Ultrasound in Med. & Biol., Vol. 48, No. 9, pp. 1858−1866, 2022

0301-5629/$ - see front matter

https://doi.org/10.1016/j.ultrasmedbio.2022.05.016

● *Original Contribution*

RELATIONSHIP BETWEEN MUSCLE QUALITY OR STIFFNESS MEASURED BY ULTRASONOGRAPHY AND RANGE OF MOTION IN HOSPITALIZED OLDER ADULTS

Koichi Nakagawa,[*,†] Hideki Kataoka,[*,†] Chiaki Murata,[†] Kyo Goto,[*,†] Junichiro Yamashita,[†] Yuichiro Honda,[*,‡] Junya Sakamoto,[*,‡] Tomoki Origuchi,[*,‡] and Minoru Okita[*,‡]

[*] Department of Physical Therapy Science, Nagasaki University Graduate School of Biomedical Sciences, Nagasaki, Japan; [†] Department of Rehabilitation, Nagasaki Memorial Hospital, Nagasaki, Japan; and [‡] Institute of Biomedical Sciences, Nagasaki University, Nagasaki, Japan

(*Received* 20 *December* 2021; *revised* 24 *March* 2022; *in final form* 11 *May* 2022)

Abstract—Older adults who require nursing care have joint contractures characterized by limited range of motion (ROM). The present study investigated age-related muscle changes using ultrasonography and the relationship between ROM and muscle changes in older adults. Twenty-two healthy young adults (mean age: 23.3 y) and 60 hospitalized older adults (mean age: 86.1 y) participated. ROM of hip abduction was measured using a goniometer. Echo intensity (EI), reflecting interstitial fibrous tissue or fat within adductor longus (ADDl) was measured using B-mode ultrasonography, and strain ratio (SR), reflecting ADDl stiffness, was measured by strain elastography. The Mann−Whitney *U*-test and Spearman's correlation test were used for analysis. The ROM and SR of older adults were significantly lower than those of young adults (both *p* values <0.001). The EI was significantly higher in older adults than in young adults ($p < 0.001$). In older adults, the SR was moderately correlated with ROM ($\rho = 0.49$, $p < 0.001$). In conclusion, limited ROM and increase in interstitial fibrous tissue or fat and stiffness occur with aging, and the SR measured by strain elastography is useful for investigating the effect of muscle stiffness on the ROM of hospitalized older adults. (E-mail: mokita@nagasaki-u.ac.jp) © 2022 World Federation for Ultrasound in Medicine & Biology. All rights reserved.

Key Words: **Contracture, Range of motion, Ultrasonography, Elastography, Echo intensity, Muscle stiffness.**

INTRODUCTION

Contractures are characterized by a limited range of motion (ROM) or an increase in resistance to passive joint movement (Fergusson et al. 2007). They are a major factor in burden of care in activities of daily living, such as eating, dressing, excretion and walking (Fergusson et al. 2007) and, consequently, a decline in quality of life. According to previous studies, 60% to 75% of older adults living in nursing homes had a contracture in more than one joint (Mollinger and Steffen 1993; Wagner et al. 2008). The systematic review reported by Offenbächer et al. (2014) revealed that immobility was a possible risk factor for development of contractures. Recent animal research has also revealed that immobility causes fibrosis in such tissues as skeletal muscle, the joint capsule and skin in contracture models (Goto et al. 2017; Sasabe et al. 2017; Honda et al. 2018). Okita et al. (2009) reported that skeletal muscle was mainly responsible for the progression of contracture, and Honda et al. (2018) reported not only fibrosis but also increased stiffness in the muscle of contracture model rats. Therefore, clinicians should evaluate these muscle changes in clinical practice.

B-Mode ultrasonographic imaging can qualitatively evaluate muscle properties. For example, the muscle echo intensity (EI) analyzed using B-mode images represents connective tissue (Pillen et al. 2009) and interstitial fat (Reimers et al. 1993) within the muscle. Similarly, ultrasound elasticity imaging can be used to evaluate mechanical muscle properties. There are multiple approaches to ultrasound elasticity imaging, such as strain elastography and shear wave elastography, each of which provides parameters related to muscle stiffness (Shiina et al. 2015). Strain elastography provides a

Address correspondence to: Minoru Okita, Department of Physical Therapy Science, Nagasaki University Graduate School of Biomedical Sciences, Sakamoto 1-7-1, Nagasaki 850-8520, Japan. E-mail: mokita@nagasaki-u.ac.jp

relative strain measure compared with a reference material through a strain ratio (SR) parameter (Inami and Kawakami 2016). Because SR is not affected by scanning depth (Ewertsen et al. 2016), it is possible to compare muscle stiffness among patients with different subcutaneous fat thicknesses. Therefore, clinicians can indirectly evaluate muscle fibrosis or increased muscle stiffness using EI or SR.

In clinical situations, contracture is assessed by the presence of limited ROM in most cases (Offenbächer et al. 2014). Therefore, it can be hypothesized that the qualitative and mechanical muscle properties measured by ultrasonography are related to ROM.

In fact, Picelli et al. (2017) reported that ankle passive ROM was significantly limited and the gastrocnemius muscle EI was significantly higher in patients with chronic stroke than in those with secondary progressive multiple sclerosis. In addition, Hirata et al. (2020) reported that ROM of dorsiflexion was negatively correlated with the stiffness of the soleus in angle-controlled conditions (15° dorsiflexion) in healthy older adults. Although the aforementioned studies reported characteristics of muscle quality and stiffness and the relationship between muscle quality or stiffness and ROM, they targeted individuals with neurological disorders or healthy older adults. In older adults who require nursing care for various diseases, the characteristics of muscle quality and stiffness and the relationship between muscle quality or stiffness and ROM are not sufficiently understood. The first purpose of the present study was to compare the EI and SR of the adductor longus (ADDl) between older adults who require nursing care and healthy young adults. Second, we aimed to investigate the relationship between ADDl EI or SR and ROM of hip abduction in older adults.

METHODS

Participants

This study had a cross-sectional design. A total of 82 adults participated in this study after providing written informed consent. Twenty-two (11 men and 11 women) healthy young adults and 60 (28 men and 32 women) older adult patients participated in the study. The older adult patients were hospitalized in a convalescent rehabilitation ward or long-term care facility of the Nagasaki Memorial Hospital, Nagasaki, Japan.

The study inclusion criteria for young adults were that individuals be in their twenties and have no history of leg trauma or surgery and no neuromuscular disorder of any kind. The study inclusion criteria for older adults were individuals undergoing rehabilitation and in stable general condition.

The study protocol was approved by the Research Ethics Committee at Nagasaki University Graduate School of Biomedical Sciences (Approval No. 19111404), and written informed consent for the collection and use of the information was obtained from all participants or their families in accordance with the Declaration of Helsinki.

Measures of characteristics

Sex, age and body mass index (BMI) of all participants and underlying diseases, length of hospitalization, comorbidities and grade of frailty in older adults were assessed. Specifically, underlying diseases were divided into orthopedic, cerebrovascular and other diseases. Comorbidities were assessed using the Charlson Comorbidity Index, which could estimate mortality (Charlson et al. 1987). The grade of frailty was assessed using the Clinical Frailty Scale, ranging from 1 (very fit) to 8 (very severely frail) (Morley et al. 2013).

Range of motion of hip abduction

Range of motion of hip abduction was measured in the leg that was not injured or paralyzed using a goniometer. Passive motion of hip abduction was performed in the supine position by a physical therapist (K.N. or C. M.), and ROM was measured based on the method published by the Japanese Orthopaedic 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 location was 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 movement arm was the median line of the thigh (Fig. 1). The measurements were recorded to the closest 5°.

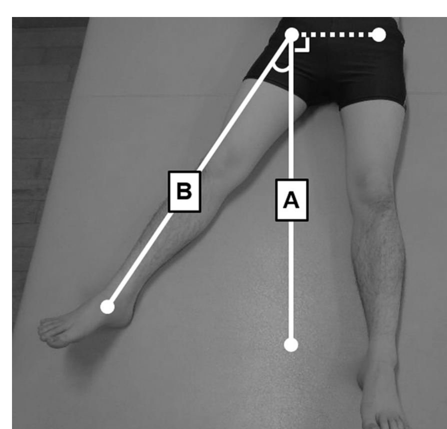

Fig. 1. Location of stationary and movement arms. The stationary arm is perpendicular to the line connecting the ASIS on both sides through the ASIS on the measurement side (A). The movement arm is the median line of the thigh (B). ASIS = anterior superior iliac spine.

Muscle quality and stiffness of ADDl

To measure muscle quality, the EI of ADDl was analyzed using B-mode ultrasonography measurements performed using a portable ultrasound imaging device (JS2, Medicare, Kanagawa, Japan) with a 4- to 16-MHz linear-array probe. The participant was placed in a supine position, and the measured leg was relaxed in a zero-abduction position during the measurement. The transducer was positioned 4 cm distal to the pubis, perpendicular to the ADDl longitudinal direction on the gel sheet (Hydro Aid, Nippon BXI, Tokyo, Japan) pasted on the skin. Ultrasound settings (frequency: 7 MHz, gain: 75) were kept consistent among the participants, and time-gain compensation was adjusted to the neutral position; however, the scanning depth was individualized for each participant. To identify the ADDl area in the B-mode image, the fascicular areas between the sartorius or gracilis (Watanabe et al. 2009) and ADDI deformation during passive hip abduction were referred. A short-axis gray-scale image of the ADDl was then obtained, and the EI was analyzed. The EI of ADDl was assessed by computer-aided gray-scale analysis using the mean of the histogram function of the ImageJ software (National Institutes of Health, Bethesda, MD, USA). An elliptical function was used to select the ADDI area, and the area was determined to include the area within the outline of the ADDI border (Fig. 2). EI values ranged from 0 to 255 AU (black = 0, white = 255). Higher EI appears white and represents a higher proportion of connective (Pillen et al. 2009) and adipose tissues (Reimers et al. 1993).

To measure muscle stiffness, the SR of the ADDl was analyzed using the strain elastography function (JS2, Medicare, Kanagawa, Japan) and a 6-mm thick gel sheet (HydroAid, Nippon BXI, Tokyo, Japan) as a reference for elasticity. The gel sheet is dressed in the form of a homogenous, mechanically resistant pad based on a special net of three polymers, including approximately 90% water. After a short-axis gray-scale image of the ADDl was obtained, the strain elastography function was started. In 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), and the ROI was set up twice the area of the ADDl based on the manufacturer's recommendations. Manual compression (2−4 Hz) was applied rhythmically (compression-relaxation cycle) with the transducer in the scan position looking at the strain curve diagram on the screen. Then, the movie was paused, and the appropriate strain elastography image was selected with a stress grade ranging from 3 to 5 on the screen. The SR (B/A) for the image, which was the ratio of the strain of the reference material (*A*) to that of the ADDl (*B*), was calculated automatically using built-in software. The ROI of the ADDl was set with an elliptical function of the software, and the ROI of the reference material was set to fit the width of the ROI of the ADDl according to the study by Saito et al. (2019)

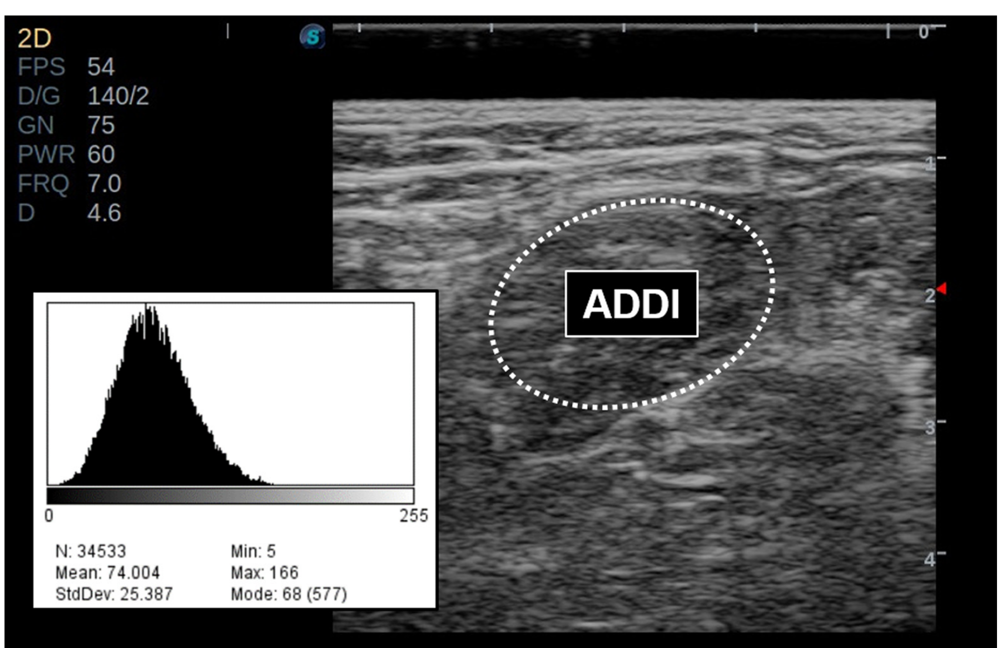

Fig. 2. Example of ADDl transverse axial B-mode image. The dotted line represents the area including the muscle. The EI of ADDl was assessed by computer-aided gray-scale analysis using the mean of the histogram function of ImageJ software (left lower corner). The ADDl has EI of 74.0 A.U. ADDl = adductor longus; EI = echo intensity.

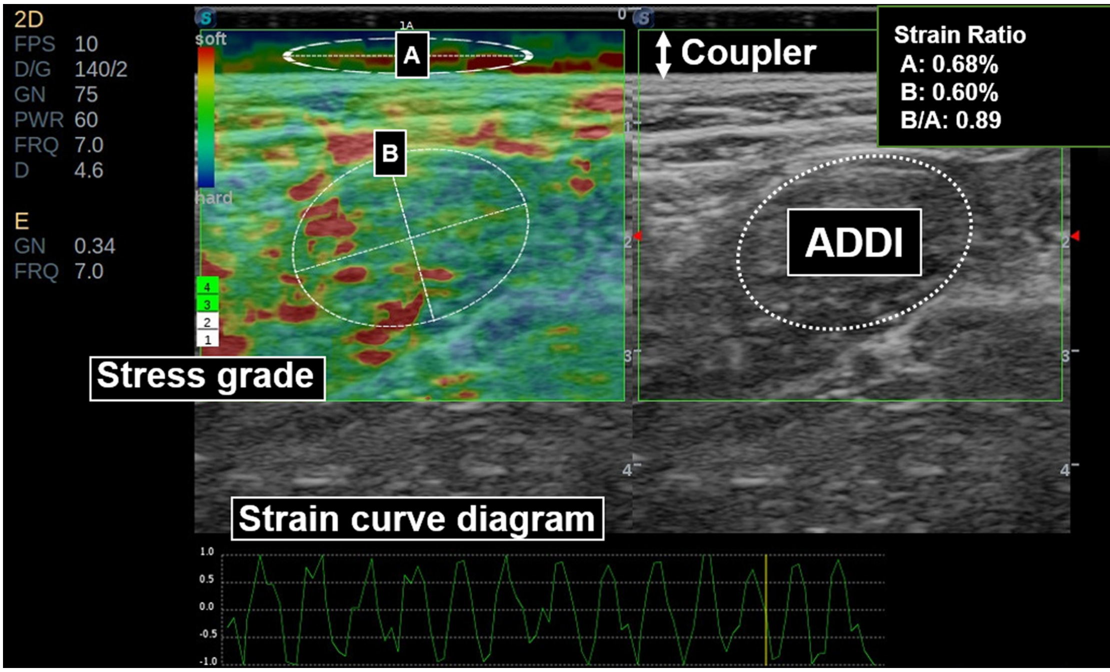

Fig. 3. Example of an ADDl transverse axial strain elastography image. The color scale within the field of view (left) is expressed as a range from *red* (softest tissue) to *blue* (hard tissue). The *white ellipses* indicate the region of interest of the acoustic coupler (A) and ADDl (B), respectively. The strain ratio (*B*/*A*) was the ratio of the strain of the acoustic coupler (A) to that of the ADDl (B). ADDl = adductor longus.

(Fig. 3). As the muscle became harder, SR decreased in this study. EI and SR were measured by a physical therapist (K.N. or C.M.).

Reliability of EI and SR measurements of the ADDl

The intra-rater and inter-rater reliabilities of the EI and SR of the ADDl were assessed in a pilot study of 20 participants (mean age: 89.7 ± 5.4 y). Two raters (K.N. and C.M.) independently measured these values twice. There were a few tens of seconds between each measurement. To analyze intra-rater reliability, intraclass correlation coefficients (ICCs) with 95% confidence intervals (CIs) were calculated by using the “1, 1” model (Shrout and Fleiss 1979) from the two measurements by each rater. To analyze inter-rater reliability, ICCs with 95% CI were calculated using the “2, 1” model (Shrout and Fleiss 1979) from the average of two measurements by each rater. Statistical analyses were performed using SPSS (version 22.0, IBM Corp., Armonk, NY, USA). The ICC (1, 1) of the EI and SR by one rater (K.N.) were 0.97 (95% CI: 0.93−0.99) and 0.92 (95% CI: 0.80−0.97), respectively, and those by another rater (C.M.) were 0.97 (95% CI: 0.92-0.99) and 0.96 (95% CI: 0.90-0.98), respectively. The ICC (2, 1) of the EI and SR were 0.73 (95% CI: 0.43−0.89) and 0.64 (95% CI: 0.29−0.84), respectively. The intra- and inter-rater reliabilities of EI and SR measurements of ADDl were found to be excellent to moderate, respectively, according to the study by Koo and Li (2016). Ultrasonography measurements were carried out by two investigators; therefore, the average value of two measurements was adopted for both EI and SR in this study.

Statistical analysis

Participant characteristics were expressed as the mean ± standard deviation (SD). The ROM of hip abduction and the EI and SR of the ADDl are expressed as the median (interquartile range [IQR]). To confirm the characteristics of older adults who required nursing care for various diseases, the EI and SR of the ADDl and the ROM of hip abduction were compared between young and older adults using the Mann−Whitney *U*-test. To confirm that EI and SR are useful for assessing contracture in older adults, the relationship between the EI and SR of the ADDl and the ROM of hip abduction in older adults was analyzed using Spearman’s rank correlation coefficient. All statistical analyses were performed using SPSS (version 22.0). The level of significance was set at $p < 0.05$.

RESULTS

Characteristics

A total of 82 participants volunteered in the present study, of whom 22 were young adults (11 women) and

60 were older adults (32 women) with mean ages (SD) of 23.3 y (1.7) and 86.1 y (6.9), respectively. The young and older adults had mean (SD) BMIs of 21.3 kg/m^2 (3.0) and 19.0 kg/m^2 (3.3), respectively. In older adults, the Clinical Frailty Scale ranged from 5 (mildly frail) to 8 (very severely frail). Table 1 summarizes the characteristics of the participants.

Comparison of ROM, EI and SR between young and older adults

The median (IQR) ROM for hip abduction in young and older adults was 45° (43.8−45) and 25° (20−30), respectively. The ROM of hip abduction was significantly lower in older adults than in young adults ($p < 0.001$; Fig. 4A). The median (IQR) EIs of the ADDl of the young and older adults were 64.3 (56.2−71.5) and 77.1 (68.3−83.2), respectively. The EI of the ADDl was significantly higher in older adults than in young adults ($p < 0.001$; Fig. 4B). The median (IQR) SRs of the ADDl of young and older adults were 2.9 (2.6−3.9) and 1.6 (0.9−2.7), respectively. The SR of the ADDl was significantly lower in older adults than in young adults ($p < 0.001$; Fig. 4C).

Relationship between the EI or the SR and ROM in older adults

The ADDl EI was not correlated with the ROM of hip abduction in older adults ($\rho = -0.06$, $p = 0.66$; Fig. 5A). The SR of ADDl was moderately correlated with the ROM of hip abduction in older adults ($\rho = 0.49$, $p < 0.001$; Fig 5B).

DISCUSSION

The present study examined differences in ROM, EI and SR between young and older adults; consequently, older adults had limited ROM, higher EIs and lower SRs compared with young adults. Moreover, when examining the usefulness of EI and SR in assessing contracture, there was no relationship between EI and ROM, and a moderate relationship between SR and ROM in older adults.

Table 1. Characteristics of participants (N = 82)

Characteristic	Young adults (n = 22)	Older adults (n = 60)
Sex (male/female)	11/11	28/32
Age (y)	23.3 ± 1.7	86.1 ± 6.9
Body mass index (kg/m^2)	21.3 ± 3.0	19.0 ± 3.3
Underlying disease (orthopedic/cerebrovascular/other)	—	27/19/14
Charlson Comorbidity Index	—	3.2 ± 1.7
Clinical Frailty Scale (5/6/7/8)	—	1/26/18/15

Data are expressed as numbers or the mean ± standard deviation.

First, the intra-rater reliabilities of EI and SR measurements of the ADDl were found to be excellent (Koo and Li 2016) in the present study. Several studies have investigated intra-rater reliabilities of EI or SR measurements of some muscles, and good to excellent (Koo and Li 2016) reliabilities were observed in them (Yanagisawa et al. 2011; Muraki et al. 2015; Santos and Armada-da-Silva 2017; Rabello et al. 2019). The intra-rater reliabilities in the present study were similar to those in previous studies. In contrast, the inter-rater reliabilities of EI and SR measurements of the ADDl were found to be moderate (Koo and Li 2016). Several studies have investigated the inter-rater reliabilities of EI measurements of the quadriceps, and good to excellent (Koo and Li 2016) reliabilities were observed in these studies (Rabello et al. 2019; Karapınar et al. 2021). The inter-rater reliability of EI in the present study was lower than that reported in previous studies. Although a previous study (Rabello et al. 2019; Karapınar et al. 2021) that revealed excellent inter-rater reliability in measuring EI targeted the quadriceps, the present study targeted the ADDl. The quadriceps direction is nearly parallel to the floor, but that of the ADDl is not. Therefore, it might have been difficult to place the transducer perpendicular to the ADDl in the present study, which would influence the lower inter-rater reliability of measuring the EI. However, when measuring the SR, compression speed and intensity remained the same as much as possible in the strain curve diagram and stress grade on the screen in the present study, and the SR inter-rater reliability was moderate. Brage et al. (2019) investigated the inter-rater reliability of SR in the supraspinatus tendon by using strain elastography, and the reported ICC of the SR was 0.70. The ICC of their study was determined to be moderate, referring to the guideline by Koo and Li (2016), and close to the ICC of SR in the present study. Considering that strain elastography measurement is highly operator dependent (Carlsen et al. 2013), the inter-rater reliability of the SR in the present study is valid.

The ROM of hip abduction in older adults hospitalized in a convalescent rehabilitation ward or long-term care facility was lower than that in young adults. Roach and Miles (1991) reported that the mean ROM of hip abduction in adults aged 25−39 y was 44±11°, whereas that in older adults aged 60−74 y was 39±12°. This result indicates that age-related changes affect joint flexibility, and the older adults in the present study have significantly limited ROM, considering that their median (IQR) ROM of hip abduction was 25° (20−30). Several studies have investigated other factors that affect ROM. Souren et al. (1995) investigated the prevalence of

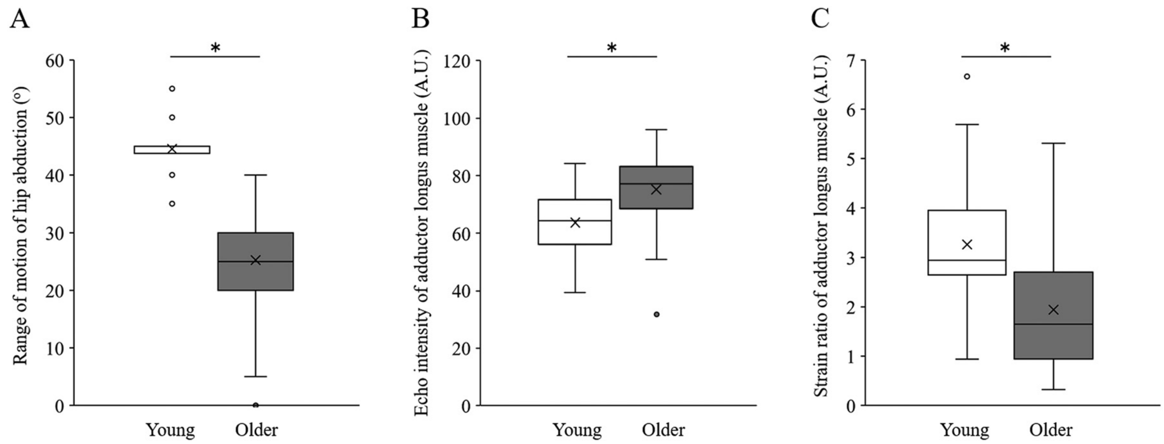

Fig. 4. Box-and-whisker plot comparing young and older adults with respect to (A) range of motion of hip abduction, (B) echo intensity of adductor longus muscle and (C) strain ratio of adductor longus muscle. The boxplot displays the median and 50th percentile (interquartile range); *X marks* in boxplots are mean values; the *tips of whiskers* represent minimum and maximum values; the *open circles* represent outliers. *Significant difference ($p < 0.05$) as compared with the young adults.

limited ROM in 161 patients with Alzheimer's disease and reported that 75% of the 32 patients with mobility impairment had limited ROM, whereas only 11% of the 129 patients with walking ability had them. Furthermore, it was revealed that inactivity is a risk factor for the occurrence of limited ROM (Offenbächer et al. 2014). These studies indicate that both aging and mobility impairment and inactivity affect joint flexibility. Considering that frailty is associated with mobility impairment (Cheung et al. 2020) or inactivity (da Silva Coqueiro et al. 2017), the limited ROM of the older adults in the present study, who scored 5 to 8 on the Clinical Frailty Scale, might have been affected by those factors in addition to aging.

Likewise, the EI of the ADDl in older adults was higher than that in young adults. Because muscle EI represents connective tissue or interstitial fat within muscle (Pillen et al. 2009; Reimers et al. 1993), those tissues within the muscles might be increasing in older adults in the present study. Fukumoto et al. (2015) reported that the mean EI of the quadriceps femoris in older adults ranging from 75 to 92 y was higher than that in young adults ranging from 19 to 30 y. These results indicate that aging affects muscle EI. However, several studies have investigated other factors affecting muscle EI. Mirón Mombiela et al. (2017) reported that the EI of the rectus femoris in frail older adults was higher than that in robust adults. Considering that frailty is associated

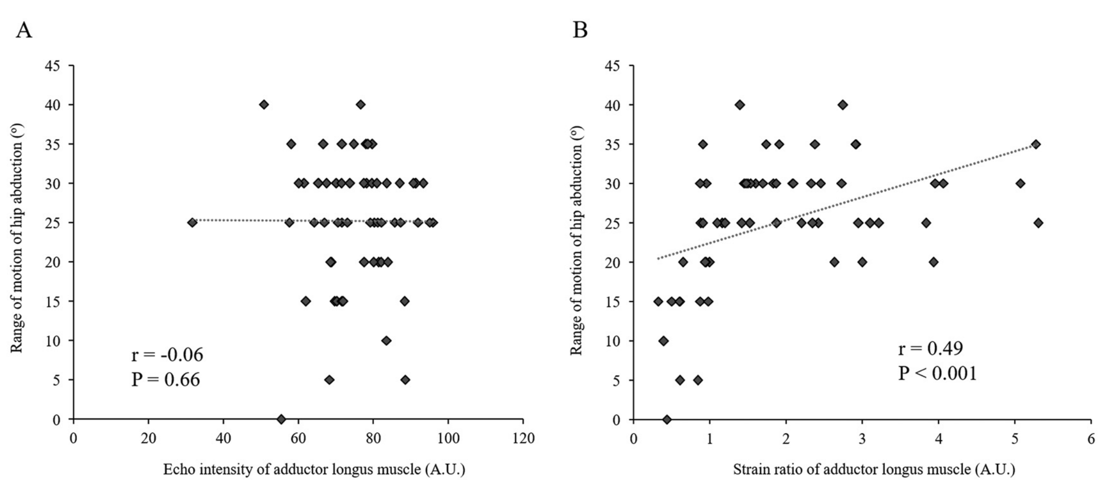

Fig. 5. Results of analysis for single correlation in older adults. (A) The result between echo intensity of the adductor longus muscle and range of motion of hip abduction. (B) The result between strain ratio of the adductor longus muscle and range of motion of hip abduction. The dependent variable was range of motion of hip abduction, while the independent variable was echo intensity or strain ratio of the adductor longus muscle.

with inactivity (da Silva Coqueiro et al. 2017), in the same way as ROM, inactivity caused by frailty might affect higher EI.

The SR measurement of relative strain compared with that of a reference material using strain elastography was employed in the present study. The results revealed that the SR of the ADDl in older adults was lower than that in young adults; in other words, the ADDl stiffness of older adults was higher than that of young adults. Eby et al. (2015) investigated the muscle stiffness of the biceps brachii by measuring their shear modulus using shear wave elastography in adults ranging from 21 to 94 y; they reported that muscle stiffness increased with age after 60 y. Although Eby et al. (2015) employed a shear modulus to estimate muscle stiffness, the shear modulus and SR correlated with increasing muscle stiffness (Shiina et al. 2015), and similar trends are expected between the two methods. Therefore, our results are similar to those reported by Eby et al. (2015), which indicate that muscle stiffness increases with age.

However, several studies have investigated other factors affecting muscle stiffness. Saito et al. (2019) reported that the lower the physical function, the stiffer is the rectus femoris by measuring SR using strain elastography in community-dwelling older women. It has been reported that lower physical function is associated with a small amount of activity (Osuka et al. 2015), and in the same way as ROM and EI, inactivity might affect muscle stiffness.

Muscle fibrosis and limited ROM have occurred following immobilization in animal experiments (Honda et al. 2018), and the muscle EI represents connective tissue within the muscle (Pillen et al. 2009). However, the EI of the ADDl in the present study was not significantly correlated with the ROM of hip abduction in older adults. As mentioned earlier, muscle EI represents not only connective tissue (Pillen et al. 2009) but also interstitial fat within muscle (Reimers et al. 1993). Interstitial fat within muscle increases with aging (Marcus et al. 2010). Thus, the results of EI in the present study might have been affected by interstitial fat within muscle, and the correlation between the EI of the ADDl and the ROM of hip abduction was not significant. This indicates that muscle fibrosis is difficult to assess indirectly by using EI.

The SR of the ADDl was significantly positively correlated with the ROM of hip abduction in older adults. Therefore, the stiffer the muscle, the more limited is the range of joint motion. Hirata et al. (2020) reported that dorsiflexion ROM was negatively correlated with soleus stiffness by measuring shear wave speed using shear wave elastography under angle-controlled conditions (15° dorsiflexion) in both young and older adults. In the present study, the measured leg was in a neutral adduction/abduction position during measurement, namely, the angle-controlled condition. Therefore, the study by Hirata et al. (2020) supports the results of the present study. Moreover, it has been revealed by animal experiments that as the limitation of ROM progresses during immobilization, muscle stiffness increases (Honda et al. 2018). The correlation between the SR of the ADDl and the ROM of hip abduction was moderate, which might indicate that the increase in muscle stiffness associated with limited ROM can be assessed with the SR.

The present study had several limitations. First, the measurement included only young adults and older inpatients with frailty. As mentioned above, ROM, muscle EI and muscle stiffness are all affected by aging, inactivity, functional impairment and frailty. Therefore, the respective effects of aging and other factors on the measurement outcomes are unclear. Therefore, further measurements targeting robust older adults are required. Second, the effects of subcutaneous fat thickness on EI and SR were not considered. Although SR is not affected by the scanning depth (Ewertsen et al. 2016), EI is affected by these factors (Young et al. 2015). Therefore, calibration based on subcutaneous fat thickness is required when analyzing muscle EI. Young et al. (2015) established calibration equations, considering subcutaneous fat thickness to estimate interstitial fat using EI, targeting the rectus femoris, biceps femoris, tibialis anterior and medial gastrocnemius. However, calibration equations for the ADDl have not yet been established. Therefore, we could not perform calibration analysis in the present study. Third, muscle activity affected by muscle stiffness has not been measured. Because muscle stiffness is associated with the Modified Ashworth Scale (Kesikburun et al. 2015), muscle stiffness is affected not only by fibrosis but also by muscle tone. To minimize the effect of muscle tone, we measured stiffness on the non-injured or non-paralyzed side and in the relaxed and neutral adduction/abduction positions in the present study. Accordingly, further measurements of muscle activity, such as electromyography during the measurement of muscle stiffness, may be required. Fourth, factors other than the muscle were not investigated. For example, previous studies revealed that joint capsule and skin fibrosis occurred in a rat joint contracture model (Goto et al. 2017; Sasabe et al. 2017). In a clinical situation, there is still no non-invasive tool for investigating joint capsule or skin fibrosis. Therefore, technological development is required in the future.

CONCLUSIONS

Muscle SR measured by strain elastography is a useful tool for investigating the effect of muscle stiffness on the ROM of older adults hospitalized in convalescent rehabilitation wards or long-term care facilities. This tool could be applicable to the evaluation of the pathological conditions of muscles and the determination of therapeutic effects on limited ROM.

Acknowledgments—The authors thank all the participants in this study. We also thank Editage for English language editing. This work was supported by Japan Society for the Promotion of Science (JSPS) KAKENHI Grant No. 20K20668.

Conflict of interest disclosure—The authors have no conflicts of interest with respect to this study.

REFERENCES

Brage K, Hjarbaek J, Kjaer P, Ingwersen KG, Juul-Kristensen B. Ultrasonic strain elastography for detecting abnormalities in the supraspinatus tendon: An intra- and inter-rater reliability study. BMJ Open 2019;9 e027725.

Carlsen JF, Ewertsen C, Lönn L, Nielsen MB. Strain elastography ultrasound: An overview with emphasis on breast cancer diagnosis. Diagnostics (Basel) 2013;25:117–125.

Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: Development and validation. J Chronic Dis 1987;40:373–383.

Cheung DSK, Kwan RYC, Wong ASW, Ho LYW, Chin KC, Liu JYW, Tse MMY, Lai CKY. Factors associated with improving or worsening the state of frailty: A secondary data analysis of a 5-year longitudinal study. J Nurs Scholarship 2020;52:515–526.

da Silva Coqueiro R, de Queiroz BM, Oliveira DS, das Merces MC, Oliveira Carneiro JA, Pereira R, Fernandes MH. Cross-sectional relationships between sedentary behavior and frailty in older adults. J Sports Med Phys Fitness 2017;57:825–830.

Eby SF, Cloud BA, Brandenburg JE, Giambini H, Song P, Chen S, LeBrasseur NK, An KN. Shear wave elastography of passive skeletal muscle stiffness: Influences of sex and age throughout adulthood. Clin Biomech (Bristol, Avon) 2015;30:22–27.

Ewertsen C, Carlsen JF, Christiansen IR, Jensen JA, Nielsen MB. Evaluation of healthy muscle tissue by strain and shear wave elastography—Dependency on depth and ROI position in relation to underlying bone. Ultrasonics 2016;71:127–133.

Fergusson D, Hutton B, Drodge A. The epidemiology of major joint contractures: A systematic review of the literature. Clin Orthop Relat Res 2007;456:22–29.

Fukumoto Y, Ikezoe T, Yamada Y, Tsukagoshi R, Nakamura M, Takagi Y, Kimura M, Ichihashi N. Age-related ultrasound changes in muscle quantity and quality in women. Ultrasound Med Biol 2015;41:3013–3017.

Goto K, Sakamoto J, Nakano J, Kataoka H, Honda Y, Sasabe R, Origuchi T, Okita M. Development and progression of immobilization-induced skin fibrosis through overexpression of transforming growth factor-1 and hypoxic conditions in a rat knee joint contracture model. Connect Tissue Res 2017;58:586–596.

Hirata K, Yamadera R, Akagi R. Associations between range of motion and tissue stiffness in young and older people. Med Sci Sports Exerc 2020;52:2179–2188.

Honda Y, Tanaka M, Tanaka N, Sasabe R, Goto K, Kataoka H, Sakamoto J, Nakano J, Okita M. Relationship between extensibility and collagen expression in immobilized rat skeletal muscle. Muscle Nerve 2018;57:672–678.

Inami T, Kawakami Y. Assessment of individual muscle hardness and stiffness using ultrasound elastography. J Sports Med Phys Fitness 2016;5:313–317.

Karapınar M, Atilla Ayyıldız V, Ünal M, Fırat T. Ultrasound imaging of quadriceps muscle in patients with knee osteoarthritis: The test-retest and inter-rater reliability and concurrent validity of echo intensity measurement. Musculoskeletal Sci Pract 2021;56 102453.

Kesikburun S, Yaşar E, Adıgüzel E, Ü Güzelküçük, Alaca R, Tan AK. Assessment of spasticity with sonoelastography following stroke: A feasibility study. PM R 2015;7:1254–1260.

Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropr Med 2016;15:155–163.

Marcus RL, Addison O, Kidde JP, Dibble LE, Lastayo PC. Skeletal muscle fat infiltration: Impact of age, inactivity, and exercise. J Nutr Health Aging 2010;14:362–366.

Mirón Mombiela R, Facal de Castro F, Moreno P, Borras CU. Ultrasonic echo intensity as a new noninvasive in vivo biomarker of frailty. J Am Geriatr Soc 2017;65:2685–2690.

Mollinger LA, Steffen TM. Knee flexion contractures in institutionalized elderly: Prevalence, severity, stability, and related variables. Phys Ther 1993;73:437–444.

Morley JE, Vellas B, van Kan GA, Anker SD, Bauer JM, Bernabei R, Cesari M, Chumlea WC, Doehner W, Evans J, Fried LP, Guralnik JM, Katz PR, Malmstrom TK, McCarter RJ, Gutierrez Robledo LM, Rockwood K, von Haehling S, Vandewoude MF, Walston J. Frailty consensus: A call to action. J Am Med Dir Assoc 2013;14:392–397.

Muraki T, Ishikawa H, Morise S, Yamamoto N, Sano H, Itoi E, Izumi S. Ultrasound elastography-based assessment of the elasticity of the supraspinatus muscle and tendon during muscle contraction. J Shoulder Elbow Surg 2015;24:120–126.

Okita M, Nakano J, Kataoka H, Sakamoto J, Origuchi T, Yoshimura T. Effects of therapeutic ultrasound on joint mobility and collagen fibril arrangement in the endomysium of immobilized rat soleus muscle. Ultrasound Med Biol 2009;35:237–244.

Osuka Y, Yabushita N, Kim M, Seino S, Nemoto M, Jung S, Okubo Y, Figueroa R, Tanaka K. Association between habitual light-intensity physical activity and lower-extremity performance: A cross-sectional study of community-dwelling older Japanese adults. Geriatr Gerontol Int 2015;15:268–275.

Picelli A, Vallies G, Chemello E, Castellazzi P, Brugnera A, Gandolfi M, Baricich A, Cisari C, Santamato A, Saltuari L, Waldner A, Smania N. Is spasticity always the same? An observational study comparing the features of spastic equinus foot in patients with chronic stroke and multiple sclerosis. J Neurol Sci 2017;380:132–136.

Pillen S, Tak RO, Zwarts MJ, Lammens MM, Verrijp KN, Arts IM, van der Laak JA, Hoogerbrugge PM, van Engelen BG, Verrips A. Skeletal muscle ultrasound: Correlation between fibrous tissue and echo intensity. Ultrasound Med Biol 2009;35:443–446.

Offenbächer M, Sauer S, Rie J, Müller M, Grill E, Daubner A, Randzio O, Kohls N, Herold-Majumdar A. Contractures with special reference in elderly: Definition and risk factors—A systematic review with practical implications. Disabil Rehabil 2014;36:529–538.

Rabello R, Fröhlich M, Bueno AF, Marcolino MAZ, Bernardi TDB, Sbruzzi G, Vaz MA. Echo intensity reliability between two rectus femoris probe sites. Ultrasound 2019;27:233–240.

Reimers K, Reimers CD, Wagner S, Paetzke I, Pongratz DE. Skeletal muscle sonography: A correlative study of echogenicity and morphology. J Ultrasound Med 1993;12:73–77.

Roach KE, Miles TP. Normal hip and knee active range of motion the relationship to age. Phys Ther 1991;71:656–665.

Saito A, Wakasa M, Kimoto M, Ishikawa T, Tsugaruya M, Kume Y, Okada K. Age-related changes in muscle elasticity and thickness of the lower extremities are associated with physical functions among community-dwelling older women. Geriatr Gerontol Int 2019;19:61–65.

Santos R, Armada-da-Silva PAS. Reproducibility of ultrasound-derived muscle thickness and echo-intensity for the entire quadriceps femoris muscle. Radiography (Lond) 2017;23:e51–e61.

Sasabe R, Sakamoto J, Goto K, Honda Y, Kataoka H, Nakano J, Origuchi T, Endo D, Koji T, Okita M. Effects of joint immobilization on changes in myofibroblasts and collagen in the rat knee contracture model. J Orthop Res 2017;35:1998–2006.

Shiina T, Nightingale KR, Palmeri ML, Hall TJ, Bamber JC, Barr RG, Castera L, Choi BI, Chou YH, Cosgrove D, Dietrich CF, Ding H, Amy D, Farrokh A, Ferraioli G, Filice C, Friedrich-Rust M, Nakashima K, Schafer F, Sporea I, Suzuki S, Wilson S, Kudo M. WFUMB guidelines and recommendations for clinical use of

ultrasound elastography: Part 1. Basic principles and terminology. Ultrasound Med Biol 2015;41:1126–1147.
Shrout PE, Fleiss JL. Intraclass correlations: Uses in assessing rater reliability. Psychol Bull 1979;86:420–428.
Souren LE, Franssen EH, Reisberg B. Contractures and loss of function in patients with Alzheimer's disease. J Am Geriatr Soc 1995;43:650–655.
Wagner LM, Capezuti E, Brush BL, Clevenger C, Boltz M, Renz S. Contractures in frail nursing home residents. Geriatr Nurs 2008;29:259–266.
Watanabe K, Katayama K, Ishida K, Akima H. Electromyographic analysis of hip adductor muscles during incremental fatiguing pedaling exercise. Eur J Appl Physiol 2009;106:815–825.
Yanagisawa O, Niitsu M, Kurihara T, Fukubayashi T. Evaluation of human muscle hardness after dynamic exercise with ultrasound real-time tissue elastography: A feasibility study. Clin Radiol 2011;66:815–819.
Young HJ, Jenkins NT, Zhao Q, McCully KK. Measurement of intramuscular fat by muscle echo intensity. Muscle Nerve 2015;52:963–971.