

Usefulness of Muscle Stiffness Evaluated by Ultrasonography for Detecting Muscle Change Related to Contracture in Frail Older Adults



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<https://doi.org/10.5770/cgj.28.827>

ABSTRACT

Background

Ultrasonography can be used to evaluate the echo intensity (EI) and strain ratio (SR) to identify muscle quality and stiffness, respectively. EI and SR are affected by aging, frailty, and joint angle positions. We investigated the effects of aging and frailty on muscle EI and SR at different joint angle positions, and identified a useful measurement method to reflect muscle changes related to contractures in frail older adults.

Methods

This study had a cross-sectional design. Twenty-two healthy young adults (young group), 22 non-frail older adults (non-frail group), and 22 frail older adults (frail group) participated in this study. The range of motion (ROM) of hip abduction, EI, and SR of the adductor longus in the zero- and full-abduction positions were measured. To investigate the effects of aging and frailty, the Kruskal–Wallis test, followed by the post-hoc Steel–Dwass test, was used. In addition, to confirm whether EI and SR in each position were useful for assessing contracture, Spearman’s correlation test was used.

Results

ROM and SR in full-abduction were significantly lower in the frail group than in the other groups and lower in the non-frail group than in the young group. The SR in full-abduction ($p = 0.73, p < .001$) and in zero-abduction ($p = 0.41, p < .001$) showed strong and moderate correlation with the ROM, respectively.

Conclusions

SR in full-abduction is affected by both frailty and aging and is useful for evaluating muscle stiffness related to contracture in frail older adults.

Key words: contracture, range of motion, ultrasonography, elastography, muscle stiffness

INTRODUCTION

Joint contractures are characterized by a limited range of motion (ROM) or an increase in resistance to passive joint movement⁽¹⁾ and are associated with a poor quality of life. The factors associated with contractures include poor functional ability, pain, muscle weakness, reduced physical mobility, and bed confinement.⁽²⁾ As these factors are also associated with frailty,⁽³⁻⁶⁾ frail older adults are more likely to have contractures. A recent study showed that in older adults living in long-term care facilities, upper and lower limb contractures in more than one joint are present (30% and 41%, respectively).⁽⁷⁾ Clinicians should provide appropriate interventions using useful evaluations and treatments for these populations.

Recent animal studies have also revealed that fibrosis occurs in various tissues, such as the skeletal muscle, joint capsule, and skin, in immobilized contracture models.⁽⁸⁻¹⁰⁾ Okita *et al.*⁽¹¹⁾ reported that skeletal muscles are mainly responsible for the progression of contracture. Moreover, Honda *et al.*⁽⁸⁾ reported not only fibrosis, but also increased stiffness in the muscles of contracture model rats following immobilization. Because these muscle quality or stiffness changes have probably occurred in the frail older adults with contractures, the treatment target for them is often the muscles. Though muscle biopsy, palpation or resistance during passive joint motion are used to evaluate muscle quality or stiffness changes in clinical situations, these evaluations are invasive or subjective. Therefore, noninvasive and objective evaluation tools for muscle quality or stiffness are needed. If such an evaluation method could be established, it would facilitate the assessment of muscle quality and stiffness of the frail older adults and improve its reliability.

Recently, ultrasonographic imaging has been widely used in several fields as a noninvasive and objective evaluation tool. Muscle echo intensity (EI) analyzed using B-mode imaging highlights the connective tissue⁽¹²⁾ and interstitial fat⁽¹³⁾ within the muscle. Muscle stiffness interpreted in terms of values, such as strain ratio (SR) or shear wave speed, can be analyzed using elastography.⁽¹⁴⁾ Therefore, EI and SR analyzed using ultrasonographic imaging may be used to evaluate the muscle quality or stiffness changes related to contractures.

Several studies have reported that aging and frailty result in higher muscle EI or stiffness.⁽¹⁵⁻¹⁹⁾ It has also been reported that as the joint angle changes, the stretched muscle EI is decreased and stiffness is increased.⁽¹⁹⁻²¹⁾ Accordingly, to examine the usefulness of the EI and SR for evaluating muscle quality or stiffness changes related to contractures in frail older adults, it is necessary to consider the effects of aging, frailty, and joint angle on the EI and SR.

We have focused on the adductor longus (ADDL) related to contracture in hip abduction, which makes it difficult to change diapers by the caregiver.⁽²²⁾ The first purpose of the study is examination of the effects of aging and frailty on the muscle EI or SR of ADDL related to contracture in hip abduction evaluated in zero- and full-abduction. Second, we aimed to investigate the valid joint angle position to reflect muscle quality or stiffness changes of the ADDL and to establish a clinical evaluation for contracture in frail older adults.

METHODS

Participants

A total of 66 adults comprising 22 healthy young adults (young group), 22 community-dwelling non-frail older adults (non-frail group), and 22 frail older adults (frail group) participated in the study. The study subjects who meet following inclusion criteria were provided with oral and written informed consent. The inclusion criteria for the young group were as follows: individuals in their 20s, no history of leg trauma or surgery, and no neuromuscular disorders of any kind. The study inclusion criteria for the non-frail group were as follows: age \geq 65 years, ability to walk outdoors, and participating in an exercise class held in the community. The study inclusion criteria for the frail group were as follows: age \geq 65 years, hospitalization in a convalescent rehabilitation ward or long-term care facility (Nagasaki Memorial Hospital, Nagasaki, Japan), rehabilitation, and a stable general condition. Those who could not give their consent or could not rest with supine position during measurement were excluded.

The study protocol was approved by the Research Ethics Committee of Nagasaki University Graduate School of Biomedical Sciences (approval number: 21080503), and written informed consent for the collection and use of information was obtained from all participants or their families in accordance with the Declaration of Helsinki.

Measures of Characteristics

The sex, age, and body mass index (BMI) of all participants and underlying diseases, comorbidities, and frailty grades in the non-frail and frail groups were assessed. Specifically, the underlying diseases were divided into orthopedic, cerebrovascular, and other types. The comorbidities were assessed using the Charlson Comorbidity Index, which can be used to estimate mortality.⁽²³⁾ Frailty grade was assessed using the Clinical Frailty Scale (CFS) version 2.0, ranging from 1 (very fit) to 8 (living with very severe frailty).⁽²⁴⁾ The concept of CFS is that, as health deficits accumulate with age, the ability to perform high-order functions which define overall health is eroded. It summarizes the overall level of fitness or frailty of an older adult, and is scored by an observer by referencing pictures and easy descriptions.

Range of Motion of Hip Abduction

The ROM of hip abduction was measured in the legs that were not injured or paralyzed using a goniometer. Passive hip abduction was performed in the supine position by a physical therapist (K.N. or R.I.), and the ROM was measured based on the method published by the Japanese Orthopedic Association and the Japanese Association of Rehabilitation Medicine. The knee on the measured side was kept straight and the examiner moved the leg out to the side. The axis is the anterior superior iliac spine (ASIS). The stationary arm was perpendicular to the line connecting the ASIS on both sides through the ASIS on the measurement side, and the moving arm was the median line of the thigh. Measurements were recorded to the closest angle of 5°.

Muscle Quality and Stiffness of ADDL

A portable ultrasound imaging device with a strain elastography function (JS2, Medicare, Kanagawa, Japan) and a 4-16 MHz linear-array transducer were used to measure the muscle quality and stiffness of the ADDL. An acoustic coupler (JSC-01, Medicare, Kanagawa, Japan) was attached to the head of the transducer using a plastic attachment (JSC-02, Medicare, Kanagawa, Japan). The ultrasound settings (frequency: 7 MHz, gain: 75) were kept consistent among the participants, and the time gain compensation was adjusted to a neutral position; however, the scanning depth was individualized for each participant. EI and SR measurements were performed as previously described.⁽²²⁾ Specifically, the participants were placed in a supine position and instructed to relax. The transducer was positioned 4 cm distal to the pubis and perpendicular to the longitudinal direction of the ADDL.

First, a short-axis gray-scale image of the ADDL was obtained, and the EI was analyzed using the mean of the histogram function of ImageJ software (National Institutes of Health, Bethesda, MD, USA). An elliptical function was used to select the ADDL area that included the area within the outline of the ADDL border. The EI values ranged from 0 to 255 AU (black = 0, white = 255), and higher EI values

appeared white and represented a higher proportion of connective⁽¹²⁾ and adipose tissues.⁽¹³⁾

Next, the SR of the ADDI was analyzed using strain elastography to measure the muscle stiffness. In the strain elastography images, the color scale of the region of interest (ROI) ranged from red for tissues with the greatest strain (softest tissues) to blue for those with no strain (hardest tissues). Manual compression (2–4 Hz) was applied rhythmically (compression–relaxation cycle) with the transducer, and then the appropriate strain elastography image was selected. SR (A/B), which was calculated automatically using the built-in software, is the ratio of the strain of the acoustic coupler (A) to that of ADDI (B). As the muscle became harder, the SR decreased in this study.

In the present study, the EI and SR of the ADDI were measured in zero- and full-abduction positions by two investigators (K.N. and R.I.). First, the EI and SR of the ADDI at zero-abduction were measured. Next, the rater moved the participant’s leg out to the side of full-abduction, and those in full-abduction were measured (Figure 1). The intra- and inter-rater reliabilities of the EI and SR of the ADDI were assessed in a previous study.⁽²²⁾ The results showed the ICC (1, 1) of the EI and SR were 0.97 and 0.92–0.96, respectively, and the ICC (2, 1) of the EI and SR were 0.73 and 0.64, respectively. The intra- and interrater reliabilities of the EI and SR measurements of ADDI were found to be excellent to moderate, respectively, according to Koo and Li.⁽²⁵⁾ The

averages value of the two measurements was adopted for both EI and SR in this study.⁽²²⁾

Sample Size

The required sample size was estimated by using G*Power 3.1 (<https://www.psychologie.hhu.de/arbeitsgruppen/allgemeine-psychologie-und-arbeitspsychologie/gpower>). We used the calculation of sample size for the one-way ANOVA because sample size for the Kruskal–Wallis test is not implemented in G*Power 3.1. The power (1- β) was set at 0.8, the significance level (α) was set at 0.05, and the effect size was set at 0.4. The power analysis indicated that 66 patients (22 per group) were required in the study.

Statistical Analysis

The participant characteristics were expressed as the mean ± standard deviation (SD). The ROM of hip abduction, EI, and SR of the ADDI in the two positions were expressed as medians (interquartile range [IQR]). To investigate the effects of aging and frailty, EI, SR, and ROM were compared among the young, non-frail, and frail groups using the Kruskal–Wallis test followed by the post hoc Steel–Dwass test. In addition, to investigate the effect of frailty more clearly, the relationship between the CFS and ROM, EI or SR in the non-frail and frail groups was analyzed using Spearman’s rank correlation coefficient. Furthermore, to confirm whether EI and SR in each position were useful for assessing contracture,

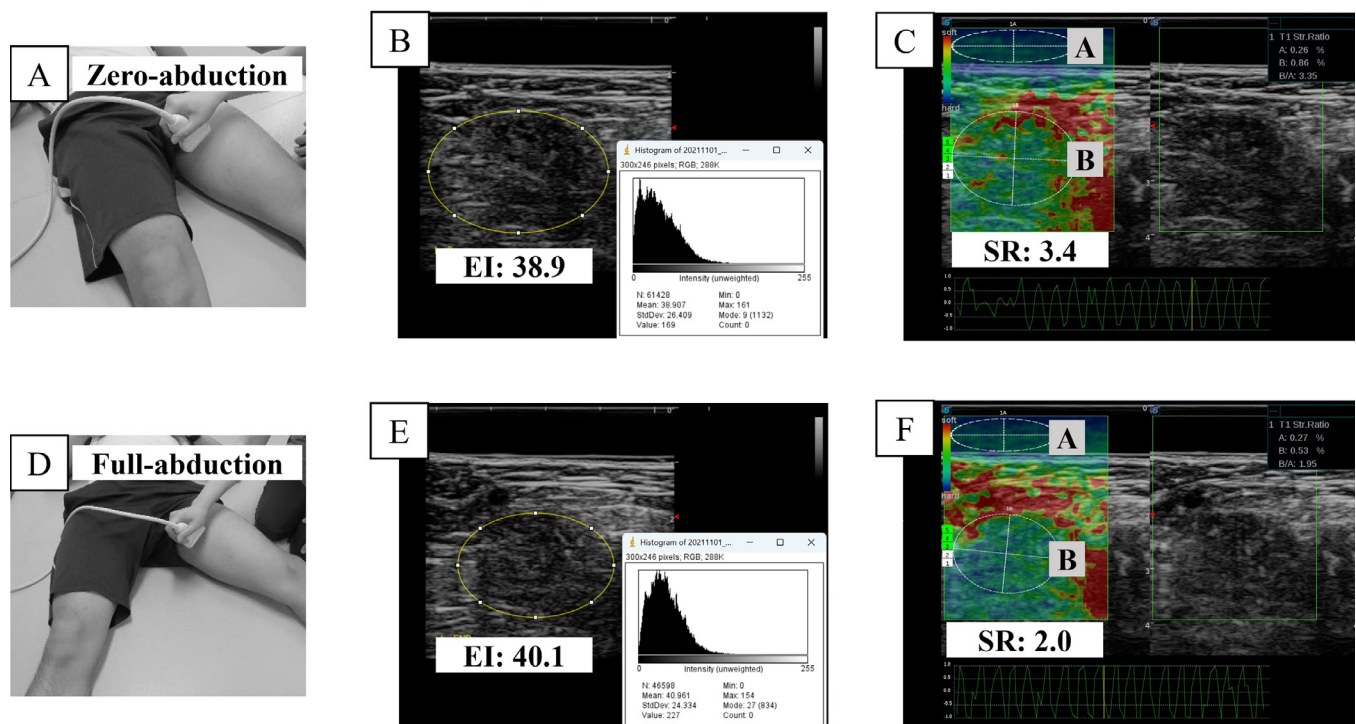


FIGURE 1. (A) Ultrasonography measurement scene in zero-abduction; (B) the screen of analyzed echo intensity (EI) of adductor longus (ADDI) surrounded by yellow ellipse in zero-abduction; (C) the screen of analyzed strain ratio (SR) of ADDI in zero-abduction; A and B (white ellipse) indicate the region of interest of the acoustic coupler and ADDI, respectively; the SR (B/A) was the ratio of the strain of the acoustic coupler to that of the ADDI; (D) ultrasonography measurement scene in full-abduction; (E) the screen of analyzed EI of ADDI in full-abduction; (F) the screen of analyzed SR of ADDI in full-abduction.

the relationships between EI, SR, and ROM were analyzed including all participants by using Spearman’s rank correlation coefficient. All statistical analyses were performed using SPSS software (version 22.0; IBM Corporation, Armonk, NY, USA). The level of significance was set at $p < .05$.

RESULTS

Characteristics

Table 1 summarizes the characteristics of the participants. A total of 66 participants volunteered in the present study, of which 22 participants were in the young group (11 women), 22 participants were in the non-frail group (11 women), and 22 participants were in the frail group (11 women), with a mean age (SD) of 24.1 yr (2.3), 79.1 yr (6.4), and 83.3 yr (6.4), respectively. Their mean (SD) body mass index (BMI)

was 21.4 kg/m² (3.1), 22.5 kg/m² (2.1) and 19.4 kg/m² (2.6), respectively. In the non-frail group, the CFS ranged from 1 (very fit) to 4 (living with very mild frailty), whereas it ranged from 3 (managing well) to 8 (living with very severe frailty) in the frail group.

Comparison of ROM, EI, and SR in the Zero- and Full-Abduction Positions Between Groups

The median (IQR) ROM for hip abduction in the young, non-frail, and frail groups were 45° (43.8–45), 37.5° (30–40), and 25° (15–30), respectively. The ROM of hip abduction was significantly lower in the frail group than in the young and non-frail groups, and lower in the non-frail group than in the young group (Figure 2A). In the non-frail and frail groups, the CFS was strongly correlated with the ROM of hip abduction ($\rho = -0.75, p < .001$; Figure 2B).

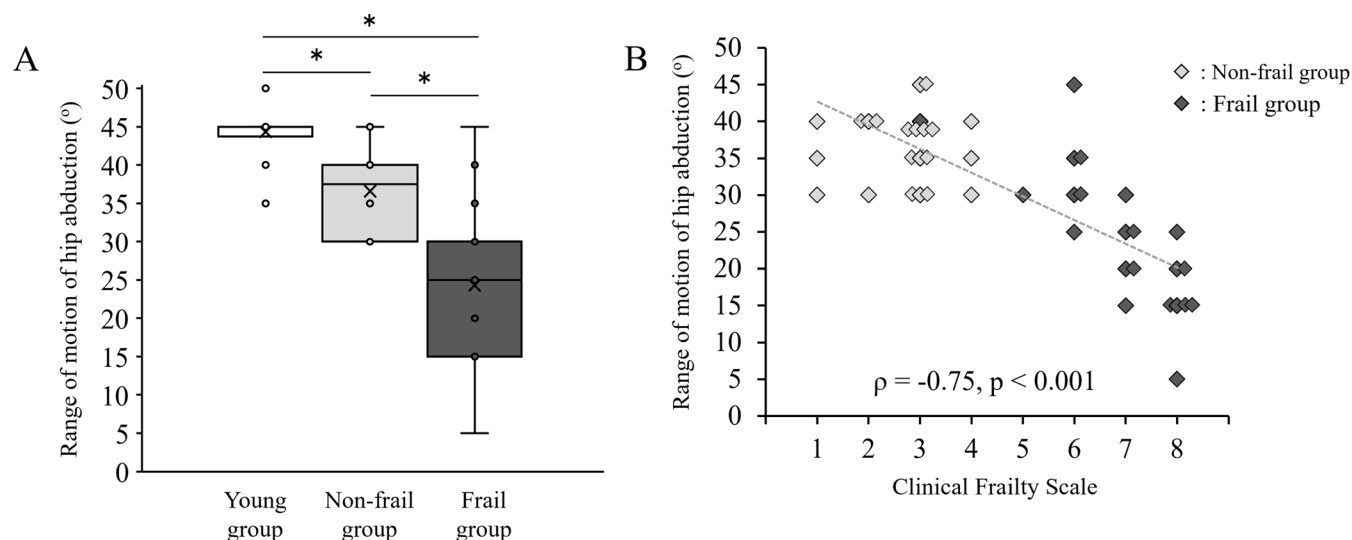


FIGURE 2. (A) Box-and-whisker plot^a comparing the young, non-frail, and frail groups with respect to the range of motion (ROM) of hip abduction; the boxplot displays the median and 50th percentile (interquartile range); X marks in boxplots are mean values; the tips of whiskers represent the minimum and maximum values; the open circles represent outliers; (B) the results of analysis for single correlation in non-frail group and frail group between Clinical Frailty Scale and ROM of hip abduction; the light gray rhombus represents the non-frail group, and dark gray rhombus represents frail group.

^aSignificant difference ($p < .05$) as compared between groups.

TABLE 1.
Participant characteristics (n = 66)^a

Characteristics	Young Group (n = 22)	Non-frail Group (n = 22)	Frail Group (n = 22)
Sex (men/women)	11/11	11/11	11/11
Age (yr)	24.1±2.3	79.1±6.4	83.3±6.4
Body Mass Index (kg/m ²)	21.4±3.1	22.5±2.1	19.4±2.6
Underlying disease (Orthopedic/Cerebrovascular/Others)	-	-	5/16/1
Charlson Comorbidity Index	-	0.1±0.3	3.5±2.1
Clinical Frailty Scale (1/2/3/4/5/6/7/8)	-	3/4/12/3/0/0/0/0	0/0/1/0/1/6/6/8

^aData are expressed as the mean ± standard deviation or n.

The median (IQR) EI of ADDI in zero-abduction in the young, non-frail, and frail groups were 40.8 (27.5–54), 42.9 (27.9–65.9), and 43.4 (36.1–61.6), respectively; whereas in full-abduction the values were 42.3 (31.0–53.2), 45.9 (34.3–82.9), and 47.3 (39.5–60.4), respectively. There was no significant difference between the groups in either measurement position (Figures 3A, 3B). In the non-frail and frail groups, the CFS did not correlate with the EI of the ADDI at either measurement position (Figures 3C, 3D).

The median (IQR) SR of ADDI in zero-abduction in the young, non-frail, and frail groups were 4.5 (3.5–6.8), 4.3 (3.8–5.3), and 3.1 (2.3–3.8), respectively, and significantly lower in the frail group than in the young and non-frail groups, whereas no significant difference was observed between the non-frail and young groups (Figure 4A). Meanwhile, that of full-abduction in the young, non-frail, and frail groups were 5.0 (4.0–6.2), 3.0 (2.6–3.8), and 2.0 (1.7–2.3), respectively, and significantly lower in the frail group than in young and non-frail groups, and lower in the non-frail group than in the young group (Figure 4B). In the non-frail and frail groups, the CFS was moderately correlated with the SR of ADDI in

zero-abduction ($\rho = -0.49, p < .001$; Figure 4C), and in full-abduction ($\rho = -0.64, p < .001$; Figure 4D).

Relationship Between the EI or the SR and ROM

The EI of ADDI in the zero-abduction and full-abduction positions were not correlated with the ROM of hip abduction in all participants (zero-abduction; $\rho = -0.16, p = .21$; Figure 5A, full-abduction; $\rho = -0.08, p = .54$; Figure 5B). The SR of ADDI in zero-abduction were correlated with the ROM of hip abduction in all participants ($\rho = 0.41, p < .001$; Figure 5C), whereas that in full-abduction were more correlated ($\rho = 0.73, p < .001$; Figure 5D).

DISCUSSION

The present study examined the effects of aging and frailty on the EI or SR of the ADDI evaluated in the zero- and full-abduction positions by comparing the EI or SR in the young, non-frail, and frail groups. The results showed the SR of the ADDI during full-abduction was lower in the frail, non-frail, and young groups in that order. Furthermore, the SR of the

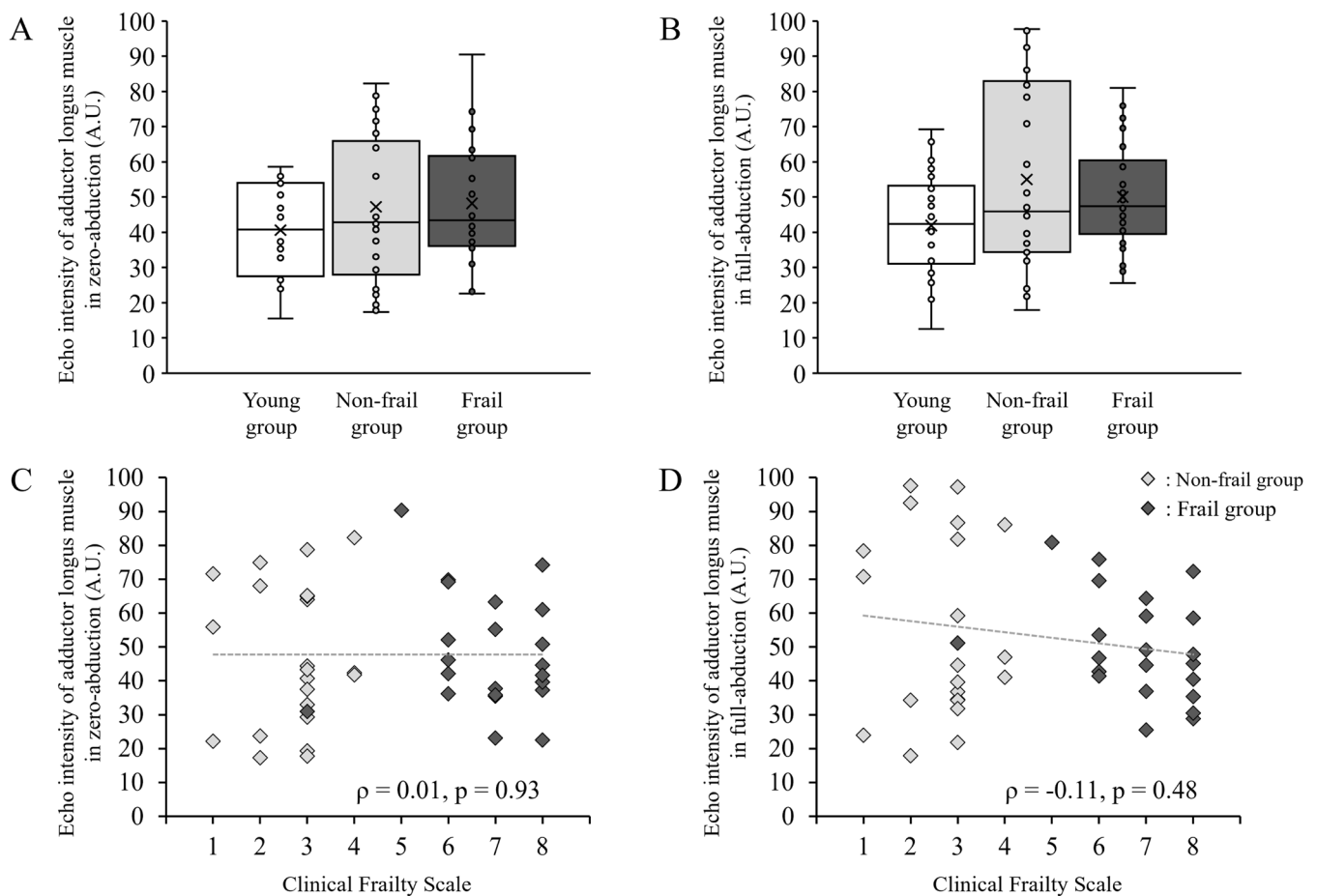


FIGURE 3. (A, B) Box-and-whisker plots comparing the young, non-frail, and frail groups with respect to echo intensity (EI) of the adductor longus (ADDI) in zero-abduction (A) or full-abduction (B); (C, D) the results of analysis for single correlation in non-frail group and frail group between Clinical Frailty Scale and EI of ADDI in zero-abduction (C) or full-abduction (D); the light gray rhombus represents the non-frail group, and dark gray rhombus represents frail group.

ADDI in full-abduction was strongly correlated with the ROM of hip abduction than that in zero-abduction.

The young, non-frail, and frail groups, in that order, had lower ROM of hip abduction in the present study. In addition, the CFS was strongly correlated with the ROM of hip abduction in the non-frail and frail groups. These results indicate that not only aging,⁽²⁶⁾ but also mobility impairment⁽²⁷⁾ and inactivity⁽²⁸⁾ related to frailty are the causes of limited ROM.

There were no significant differences observed in the EI of the ADDI among the three groups in the present study. Several studies have reported age-related increases in EI in the quadriceps femoris,⁽¹⁵⁾ hamstrings,⁽¹⁶⁾ and tibialis anterior.⁽¹⁷⁾ In contrast, Akagi *et al.*⁽²⁹⁾ reported no age-related differences in plantar flexors. Accordingly, some muscles, including the ADDI, may be less affected by aging. With respect to the effect of frailty, Mirón Mombiola *et al.*⁽³⁰⁾ reported no significant difference in the rectus femoris EI between robust, pre-frail, and frail groups. This result is similar to the present study. Additional studies are needed to confirm the effects of aging and frailty on the quality of individual muscles.

The present study revealed that the EI of the ADDI in the zero- and full-abduction positions was not related to the ROM of hip abduction in all participants. Muscle EI represents not only connective tissue,⁽¹²⁾ but also interstitial fat within the muscle.⁽¹³⁾ Accordingly, it is difficult to evaluate muscle fibrosis indirectly using EI. Further studies are required to clarify the usefulness of EI in assessing the changes in muscle quality related to contractures in frail older adults.

The SR of the ADDI in zero-abduction was significantly lower in the frail group than in the young and non-frail groups, and no significant difference was observed between the non-frail and young groups in the present study. In contrast, the SR of the ADDI in full-abduction was significantly lower in the frail group than in the young and non-frail groups, and lower in the non-frail group than in the young group in the present study. Previous studies reported that biceps brachii stiffness in chronic post-stroke survivors evaluated in 90° elbow flexion and maximally achievable extension was higher than that in healthy volunteers.^(31,32) On the other hand, Liu *et al.*⁽¹⁹⁾ reported that gastrocnemius medialis stiffness in older adults

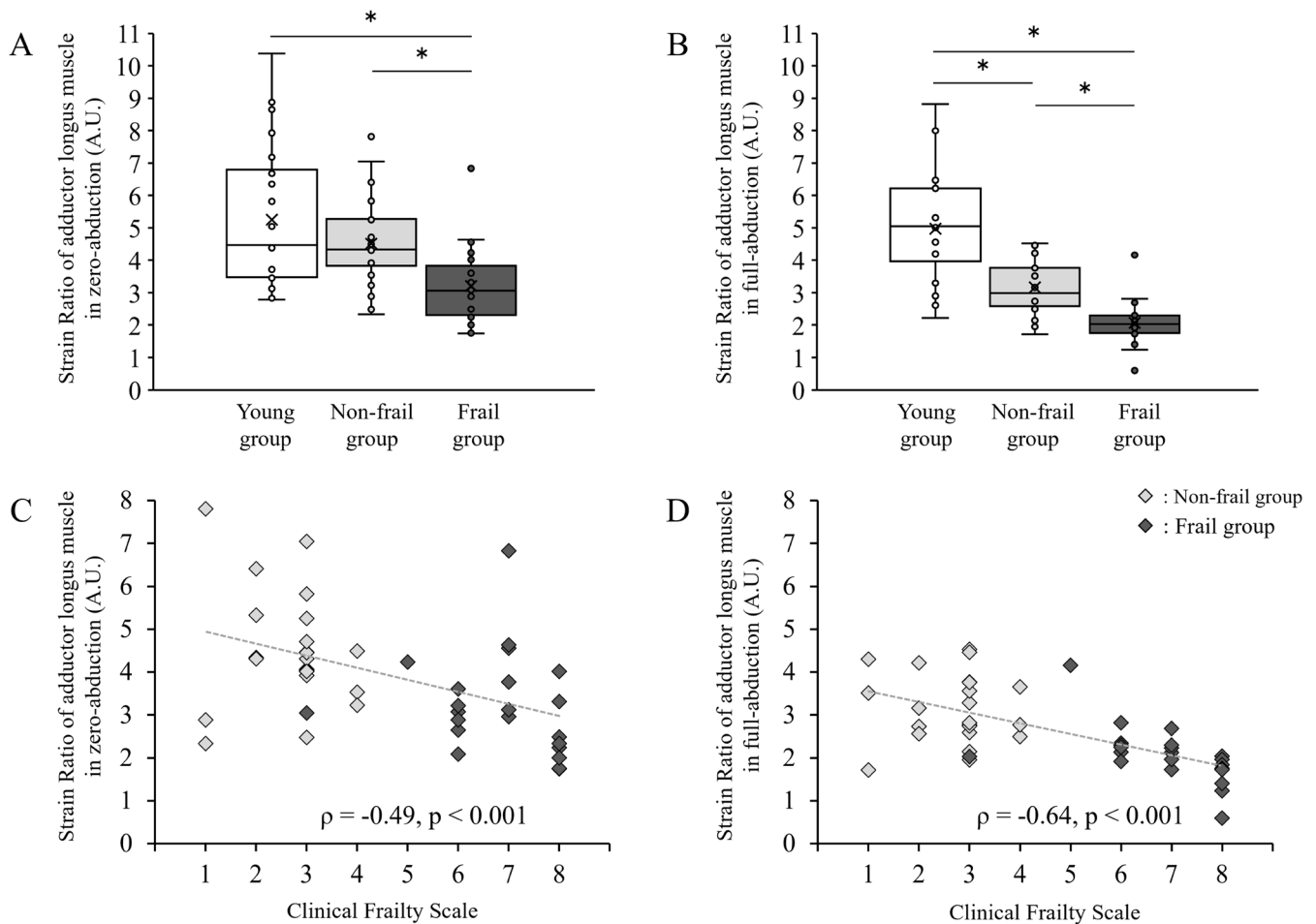


FIGURE 4. (A, B) Box-and-whisker plots^a comparing the young, non-frail, and frail groups with respect to the strain ratio (SR) of the adductor longus (ADDI) in zero-abduction (A) or full-abduction (B); (C, D) the results of analysis for single correlation in non-frail group and frail group between the Clinical Frailty Scale and SR of ADDI in zero-abduction (C) or full-abduction (D); light gray rhombus represents the non-frail group, and dark gray rhombus represents the frail group.

^aSignificant difference ($p < .05$) as compared between groups.

evaluated in 40° to 0° plantarflexion was not significantly different from that in children and middle-aged adults, whereas stiffness in 10° to 30° dorsiflexion in older adults was higher than that in children and middle-aged adults. These results and those of our study indicate that muscle stiffness evaluated in the unstretched position may be affected by frailty, which contributes to diseases, such as cerebrovascular and musculoskeletal diseases. And then, muscle stiffness in the stretched position may be affected by frailty and aging.

We also found that the SR of the ADDI in full-abduction was strongly correlated with the ROM of hip abduction, whereas it was moderately correlated with zero-abduction. In animal experiments, Honda *et al.*⁽⁸⁾ reported that passive tension of the immobilized muscle, which causes limited ROM, increased more as it was stretched than that of the control muscle. Liu *et al.*⁽¹⁹⁾ and Le Sant *et al.*⁽²¹⁾ also reported that the muscle stiffness of older adults or stroke survivors who had limited ROM increased more as they stretched than that of healthy adults in human experiments. Thus, as the ROM is closer to the full range (i.e., as the muscle is stretched),

muscle stiffness remarkably increases in older adults or stroke survivors compared to healthy adults. This may explain why a higher correlation was observed in the ROM of hip abduction with the SR of the ADDI in full-abduction than in zero-abduction in the present study. Therefore, the SR of the ADDI in full-abduction may reflect muscle stiffness change-related contractures during hip abduction in the frail group.

The results of our present study imply that the EI of the ADDI is not affected by frailty and aging and cannot evaluate the changes in muscle quality related to contractures in frail older adults. In contrast, the SR of the ADDI in full-abduction is affected by frailty and aging and is able to evaluate the changes in muscle stiffness related to contractures in frail older adults. The muscle stiffness evaluated by SR has the potential to be a clinical innovative tool for contracture in frail older adults to overcome the reliance on conventional invasive or subjective assessment such as muscle biopsy, palpation or resistance during passive joint motion.

The present study has several limitations. First, only the relationship between the EI or SR of the ADDI and ROM of

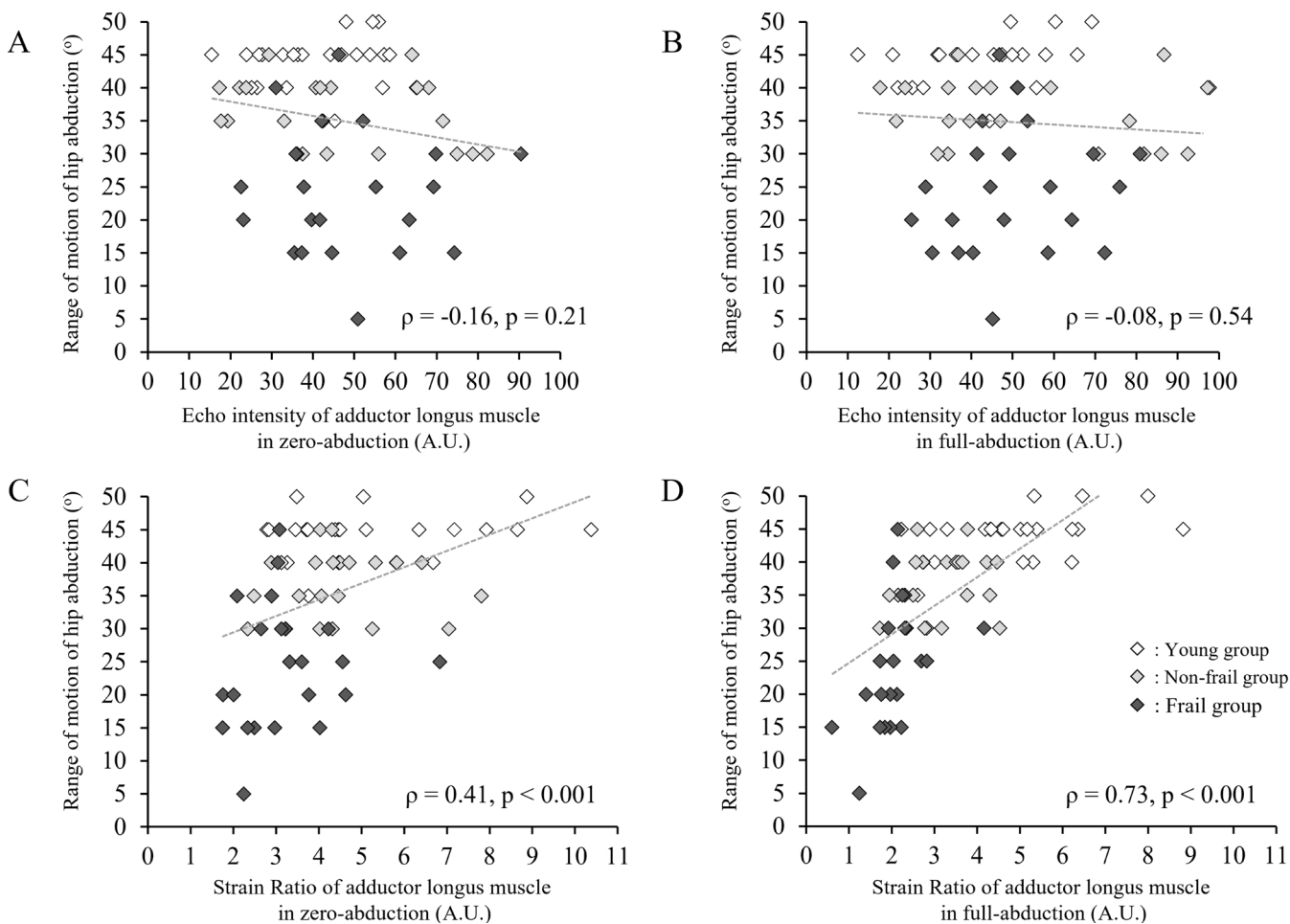


FIGURE 5. (A, B) The results of analysis for single correlation in all participants between echo intensity (EI) of adductor longus (ADDI) in zero-abduction (A) or full-abduction (B) and range of motion (ROM) of hip abduction; (C, D) the results of analysis for single correlation in all the participants between strain ratio (SR) of ADDI in zero-abduction (C) or full-abduction (D) and ROM of hip abduction; white rhombus, light gray rhombus, and dark gray rhombus represents the young, non-frail, and frail groups, respectively.

hip abduction was cross-sectionally evaluated in the present study. Different tendencies might be observed by examining different muscle and joint motions, and it has not been revealed whether the muscle quality or stiffness changes occurring with the progression of limited ROM could be examined by EI or SR of ADDI. Second, the effects of diseases on each evaluation were unclear because the frail group in the present study had various diseases, including orthopedic, cerebrovascular, and other diseases. For example, patients with cerebrovascular disease often have higher muscle tone, which affects muscle stiffness.⁽³³⁾ Because frail groups generally have multiple comorbidities, it is difficult to evaluate the effects of individual diseases on EI or SR clearly. Third, it might be difficult to directly compare the EI results of the present study with those of other studies⁽²²⁾ because the evaluation settings, such as the acoustic coupler, subcutaneous fat thickness, and image resolution, which affect muscle EI,⁽³⁴⁻³⁷⁾ could not be unified between studies. To allow comparisons of EI between studies, further studies are needed to develop standardization and calibration analyses of EI.

CONCLUSION

The SR of the ADDI in zero-abduction was affected by frailty, whereas that in full-abduction was affected by both frailty and aging. The SR of the ADDI in full-abduction is useful for evaluating muscle stiffness changes related to contracture during hip abduction in frail older adults. Strain ratio measured in full range of motion position by ultrasonography is expected to be used to evaluate muscle stiffness changes related to contractures in clinical situations.

ACKNOWLEDGEMENTS

The authors thank all the participants of this study. We would also like to thank Editage for the English language editing.

CONFLICT OF INTEREST DISCLOSURES

We have read and understood the *Canadian Geriatrics Journal's* policy on conflicts of interest disclosure and declare there are no conflicts of interest.

FUNDING

This work was supported by JSPS KAKENHI Grant Number 23K18374 and 23H05372.

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