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ORIGINAL ARTICLE

Age-related changes in muscle thickness, echo intensity and shear modulus of the iliocapsularis

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Abstract

Purpose: This study aimed to clarify age-related changes in the iliocapsularis (IC) using indicators of quantity, quality, and mechanical properties. We also compared the age-related changes in the IC and other hip muscles.

Methods: Eighty-seven healthy women (ages: 21–82 years, mean age: 45.9 ± 15.7 years) participated in the experiment. We measured thickness, echo intensity, and shear modulus of the IC, iliacus muscle, rectus femoris, and the thickness and shear modulus of the hip joint capsule. Spearman's rank correlation coefficient was used to measure the association of age with variables measured in the muscles and joint capsule.

Results: Thickness of the iliacus muscle and rectus femoris decreased significantly with age, but the thickness of the IC and hip joint capsule showed no significant correlation. The echo intensities of the IC, iliacus muscle, and rectus femoris were positively correlated, which increased with age. Furthermore, the shear modulus of the iliacus, rectus femoris, and hip joint capsule showed an increase with age, whereas the shear modulus of the IC exhibited no correlation with age.

Conclusion: The muscle quality of the IC changed significantly, unlike that of the iliacus or rectus femoris. Additionally, the correlation with echo intensity was relatively weaker in the IC compared with the iliacus or rectus femoris.

KEYWORDS
aging, elastography, hip, muscle, ultrasound

1 | INTRODUCTION

The iliocapsularis (IC) originates from the anterior inferior iliac spine and anteromedial part of the hip joint capsule and is inserted into the lesser trochanter (Breckling et al., 2022). The distinctive anatomical features of the IC suggest that its contraction holds significance in stabilising the hip joint through the tightening of the hip joint capsule (Elvan et al., 2019). According to previous studies, the IC is thickened in unstable hip joints with acetabular dysplasia, and the proportion of muscle fat infiltration is lower in the dysplastic hips than in hips with excessive acetabular coverage (Babst et al., 2011; Haefeli et al., 2015). Many studies have investigated changes in the quantity and quality of the IC in patients with hip joint instability and dysplasia (Babst et al., 2011; Haefeli et al., 2015; Wang et al., 2021). In general, as muscle quantity and quality change with aging, eliminating the effects of aging to identify the effects of diseases is necessary. Muscle quantity and quality can be evaluated using an ultrasonic image as indexes of muscle thickness and echo intensity. Muscle atrophy can be estimated by measuring muscle thickness (Ikezoe et al., 2011), and increase in echo intensity indicates changes in composition (e.g., increased fatty infiltration, fibres, water, and extracellular matrix in muscle) and decreased muscle quality (Fukumoto et al., 2012b; Ikezoe, 2020). However, there are few reports on age-related changes in the IC, and it is unclear how aging affects the IC muscle quantity and quality. Regarding the relationship between the IC and aging, changes in muscle size have been reported in investigations in cadaver hips (Mac Dermott et al., 2022) and using magnetic resonance imaging (Yagi et al., 2022). These studies showed that the IC muscle length was weakly correlated with aging, while muscle width showed no correlation (Mac Dermott et al., 2022), and there was no difference in the cross-sectional area of the IC between the young group (<40 years old) and the elderly group (≥60 years old) (Yagi et al., 2022). Changes in both quantitative and mechanical characteristics occur in muscles with aging (Alfuraih et al., 2019; Fukumoto et al., 2012b; Ikezoe, 2020; Ikezoe et al., 2011; Kent-braun et al., 2000), but to the best of our knowledge, there are no reports regarding how the quality and mechanical characteristics of the IC change with aging.

Muscle thickness, echo intensity, and shear modulus are used as indices of muscle quantity, quality, and mechanical properties, respectively (Fukumoto et al., 2015; Wang et al., 2014). B-mode ultrasound can be used to noninvasively evaluate muscle thickness and echo intensity. In general, skeletal muscle thickness is known to decrease with aging (Ikezoe et al., 2011). Moreover, despite a prior study did not encompassing the IC, the deep muscles exhibited reduced susceptibility to atrophy from frequent use, even during advanced age (Ikezoe, 2020). Muscle echo has been suggested to increase in intensity with aging owing to reduced physical activity (Fukumoto et al., 2012b; Kent-braun et al., 2000). By using the shear wave elastography mode of ultrasound imaging systems, tissue stiffness can be quantitatively and noninvasively evaluated (Alfuraih et al., 2019). Age-related changes in the shear modulus of the muscle did not show consistent trends as they vary between muscles of the upper limb, lower limb, and trunk (Alfuraih et al., 2019; Kobayashi et al., 2023). However, age-related changes in the echo intensity and shear modulus of the IC have not yet been clarified.

The IC attaches to the anterior hip joint capsule, which is suggested to play a role in tightening the hip joint capsule (Elvan et al., 2019). Since the IC and hip joint capsule are regarded as a single unit, it is important to investigate the thickness, echo intensity, and shear modulus of the IC and hip joint capsule. Comparison of the elderly group (≥55 years) with the young group (<55 years) in a study using fresh-frozen cadaver hips revealed that the elderly group had lower stiffness of the hip joint capsule (Schleifenbaum et al., 2016). However, only a limited number of studies have investigated age-related changes in the thickness or mechanical properties of the joint capsule, and the way they evolve with aging is still poorly understood.

Changes in the echo intensity of skeletal muscles occur earlier than changes in muscle mass with aging (Ikezoe., 2020), and the shear modulus may reflect aging more accurately than muscle thickness in a relaxed position (Alfuraih et al., 2019). In addition, a previous study suggested that muscle mass and echo intensity are both independently associated with muscle force (Alfuraih et al., 2019; Fukumoto et al., 2012b). Since the thickness, echo intensity, and shear modulus of the muscle change independently with aging, it is necessary to comprehensively examine these indices for age-related changes in muscles. However, no study has investigated how the IC changes using all three indices, muscle thickness, echo intensity, and shear modulus, and the muscle mass of the IC was compared only in two groups (<40 vs. ≥60 years old) in a vivo study (Yagi et al., 2022). The purpose of this study was to compare age-related changes in the IC with those occurring in the other anterior muscles and hip joint capsule. We hypothesised that the IC and hip joint capsule would not change with aging in thickness, echo intensity, and shear modulus, while the iliacus and rectus femoris muscles would decrease in muscle thickness and shear modulus, and increase in echo intensity.

2 | PARTICIPANTS AND METHODS

2.1 | Participants

We enroled 87 healthy women (age range 21–82 years, mean age 45.89 ± 15.7 years, mean height 158.1 ± 5.34 cm, mean weight 52.7 ± 7.88 kg; Table 1). We calculated the sample size using the

TABLE 1 Participants' characteristics.

Characteristics	Mean	*SD*
n	87	
Age (years)	45.89	15.67
BMI (kg/m^2)	21.07	2.82
Thickness (cm)		
IC	0.79	0.15
IL	1.68	0.23
RF	1.53	0.30
capsule	0.34	0.06
Echo intensity		
IC	35.97	11.44
IL	41.70	14.14
RF	84.50	16.12
Shear modulus (kPa)		
IC	9.77	3.25
IL	10.45	3.66
RF	4.50	2.11
capsule	12.49	6.61

Abbreviations: BMI, body mass index; IC, iliocapsularis; IL, iliacus; RF, rectus femoris.

G*Power software (version 3.1; Heinrich Heine University, Dusseldorf, Germany) for a correlation analysis model (effect size = 0.3, α error = 0.05, and power = 0.8). The required sample size was 82 participants. Thus, 87 participants were recruited in this study, considering the absence of data. Before participating, the study procedures and purpose were explained verbally, and all participants provided written informed consent. The Ethics Committee of Kyoto University Graduate School and Faculty of Medicine approved this study (Protocol Identification Number: R1674). Exclusion criteria were current hip/knee musculoskeletal disease or pain, history of hip/knee surgery or trauma, and neurological disease.

2.2 | Measurement

B-mode images and elastographic images of an ultrasound imaging system (manufactured by Supersonic Imagine) and a linear probe (SL10-2) were used. The measurements were conducted in the supine position (neutral position of hip flexion/extension, adduction/abduction, and internal/external rotation). We measured the thickness and shear modulus of the anterior hip joint capsule and muscle thickness, echo intensity, and shear modulus of the IC, iliacus muscle (IL), and rectus femoris (RF). Although the IC is a small and deep muscle, its mechanical properties can still be quantified (Wang et al., 2021). In this study, we measured the shear modulus of the IC, similar to a prior investigation involving healthy participants. Only the right limbs were measured based on a previous study that no difference in the muscle size of the IC was noted between the right and left limbs (Mac Dermott et al., 2022). However, the echo intensity of the joint capsule was not measured because changes in the echo intensity of the joint capsule were unclear, even though the echo intensity of the muscles reflected their quality (Fukumoto et al., 2012b; Ikezoe, 2020). The measurement sites were demarcated using a skin-marking pen. The IC, IL, and hip joint capsule measurements were taken 4 cm distal to the anterior superior iliac spine, following the methodology of Nojiri et al. (2021). Meanwhile, the RF was measured at the midpoint between the anterior superior iliac spine and the upper edge of the patella, in accordance with Fukumoto et al. (2012b). Subsequent to marking the locations, muscle measurements were conducted using ultrasound scans to identify the muscle belly, as indicated by the

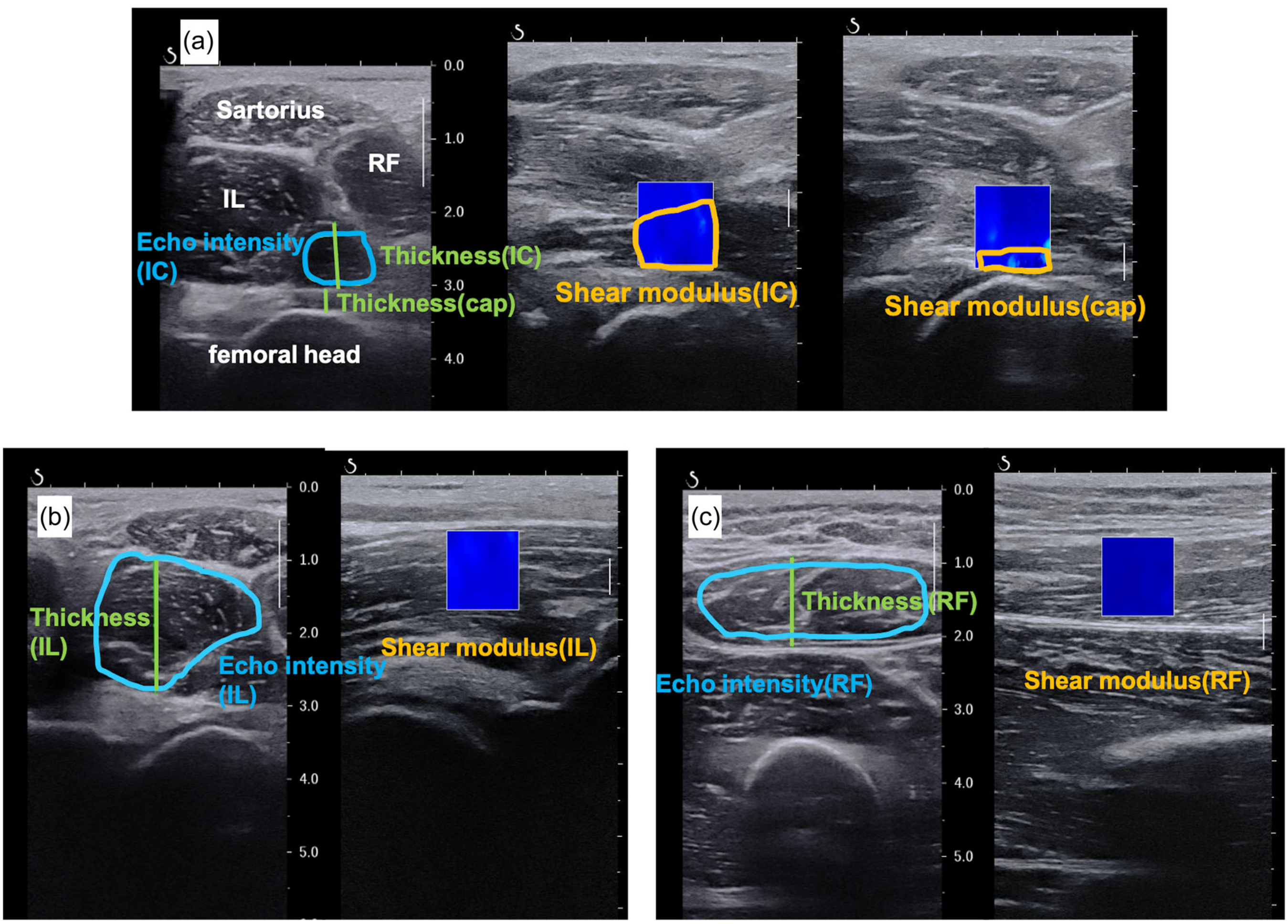

FIGURE 1 Example of an analysis image. Analysis images of B and SWE modes in ultrasound. (a) The iliocapsularis and anterior hip joint capsule, (b) iliacus muscle, (c) rectus femoris. cap, anterior hip joint capsule; IC, iliocapsularis; IL, iliacus muscle; RF, rectus femoris.

markings (see Figure 1a–c). Additionally, the thickness of the hip joint capsule was measured, with a clear imaging of the most anterior part of the femoral head (see Figure 1a). Each measurement of thickness, echo intensity, and shear modulus was conducted twice, and the average value was used for subsequent analysis.

2.2.1 | Measurements of thickness

The thicknesses of the muscles and joint capsule were measured from transverse B-mode images. To assess thickness, we employed OsiriX software (version 3.8.1, Pixmeo). This involved measuring the distance between the proximal and distal fascia within the muscles, as well as between the surface of the joint capsule and the femoral head in the case of the joint capsule (Figure 1).

2.2.2 | Measurements of echo intensity

The echo intensity was also measured from the same transverse B-mode images used for thickness measurements. We calculated the average echo intensity within the region of interest (ROI) as a value scaled from 0 (black) to 255 (white) using an 8-bit grayscale image of the standard histogram using Osirix MD. The largest ROI, without the bone or fascia, was traced, and the average echo intensity of the ROI was calculated. A high echo intensity indicates a high proportion of intramuscular fat and interstitial fibrous tissue, which indicates poor muscle quality (Fukumoto et al., 2012a, 2015).

2.2.3 | Measurements of shear modulus

We measured the Young's modulus using elastography mode in longitudinal images of the muscle and joint capsule, which runs parallel to the muscle fibres. The ROI was set to 1 × 1 cm at the centre of the muscle belly to analyze the image. To calculate the shear modulus, we outlined the area of the largest ROI, excluding bone or fascia. The shear modulus (G) of a material can be determined using this equation:

$$G = \rho V2,$$

here, V represents the velocity of shear wave propagation, and ρ signifies muscle density. In this study, we assumed a muscle density of 1 g/cm^3, following Nakamura et al. (2014).

2.3 | Statistical analysis

We calculated the intraclass correlation coefficients (ICC) (1.2) for each measurement of thickness, echo intensity, and shear modulus of each muscle and joint capsule to analyze the reproducibility.

The assessment of data distribution normality was conducted using the Shapiro–Wilk test. None of the following variables showed a normal distribution: shear modulus of the IC, IL, RF, or joint capsule; thickness of the joint capsule; or echo intensity of the RF. Thus, we used Spearman's rank correlation coefficient to calculate the relationship between age and thickness, echo intensity, and shear modulus of each muscle and joint capsule. According to Guilford's rule of thumb, the correlation coefficient (ρ) is described as $\rho = |0.2| – |0.4|$ as a low relationship, $\rho = |0.4| – |0.7|$ as a moderate relationship, and $\rho = |0.7| – |0.9|$ as a strong relationship.

The statistical significance level was set at <5%. We used R version 4.0.2 (CRAN, freeware) for Mac OS for all analyses.

3 | RESULTS

3.1 | Reproducibility

As shown in Table 2, the ICC (1.2) was >0.876, confirming the high reproducibility of all measurement items (Table 2).

3.2 | Age-related changes in thickness, echo intensity, and shear modulus of each muscle and hip joint capsule

The thicknesses of the IL and RF decreased with age (Figure 2b,c). The IL, RF, and IC showed an increase in echo intensity, and the IC had a weak positive relationship with age (Figure 3a–c). For the change in shear modulus, the IL, RF, and hip joint capsule showed a decrease, and the RF and hip joint capsule showed a low negative correlation (Figure 4c,d) with age. No age-related change was noted in the thickness of the IC or hip joint capsule and the shear modulus of the IC (Figure 2a,d; Figure 4a).

4 | DISCUSSION

The purpose of this study was to clarify the age-related changes in the IC in thickness, echo intensity, and shear modulus by comparing the age-related changes in the IC with those in the IL, RF, and hip

TABLE 2 Reproducibility: ICC(1.2).

Thickness				Echo intensity			Shear modulus			
IC	IL	RF	cap	IC	IL	RF	IC	IL	RF	cap
0.982	0.988	0.999	0.962	0.989	0.991	0.998	0.883	0.979	0.981	0.877

Abbreviations: cap, anterior hip joint capsule; IC, iliocapsularis; IL, iliacus muscle; RF, rectus femoris.

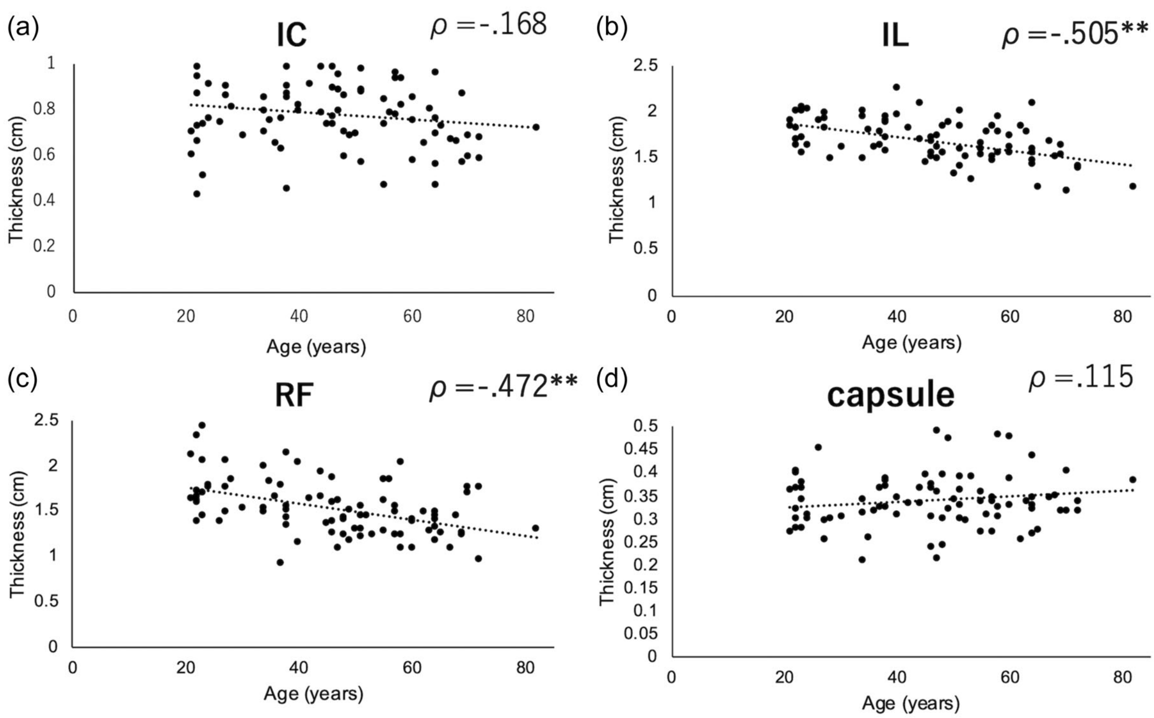

FIGURE 2 Scatter plot of the correlation between age and thickness of each muscles and joint capsule. The horizontal axis indicates age (years) and the vertical axis indicates the thickness of each tissue (cm). ** $p < 0.01$. IC, iliocapsularis, IL, iliacus muscle, RF, rectus femoris.

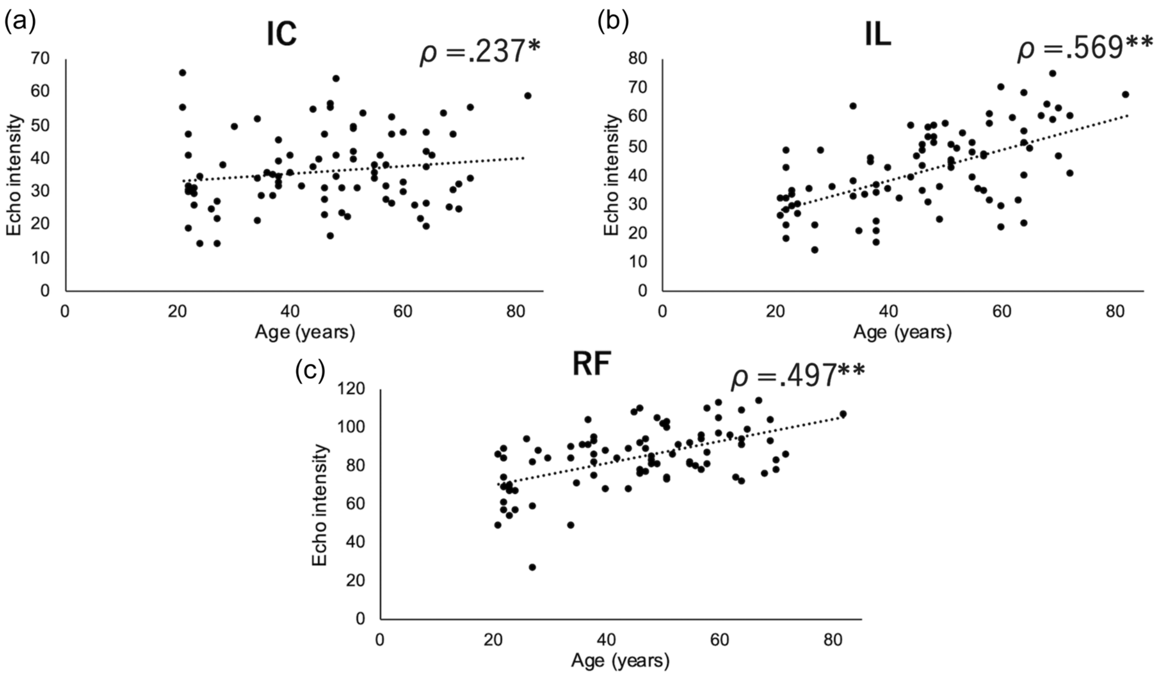

FIGURE 3 Scatter plot of the correlation between age and echo intensity of each of the muscles. The horizontal axis indicates age (years) and the vertical axis indicates the echo intensity of each muscle. * $p < 0.05$, ** $p < 0.01$. IC, iliocapsularis, IL, iliacus muscle, RF, rectus femoris.

joint capsule in healthy women. To the best of our knowledge, this is the first study to identify age-related changes in the IC in terms of quantity, quality, and mechanical properties. Overall, the IL and RF showed a decrease in muscle thickness, increase in echo intensity, and decrease in shear modulus, which are consistent with the findings of previous studies (Alfuraih et al., 2019; Fukumoto et al., 2012b; Ikezoe, 2020; Ikezoe et al., 2011), whereas the echo intensity of the IC and shear modulus of the hip joint capsule showed

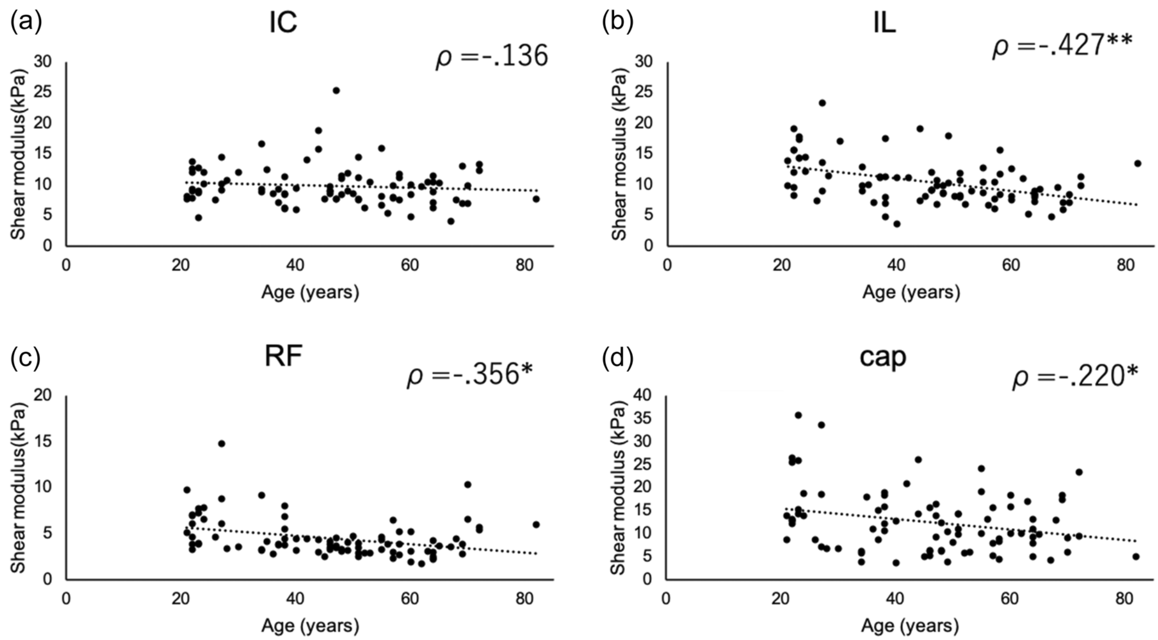

FIGURE 4 Scatter plot of the correlation between age and shear modulus of each muscles and joint capsule. The horizontal axis indicates age (years) and the vertical axis indicates the shear modulus of each tissue (kPa). *$p < 0.05$, **$p < 0.01$. IC, iliocapsularis, IL, iliacus muscle, RF, rectus femoris.

a weak correlation with age. No age-related changes in muscle thickness and shear modulus in the IC and thickness of the hip joint capsule were observed. The results of this study were consistent with previous studies regarding the muscle mass of the IC not being affected by aging (Mac Dermott et al., 2022; Yagi et al., 2022). These results support the hypothesis that the IC and hip joint capsules do not change with aging in thickness, echo intensity and shear modulus, while IL and RF show a decrease in muscle thickness and shear modulus and an increase in echo intensity with aging.

Age-related changes in muscle mass depend on the type of muscle fibre and muscle function. Regarding the types of muscle fibres, type II fibres are more likely to atrophy than type I fibres (Lexell et al., 1988). Although the IC may contain a high percentage of type I fibres, similar to the iliacus (Sato et al., 2016), the fibre composition is unknown, and the lack of correlation between age and the muscle quantity of the IC may be because of its muscle fibre type. Muscle atrophy is more frequently detected in muscles that are rarely used in older adults, and muscles involved in posture control, such as deep muscles, do not tend to atrophy with age (Ikezoe, 2020). Since the IC is a deep muscle that contributes to the stabilisation of the hip joint, and the IC plays a role in stabilising the joint even in the elderly, age-related changes in the IC may be less likely to occur (Babst et al., 2011; Elvan et al., 2019; Haefeli et al., 2015).

A weak correlation was observed between the echo intensity of the IC and age; in other words, the muscle quality of the IC decreased slightly with aging. Changes in echo intensity are associated with the transformation of composition, such as muscle fibres and adipose tissue in the muscle (Fukumoto et al., 2012b; Ikezoe, 2020; Pillen et al., 2009). Previous studies have reported that an increase in intramuscular fat is associated with less physical activity, while age-related changes in muscles are thought to be due to a decrease in physical activity (Fukumoto et al., 2012b; Kent-braun et al., 2000). In the present study, muscle quality decreased in the IC, IL, and RF muscles. Fukumoto et al. reported that the echo intensity of the quadriceps in the lower extremities and biceps brachii in the upper extremities increased with age (Fukumoto et al., 2012b, 2015). In addition, while changes in trunk flexor muscle thickness occurred only in the superficial muscles, such as the rectus abdominis and abdominal oblique muscles, the echo intensity of the transversus abdominis, which is a deep muscle, increased with aging (Fukumoto et al., 2015; Ota et al., 2012). These results suggest that echo intensity is relatively more variable than muscle thickness and changes in echo intensity can be detected even in the deep muscles. In this study, echo intensity of the IC, which is a deep muscle, showed a positive correlation with age. The correlation between the echo intensity of the IC and aging was weaker compared with that between the IL and RF, probably because of the stabilising role of the IC even in the elderly people, as mentioned earlier; in addition, echo intensity changes occur at younger ages in comparison with muscle mass (Fukumoto et al., 2015; Ota et al., 2012). In the present study, age-related changes in the echo intensity of the IC may precede a decrease in muscle thickness, and it is possible that muscle quantity may change in older individuals following a decrease in muscle quality.

No significant correlation with age was observed for the shear modulus of the IC. Although there is still no consensus regarding changes in shear modulus, age-related histological changes, such as increased intermuscular adipose and changes in muscle fibres (Alfuraih et al., 2019), and extracellular matrix fibres losing elasticity (Alfuraih et al., 2019; Rodrigues & Rodrigues Junior, 2000) are considered to be related to a decrease in shear modulus. A decrease in the shear modulus also contributes to muscle weakness through a decrease in muscle stiffness (Alfuraih et al., 2019). Assuming that the shear modulus of the IC is maintained even in the elderly, the force exerted by the IC may also be maintained. In contrast, the hip joint capsule showed a low negative correlation between shear modulus and age. Because age-related changes in the shear modulus of the muscle are caused by changes in muscle composition (Fukumoto et al., 2012a; Ikezoe, 2020), changes in the shear modulus of the joint capsule may also be affected by age-related changes in its composition. However, the mechanism underlying age-related changes in the joint capsule currently remain unclear (Schleifenbaum et al., 2016). Owing to their anatomical continuity, the IC and hip joint capsule are believed to jointly contribute to hip stabilisation. However, in the current study, aging was found to be negatively correlated only with the hip joint capsule, and not with the IC. Although it has not yet been confirmed in vivo, the IC is presumed to have a role in preventing impingement of the capsular ligament at the anterior hip joint (Breckling et al., 2022). The shear modulus of the IC did not change with age, and this could be because of the function to prevent hip impingement. As the shear modulus did not significantly change in the IC with aging, the IC possibly plays a role in compensating for the decrease in the shear modulus of the hip joint capsule. Further studies on age-related changes as a synergistic effect of the IC and hip joint capsule are required.

Our study has two limitations. First, relatively young individuals were recruited for this study. There were a few participants aged 70 and over, with only four in their 70s and one in her 80s, and most participants were in their 20s–60s. The shear modulus of the muscles undergoes significant changes after the age of 75 (Alfuraih et al., 2019), and age-related changes should be determined in older individuals in the future. Second, the participants were only women. It has been reported that there are gender differences in the cross-sectional area of the IC (Yagi et al., 2022). When considering age-related alternations in muscle strength, muscle weakness during eccentric contraction is less likely to occur in women than in men (Lindle et al., 1997). Furthermore, distinctions in muscle mass, quality, and mechanical properties from aging may manifest differently between men and women. In subsequent research, exploring age-related changes in the IC of men would be worthwhile.

5 | CONCLUSION

We analyzed the age-related changes in muscle quantity, quality, and mechanical properties of the IC and compared them with those of other hip muscles in healthy women. IL and RF showed age-related decreases in muscle thickness, increases in echo intensity, and decreases in shear modulus, whereas the IC showed age-related changes only in echo intensity and not in muscle thickness or shear modulus. The IC is less likely to change with age in terms of muscle quantity and mechanical properties than other muscles.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data not available due to ethical restriction.

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