrinsic factor for rotator cuff tendinopathy [20], some studies have demonstrated that surgical decompression has had no beneficial effects in patients with SAI in the short-term period compared with exercise therapy or placebo surgery for patients with SAI [38–46]. Regarding long-term outcome, Ketola et al. reported no long-term beneficial effect of subacromial decompression on pain compared with placebo and exercise in the treatment of patients with rotator cuff tendinopathy at least 10 years after the treatment [47]. On the other hand, Farfaras et al. investigated clinical outcomes using functional questionnaires (the Constant score, the 36-Item Short Form Health Survey questionnaire, and the Watson and Sonnabend score) and revealed a better long-term (a minimum of 10 years) clinical outcome with this surgical procedure than with exercise therapy alone [48]. Considering these studies, it seems likely that the long-term outcome of subacromial decompression is inconsistent, and not much is known about the long-term benefit of this surgical technique. Therefore, an unanswered question would remain as to whether SAI affects rotator cuff abnormalities in the long-term period as opposed to the short-term period. Thus, as age-related rotator cuff abnormalities seem to develop over a longer time period, we hypothesized that older individuals would display SAI characteristics when compared with younger individuals. Contrary to our hypothesis, however, our results suggested that even healthy older adults without any shoulder symptoms had age-related asymptomatic rotator cuff abnormalities without SAI. Thus, intrinsic factors (tendon blood circulation, biology, mechanical properties, morphology, and genetics [20]) may contribute to the age-related rotator cuff abnormalities rather than extrinsic factors like SAI. Indeed, morphological changes in tendons are included for intrinsic factors of tendons [20]. Consistent with the implication of this study, Sano et al. [49], as well as Factor and Dale [50], also considered that intrinsic factors were more important than extrinsic factors during the development of rotator cuff abnormalities (e.g., tendinopathy and tendon tear). Thus, any interventions that affect the intrinsic factors of the tendon would be effective in preventing age-related rotator cuff abnormalities. Unfortunately, few studies have investigated the effects of any interventions on those intrinsic factors in rotator cuff tendons. On the other hand, several researchers investigated the effects of exercises on intrinsic factors in the other tendons [51–53]. For example, Kubo et al. reported tendon mechanical properties showed different changes between isometric and plyometric training [51]. Also, low-load eccentric training for Achilles tendons increased tendon blood circulation and improved tendon collagen organization [53]. Considering these studies, various kinds of exercises may affect the intrinsic factor of tendons. Hence, further studies are required to clarify the specific type of exercise which improves the intrinsic factors of rotator cuff tendons.

It is plausible that some limitations could have influenced the results obtained. First, the characteristics of the subjects may affect the current results. The recruitment strategies of the subjects and the recruitment costs led to differences in the number of subjects between the groups in this study. However, the post hoc power analysis demonstrated sufficient statistical power. Moreover, because sex ratio differed between the groups, the sex difference may have affected the results of this study. However, sex differences are unlikely to affect the prevalence of rotator cuff tears [29]. Additionally, in our subjects, there were no differences in any variables between males and females (results are not shown). Therefore, it seems that the sex ratio does not have a major impact on the current main results. Second, while we measured AHD during arm elevation, the same amount of weight was applied in both groups. Considering that muscle strength generally decreases with aging [54, 55], the relative load in our older subjects may be greater than that in the younger subjects. A study demonstrated that the loaded condition remarkably reduced AHD compared to the unloaded condition during arm elevation [33]. Based on this effect of loading conditions on AHD, older subjects with greater relative load may have exhibited greater reduction in AHD than younger subjects with lesser relative load during arm elevation. However, this study identified greater AHD in older subjects, and also identified no significant difference in ∆AHD between different age groups. Thus, the amount of load would have hardly influenced the current results. Third, differences in anthropometric data such as arm length and scapular morphology might also affect the results of AHD. Although we did not measure arm length in our subjects, previous studies reported that height was associated with arm length and arm span [56, 57]. Given this previous study and a significant height difference between the older and younger groups, arm length may vary between groups. However, in an additional analysis of Pearson’s correlation coefficient, there was no relationship between height and AHD in elevation.
However, the SST insertion site passes beneath the acromion and OcAHD between the younger and older subjects. 60° of elevation may reveal differences in AHD, ΔAHD, and thickness is very small and unclear in terms of clinical significance. Although the magnitude of the difference in SST thickness may change with shoulder elevation [60, 61], measuring AHD above 60° of elevation may reveal differences in AHD, ΔAHD, and OcAHD between the younger and older subjects. However, the SST insertion site passes beneath the acromion at approximately 70° of elevation [62]. Additionally, the impingement of the SST within the subacromial space was remarkable at 60° of elevation [63]. Thus, our results appear to have important implications on the effects of SAI on age-related rotator cuff abnormalities. Fourth, given that AHD decreases with shoulder elevation [60, 61], measuring AHD above 60° of elevation may reveal differences in AHD, ΔAHD, and OcAHD in the current study. However, SST thickness may change with shoulder elevation. Therefore, it is difficult to fully understand how much compression force is exerted on SST during shoulder elevation. This point should be considered in future studies. Lastly, given that patients with various types of tendinopathies show thicker tendons, we measured SST thickness to evaluate tendon abnormalities; however, there is no evidence of the relationship between tendon thickness and histological tendon degeneration. Hence, further studies are needed on age-related changes in intrinsic factors of tendons, such as structure and mechanical properties.

Conclusions
Whereas the older subjects showed significantly increased SST thickness and AHD compared to the younger subjects, there were no differences between the younger and the older subjects in SAI characteristics such as ΔAHD and OcAHD. These results suggest that older adults showed age-related rotator cuff abnormalities without SAI. Therefore, intrinsic factors seem to be the key pathogenesis of age-related rotator cuff degeneration, although the magnitude of the difference in SST thickness is very small and unclear in terms of clinical significance.

Abbreviations
SAI: Subacromial impingement; SST: Supraspinatus tendon; AHD: Acromiohumeral distance; ΔAHD: Rate of changes in acromiohumeral distance; OcAHD: Occupation ratio.

Acknowledgements
We thank the Grant-in-Aid for JSPS Fellows (19 J00824 to T.Ishigaki) and Grant-in Aid for Early-Career Scientists (20K19461 to T.Ishigaki) from Japan Society for the Promotion of Science. Also, we would like to thank Editage for English language editing.

Authors’ contributions
All authors contributed to design of this work. Tomonobu Ishigaki, Koichiro Yoshino, and Motoaki Hirokawa obtained the data. Tomonobu Ishigaki, Masanori Yamanaka, and Makoto Sugawara analyzed and interpreted data. Tomonobu Ishigaki drafted the manuscript. All authors critically revised the manuscript and approved the manuscript for submission.

Funding
Partial financial support was received from a Grant-in-Aid for JSPS Fellows (19 J00824 to T.Ishigaki) and Grant-in Aid for Early-Career Scientists (20K19461 to T.Ishigaki) from Japan Society for the Promotion of Science.

Availability of data and materials
All data generated or analyzed during this study are included in this published article.

Declarations
Ethics approval and consent to participate
The Institutional Review Board of Hokkaido University approved all procedures, methods, and purposes of this study. Before the examination, we explained the subjects the purpose of this study and the procedures to be carried out and written informed consent was obtained from all participants. All procedures were carried out in accordance with relevant guidelines and regulations.

Consent for publication
Not applicable.

Competing interests
The authors have no potential conflicts of interest to declare.

Author details
1 Graduate School of Human Life Design, Toyo University, Oka-48-1, Asaka, Saitama 351-8510, Japan. 2 Graduate School of Health Science, Hokkaido University, Sapporo, Hokkaido, Japan. 3 Matsuda Orthopedic Memorial Hospital, Sapporo, Hokkaido, Japan. 4 Obihiro Kosei Hospital, Obihiro, Hokkaido, Japan. 5 Department of Physical Therapy, Chitose Rehabilitation College, Chitose, Hokkaido, Japan.

Received: 22 March 2021 Accepted: 25 February 2022
Published online: 11 March 2022

References
1. Teunis T, Lubberts B, Reilly BT, Ring D. A systematic review and pooled analysis of the prevalence of rotator cuff disease with increasing age. J Shoulder Elb Surg. 2014;23(12):1913–21.
2. Tempelhof S, Rupp S, Seil R. Age-related prevalence of rotator cuff tears in asymptomatic shoulders. J Shoulder Elb Surg. 1999;8(4):296–9.
3. Minagawa H, Yamamoto N, Abe H, Fukuda M, Seki N, Kikuchi K, et al. Prevalence of symptomatic and asymptomatic rotator cuff tears in the general population: from mass-screening in one village. J Orthop. 2013;10(1):6–12.
4. Schibany N, Zehetgruber H, Kainberger F, Wurnig C, Ba-Salalah M, Herneth A, et al. Rotator cuff tears in asymptomatic individuals: a clinical and ultrasonographic screening study. Eur J Radiol. 2004;51(3):263–8.
5. Yamamoto A, Takagishi K, Osawa T, Yanagawa T, Nakajima D, Shitara H, et al. Prevalence and risk factors of a rotator cuff tear in the general population. J Shoulder Elbow Surg. 2010;19(1):116–20.

6. Hashimoto T, Nobukura K, Hamada T. Pathologic evidence of degeneration as a primary cause of rotator cuff tear. Clin Orthop Relat Res. 2003;415:111–20.

7. Michener LA, Subasi Yesilyaprak SS, Seitz AL, Timmons MK, Walsworth MK. Supraspinatus tendon and subacromial space parameters measured on ultrasonographic imaging in subacromial impingement syndrome. Knee Surg Sports Traumatol Arthrosc. 2015;23(2):363–9.

8. Jørgensen E, Couper C, Bjordal JM. Increased palpatory tenderness and muscle strength deficit in the prediction of tendon hypertrophy in symptomatic unilateral shoulder tendinopathy: an ultrasonographic study. Physiotherapy. 2009;95(2):83–93.

9. Yu TY, Tsai WC, Cheng JW, Yang YM, Liang FC, Chen CH. The effects of aging on quantitative sonographic features of rotator cuff tendons. J Clin Ultrasound. 2012;40(8):471–8.

10. Toprak U, Baskan B, Ustuner E, Oten E, Altin L, Karademir MA, et al. Comparison of the sono-anatomical features of the rotator cuff in patients with and without rotator cuff tendinopathy. BMC Musculoskeletal Disorders. 2012;13(1):145–150.

11. McCreesh KM, Purtill H, Donnelly AE, Lewis JS. Increased supraspinatus tendon thickness following fatigue loading in rotator cuff tendinopathy: potential rehabilitation implications for exercise therapy. BMJ Open Sport Exerc Med. 2017;3(1):e000279.

12. Romero-Morales C, Martín-Llantino PJ, Calvo-Lobo C, Palomo-López P, López-Álvaro D, Pareja-Galeano H, et al. Comparison of the sonographic features of the rotator cuff in asymptomatic patients with and without rotator cuff tendinopathy: a case–control study. Phys Ther Sport. 2019;35:122–6.

13. Kulig K, Landel R, Chang YJ, Hannanvash N, Reischl S, Song P, et al. Patellar tendon morphology in athletes with and without patellar tendinopathy. Scand J Med Sci Sports. 2013;23(2):e81–8.

14. Leung JL, Griffith JF. Sonography of chronic Achilles tendinopathy: a case–control study. J Clin Ultrasound. 2008;36(1):27–32.

15. Arend CR, Arend AA, da Silva TR. Diagnostic value of tendon thickness and structure in the sonographic diagnosis of supraspinatus tendonitis: a case–control study. Radiol Med. 2014;84(6):975–9.

16. Ishigaki T, Hirokawa M, Ezawa Y, Yamakawa M. Supraspinatus Tendon Tear Frequency and Glenohumeral Range of Motion in College Baseball Players. Int J Sports Med. 2021;43(2):145–150.

17. Kim HM, Dahiya N, Lebaschi AH, Camp CL, Carballo CB, Nakagawa Y, Wada S, et al. Evaluating the role of subacromial impingement in rotator cuff tendinopathy: Development and analysis of a novel murine model. J Orthop Surg Res. 2018;13(1):2780–80.

18. Seitz AL, McClure PW, Ficunace S, Boardman ND III, Michener LA. Mechanisms of rotator cuff tendinopathy: intrinsic, extrinsic, or both? Clin Biomech. 2011;26(1):1–12.

19. Hebert LJ, Moffet H, Dufour M, Moisan C. Acromiohumeral distance in a seated position in persons with impingement syndrome. J Magn Reson Imaging. 2003;18(1):72–9.

20. Bureau NJ, Bascand B, Ustuner E, Oten E, Altin L, Karademir MA, et al. Subacromial decompression surgery for rotator cuff disease: a multicentre, pragmatic, parallel group, placebo-controlled, three-group, randomised surgical trial. Lancet. 2018;391(10118):329–38.

21. Papadonikolaou A, Mckenna M, Warne M, Martin BI, Matsen FA 3rd. Published evidence relevant to the diagnosis of impingement syndrome of the shoulder. J Bone Joint Surg Am. 2011;93(19):1827–32.

22. Lähdeöja T, Karjalanen T, Jokiharja J, Salamh P, Kavaja L, Agarwal A, et al. Subacromial decompression surgery for adults with shoulder pain: a systematic review with meta-analysis. Br J Sports Med. 2020;54(1):665–73.

23. Karjalainen TV, Jain NB, Page CM, Lähdeöja TA, Johnston RV, Salamh P, et al. Subacromial decompression surgery for rotator cuff disease. Cochrane Database Syst Rev. 2015;10:CD010561.

24. Farfars S, Sernert N, Hallström E, Kartus J. Comparison of open acromio-plasty, arthroscopic acromioplasty and physiotherapy in patients with acromiohumeral distance variation measured by ultrasonography and its association with the outcome of rehabilitation for shoulder impingement syndrome. Clin J Sport Med. 2004;14(4):197–205.

25. Mackenzie TA, Bdaawi AH, Herrington L, Cools A. Inter-rater reliability of real-time ultrasound to measure acromiohumeral distance: PM&R. 2016;8(7):629–34.

26. Endo K, Yukata K, Yasui N. Influence of age on scapulo-thoracic orientation. Clin Biomech. 2004;19(10):1099–13.

27. Milgrrom C, Schaffer M, Gilbert S, van Hollbeeck M. Rotator cuff changes in asymptomatic adults: The effect of age, hand dominance and gender. J Bone Joint Surg Br. 1995;77(5):296–8.

28. Ferri M, Finlay K, Popovich T, Stamp G, Schuringa P, Friedman L. Sonography of full-thickness supraspinatus tears: comparison of patient positioning technique with surgical correlation. AJR Am J Roentgenol. 2005;184(1):180–4.

29. McCreesh KM, Anand S, Crotty JM, Lewis JS. Ultrasound measures of supraspinatus tendon thickness and acromiohumeral distance in rotator cuff tendinopathy are reliable. J Clin Ultrasound. 2016;44(3):159–66.

30. Tham ER, Briggs L, Murrell GA. Ultrasound changes after rotator cuff repair: is supraspinatus tendon thickness related to pain? J Shoulder Elbow Surg. 2013;22(8):e8–e15.

31. Thompson MD, Landin D, Page PA. Dynamic acromiohumeral interval changes in baseball players during scaption exercises. J Shoulder Elbow Surg. 2011;20(2):251–8.

32. Norouzian R, Plosky L. Et-a-and partial eta-squared in L2 research: A cautionary review and guide to more appropriate usage. Second Lang Res. 2018;34(2):257–71.

33. Wang HK, Lin JJ, Pan SL, Wang TG. Sonographic evaluations in elite college baseball athletes. Scand J Med Sci Sports. 2005;15(1):29–35.

34. Leong H-T, Tsai S, Ying M. Leung YY-F, Fu SN. Ultrasound measurements on acromio-humeral distance and supraspinatus tendon thickness: test-retest reliability and correlations with shoulder rotational strengths. J Sci Med Sport. 2012;15(4):284–91.

35. Hufeland M, Brusis C, Kubo H, Grassmann J, Latz D, Patzer T. The acromiohumeral distance in the MRI should not be used as a decision criterion to assess subacromial space width in shoulders with an intact rotator cuff. Knee Surg Sports Traumatol Arthrosc. 2021;29:2085–2089.

36. Ketola S, Lehtinen J, Routi T, Nissinen M, Huhtala H, Korttinnen Y, et al. No evidence of long-term benefits of arthroscopic acromioplasty in the treatment of shoulder impingement syndrome: five-year results of a randomised controlled trial. Bone Joint Res. 2013;2(7):132–9.

37. Ketola S, Lehtinen J, Annala I, Nissinen M, Westenius H, Sintonen H, et al. Does arthroscopic acromioplasty provide any additional value in the treatment of shoulder impingement syndrome? A two-year randomised controlled trial. J Bone Joint Surg Br. 2009;91(10):1326–34.

38. Ketola S, Lehtinen J, Routi T, Nissinen M, Huhtala H, Annala I. Which patients do not recover from shoulder impingement syndrome, either with operative treatment or with non-operative treatment? Subgroup analysis involving 140 patients at 2 and 5 years in a randomized study. Acta Orthop. 2015;86(6):641–6.
subacromial impingement syndrome: a prospective randomised study. Knee Surg Sports Traumatol Arthrosoc. 2016;24(7):2181–91.

47. Ketola S, Lehtinen JT, Arnala I. Arthroscopic decompression not recommended in the treatment of rotator cuff tendinopathy: a final review of a randomised controlled trial at a minimum follow-up of ten years. Bone Joint J. 2017;99-B(6):799–805.

48. Farfaras S, Sermert N, Rostgaard Christensen L, Hallström EK, Kartus J-T. Subacromial decompression yields a better clinical outcome than therapy alone: a prospective randomized study of patients with a minimum 10-year follow-up. Am J Sports Med. 2018;46(6):1397–407.

49. Sano H, Ishii H, Trudel G, Uhthoff HK. Histologic evidence of degeneration at the insertion of 3 rotator cuff tendons: a comparative study with human cadaveric shoulders. J Shoulder Elbow Surg. 1999;8(6):574–9.

50. Factor D, Dale B. Current concepts of rotator cuff tendinopathy. Int J Sports Phys Ther. 2014;9(2):274.

51. Kubo K, Ishigaki T, Ikebukuro T. Effects of plyometric and isometric training on muscle and tendon stiffness in vivo. Physiol Rep. 2017;5(15):e13374.

52. Reeves ND, Maganaris CN, Narici MV. Effect of strength training on human patella tendon mechanical properties of older individuals. J Physiol. 2003;548(3):971–81.

53. Ishigaki T, Kubo K. Effects of eccentric training with different training frequencies on blood circulation, collagen fiber orientation, and mechanical properties of human Achilles tendons in vivo. Eur J Appl Physiol. 2018;118(12):2617–26.

54. Ishigaki T, Kubo K. Mechanical properties and collagen fiber orientation of tendon in young and elderly. Clin Biomech. 2020;71:5–10.

55. Strasser EM, Draskovits T, Praschak M, Quitmann M, Graaf A. Association between ultrasound measurements of muscle thickness, pennation angle, echogenicity and skeletal muscle strength in the elderly. Age. 2013;35(6):2377–88.

56. Shah T, Patel M, Nath S, Menon SK. A model for construction of height and sex from shoulder width, arm length and foot length by regression method. J Forensic Sci Criminol. 2015;3(1):102.

57. Yabanci N, Kilic S, Simsek I. The relationship between height and arm span, mid-upper arm and waist circumferences in children. Ann Hum Biol. 2010;37(1):70–5.

58. Moor BK, Wieser K, Slankamenac K, Gerber C, Bouacha S. Relationship of individual scapular anatomy and degenerative rotator cuff tears. J Shoulder Elbow Surg. 2014;23(4):536–41.

59. Pandey V, Vijayan D, Tapashetti S, Agarwal L, Kamath A, Acharya K, et al. Does scapular morphology affect the integrity of the rotator cuff? J Shoulder Elbow Surg. 2016;25(3):413–21.

60. Seitz AL, McClure PW, Lynch SS, Ketchum JM, Michener LA. Effects of scapular dyskinesis and scapular assistance test on subacromial space during static arm elevation. J Shoulder Elbow Surg. 2012;21(5):631–40.

61. Bey MJ, Brock SK, Beerwaltes WN, Zuelz R, Kolowich PA, Lock TR. In vivo measurement of subacromial space width during shoulder elevation: technique and preliminary results in patients following unilateral rotator cuff repair. Clin Biomech. 2007;22(7):767–73.

62. Giphart JE, van der Meijden OA, Millett PJ. The effects of arm elevation on the 3-dimensional acromiohumeral distance: a biplane fluoroscopy study with normative data. J Shoulder Elbow Surg. 2012;21(11):1593–600.

63. Brossmann J, Preidler K, Pedowitz R, White L, Trudell D, Resnick D. Shoulder impingement syndrome: influence of shoulder position on rotator cuff impingement—an anatomic study. AJR Am J Roentgenol. 1996;167(6):1511–5.