Differences in muscle thickness and echo intensity between stroke survivors and age- and sex-matched healthy older adults

Hiroki Monjo, PT, MSc1,2, Yoshihiro Fukumoto, PT, PhD3, Tsuyoshi Aisai, PT, PhD1, Hiroki Kubo, PT, MSc4, Kensuke Ohshima, PT, MSc1, Hirotugu Tajitsu, PT, MSc1 and Shota Koyama, PT, MSc1

1) Kobe Gakuin University
2) Avanzar Co., Ltd
3) Department of Physical Medicine and Rehabilitation, Kansai Medical University
4) Itami Kousei Neurosurgical Hospital

ABSTRACT. Objective: The stroke survivors exhibit change in muscle quantity and quality compared to healthy older adults. This study aimed to compare the muscle thickness (MT) and echo intensity (EI) values of individual muscles between stroke survivors and age- and sex-matched healthy older adults. Methods: In total, 27 stroke survivors and 34 healthy older adults participated in this study. The MT and EI values of the following muscles were assessed from transverse ultrasound images: rectus abdominis (RA), external oblique, internal oblique, transversus abdominis, rectus femoris, vastus intermedius (VI), vastus lateralis (VL), vastus medialis (VM), tibialis anterior (TA), gastrocnemius (Gas), and soleus (Sol). The MT and EI values of these muscles were compared between stroke survivors and healthy older adults. Results: The MT values of the VL, VM, and RA on the non-paretic sides were significantly higher and those of the TA, Gas, and Sol on the paretic sides were significantly lower in the stroke survivors than in the healthy older adults (P < 0.05). The EI values of the VI, VL, VM, TA on the paretic sides and those of the Gas on both the paretic and non-paretic sides were significantly higher in the stroke survivors than in the healthy older adults (P < 0.05). Conclusion: Stroke survivors seem to develop muscle hypertrophy of the non-paretic thigh muscles owing to a compensatory strategy. In addition, the lower-leg muscles on the paretic side of stroke survivors tend to show both quantitative and qualitative muscle changes.

Key words: Stroke, Muscle thickness, Echo intensity, Ultrasound

S troke is a severe neurological disease, which induces neurological symptoms and deconditioning of muscle (sarcopenia). Some reports showed that stroke survivors exhibit change in muscle quantity and quality1-3). Meta-analyses of muscle mass (muscle quantity) in stroke survivors revealed that muscle mass on the paretic limbs was significantly smaller than that on the non-paretic limbs4). Changes in muscle quality, defined as structural changes in the muscles including increased fibrous tissue and fat content and shift in fiber-type distribution, were also observed after stroke5,6). Previous studies using computed tomography and MRI reported that the thigh and lower-leg muscles on the paretic side show a greater fat content than the non-paretic side7,8). The fat content was also greater than that in healthy older adults8). In addition, a fiber-type shift has been observed after strokes, with a decrease in slow twitch myosin heavy chain fibers7,9). Decrease in muscle mass and changes in muscle quality leads to the decline in muscle functions, such as reduced muscle strength and decline in motor functions7,10).

The echo intensity (EI) of ultrasound imaging can be used to assess changes in muscle quality. It is a non-invasive and easily accessible technique. Enhanced EI indi-
cates infiltration of fatty and fibrous tissues within muscles. Previous studies reported that EI of paretic limbs is increased compared with that of non-paretic limbs. In recent years, Berenpas F et al. compared EI and muscle thickness (MT) values of chronic stroke survivors with those of healthy older adults via ultrasound. The results showed that changes in muscle quantity and quality were observed not only on the paretic sides but also on the non-paretic sides and the degree of these changes differed according to the anatomical sites. The findings of the study by Berenpas F et al. are interesting; however, to the best of our knowledge, this is the only study investigating this point, and their results were insufficient to draw clinical suggestions. Thus, further investigations are strongly needed. In addition, no studies have compared the muscle quality of abdominal muscles in stroke survivors with that of abdominal muscles in healthy older adults. Our previous study reported that the MT and EI values of the abdominal muscles did not show a side-to-side difference, but previous studies reported that the muscle strength of the trunk muscle is significantly lower in stroke survivors than in healthy controls. Considering these findings, it was hypothesized that change in MT and EI values of abdominal muscles on both the paretic and non-paretic sides may differ between stroke survivors and healthy older adults.

In clinical settings, it is important to know the changes in muscle quantity and quality of lower limbs and abdominal muscles on both the paretic and non-paretic side after stroke to improve motor function. This study aimed to compare the MT and EI of the abdominis, thigh, and lower-leg muscles between stroke survivors and age- and sex-matched healthy older adults.

**Methods**

This study included 27 chronic stroke survivors (hemi-group) who were receiving rehabilitation services in the Japanese long-term care insurance system. The inclusion criteria for the hemi-group were ≥60 years of age, unilateral stroke, independent ambulation, and at least 6 months after stroke onset. The exclusion criteria for the hemi-group were orthopedic or chronic pain conditions, severe sensory impairment or spasticity, and dementia. The severity of paralysis was measured using lower extremity Fugl-Meyer (LE-FM) assessment. In this study, only synergy items (22 point) of LE-FM were used to grade paralysis severity. Participants in the healthy older adults were recruited by community advertisement. The inclusion criteria for the healthy older adults were ≥60 years of age and independent ambulation. The exclusion criteria for the healthy older adults were orthopedic, neurological, or chronic pain conditions, and history of surgery. The protocol was approved by the ethics committee of the Kobe Gakuin University Graduate School (IRB No. HEB20151202-1). Written informed consent was obtained from all participants before collecting any data.

**Ultrasound measurement**

Ultrasound images were obtained using B-mode ultrasound imaging (LOGIQ e; GE Healthcare, Japan) with a multi-frequency linear transducer (8-12 MHz). All measurements were conducted with following settings: a frequency of 8 MHz, a gain of 58 dB, and a dynamic range of 78 dB. Dynamic depth focusing was applied to the depth of the muscle of interest. The depth was initially set at 4.0 cm and was allowed to change during imaging according to an individual’s muscle size. Ultrasound images were assessed on both the paretic and non-paretic sides in the hemi-group and only on the dominant side in the healthy older adults. The MT and EI values of rectus abdominis (RA), external oblique (EO), internal oblique (IO), transversus abdominis (TrA), rectus femoris (RF), vastus intermedius (VI), vastus lateralis (VL), vastus medialis (VM), tibialis anterior (TA), gastrocnemius (Gas), and soleus (Sol) were measured. The measurement site and position of each muscle during the measurement are shown in Table 1. Rest periods in the measurement position (supine or sitting) before ultrasound measurement were not applied. A water gel was used to avoid the excessive compression of the dermal surface by the probe. Abdominal MT values are affected by respiration; therefore, recordings were made at a consistent point at the end of relaxed expiration. Two consecutive ultrasound images were obtained for each muscle. Mean MT and EI were calculated from the two images and used for statistical analyses. The same investigator performed all measurements to minimize interobserver variation.

Muscle quality was expressed using the index of EI values of each muscle which was analyzed using Image-J (National Institute of Health, USA, version 1.37). Regions of interest were set in as much of the muscle as possible, excluding the surrounding facia and bone. Both lateral ends of the ultrasound image were occasionally unclear when the pressure of the transducer on the skin was minimized. We excluded the unclear sections from the region of interest for EI measurements. EI of individual pixels was expressed as a value between 0 (black) and 255 (white) by 8-bit grayscale, and the mean EI value of each pixel in the region of interest was obtained. Reliability of MT and EI measurements has been established, with intraclass correlation coefficient (ICC) values in the range of 0.90-1.00 for MT and 0.77-0.95 for EI. To examine the reliability of our measurements, an ultrasound image of each muscle was obtained on two separate days in eight healthy subjects in another sample of this study. Then, ICC (1.1) of MT and EI measurements was calculated using two images for each muscle. ICC (1.1) values were 0.98 for abdominal MT, 0.98-0.99 for thigh MT, 0.97-0.98 for lower-leg MT, 0.91-0.95 for abdominal EI, 0.82-0.95 for thigh EI, and 0.90-0.94 for...
lower-leg EI. Given that ICC values of 0.81-1.00 are generally interpreted as “almost perfect” reproducibility, ultrasound measurements in this study can be considered as reproducible.

Statistical analyses

Statistical analyses were performed using SPSS (version 20.0; SPSS Japan Inc., Tokyo, Japan). Chi-square (χ²) test was used to compare the proportion of sex between the hemi-group and healthy older adults. Unpaired t-test was used to compare age, height, weight, and body mass index (BMI) between the hemi-group and healthy older adults.

Analysis of covariance (ANCOVA) was used to compare the MT and EI values between the hemi-group (paretic side) and healthy older adults, including age, sex, and BMI as confounding factors. Pearson product moment correlation was performed to evaluate the relationship between MT and EI values in the hemi group for muscles which significantly differed from healthy older adults in MT or EI. P < 0.05 was considered statistically significant.

Results

The present study included 27 participants in the hemi-group and 34 participants in the healthy older adults.

Table 2 shows the demographic data in the hemi-group and healthy older adults. There were no significant differences in age, height, weight, BMI, and the ratio of males to females between the hemi-group and healthy older adults.

Table 3 and 4 shows the MT and EI values of the hemi-group and healthy older adults. The MT values of the VL, VM, and RA on the non-paretic sides were significantly higher in the hemi-group than in the healthy older adults.
The characteristic findings are that the thigh muscles on the paretic sides were significantly lower in the hemi-group than in the healthy older adults. The EI values of the VI, VL, VM, and TA on the non-paretic sides, those of the TA, Gas, and Sol on the non-paretic sides, and those of the EO, IO, TrA, and RF on both sides.

Correlation analysis revealed a significant positive correlation between MT and EI for TA (r = 0.37, p = 0.030) and Sol (r = 0.43, P = 0.013) on the paretic sides. There was no significant correlation for VI, VL, VM and Gas on both sides and RA on the non-paretic sides.

### Discussion

This study is the first to compare muscle quantity and quality in the abdominal, thigh, and lower-leg muscles on both the paretic and non-paretic sides in stroke survivors with those in age- and sex-matched healthy older adults. The characteristic findings are that the thigh muscles on the non-paretic side showed muscle hypertrophy. In addition, the lower-leg muscles on the paretic side showed changes in both muscle quantity and quality in the stroke survivors than in the healthy older adults.

Many previous studies have reported that the muscle mass of the quadriceps femoris on the paretic limb was smaller than that of the quadriceps femoris on the non-paretic limb in stroke survivors. Our previous study showed that compared with the decrease in the MT values of the quadriceps muscles on the non-paretic side, that on the paretic side was highest in the trunk and lower-leg muscles. Additionally, the results of the present study showed that the MT values of any of the quadriceps muscles on the paretic side showed decrease, whereas the MT values of the VM and VL on the non-paretic side showed increase in the stroke survivors than in the healthy older adults. Our previous study reported that the MT values of the VL on the non-paretic side were correlated with latency from stroke onset. Another longitudinal study in stroke survivors revealed that the muscle mass on the non-paretic limb during the first year from stroke onset increased, whereas that on the paretic limb did not change. The findings of these previous studies may support those of the current study. Muscle hypertrophy of the VL and VM on the non-paretic side may be associated with the long-term compensatory strategy on the non-paretic limb during daily activities.

The present study also evaluated EI as an index of muscle quality. Accumulation of fat and fibrous tissue is responsible for reflective interfaces of echo beam and thus leads to increased muscle EI on an ultrasound image. Previous studies demonstrated that EI is strongly correlated with

### Table 3. MT values on the paretic and non-paretic side in the hemi-group and the healthy older adults

| Muscles | Paretic (cm) | Non-Paretic (cm) | Healthy Older Adults (cm) |
|---------|-------------|------------------|--------------------------|
| RA      | 0.71±0.19   | 0.76±0.21*       | 0.63±0.17                |
| EO      | 0.39±0.15   | 0.43±0.14        | 0.41±0.11                |
| IO      | 0.65±0.23   | 0.62±0.21        | 0.77±0.42                |
| TrA     | 0.27±0.10   | 0.28±0.09        | 0.31±0.23                |
| RF      | 1.66±0.35   | 1.75±0.38        | 1.57±0.32                |
| VI      | 1.34±0.42   | 1.62±0.54        | 1.46±0.39                |
| VL      | 1.51±0.27   | 1.81±0.39*       | 1.63±0.30                |
| VM      | 1.32±0.38   | 1.54±0.36**      | 1.27±0.29                |
| TA      | 1.77±0.22*  | 1.93±0.25        | 1.91±0.33                |
| Gas     | 1.29±0.31*  | 1.35±0.33        | 1.48±0.34                |
| Sol     | 1.42±0.24*  | 1.52±0.30        | 1.59±0.31                |

RA: rectus abdominis EQ: external oblique IQ: internal oblique TrA: transversus abdominis RF: rectus femoris VI: vastus intermedius VL: vastus lateralis VM: vastus medialis TA: tibialis anterior Gas: gastrocnemius Sol: soleus

*P<0.05, **P<0.01 significant difference compared with the healthy older adults
the amount of fibrous and fat content measured by muscle biopsy\(^6\). In our study, muscle atrophy was not observed in the quadriceps muscle on the paretic side, but the EI values of the VI, VL, and VM on the paretic side were significantly higher in the stroke survivors than in the healthy older adults. These suggest that the contractile tissues of these muscles substantially decrease as a result of the accumulation of fat and connective tissues.

With regard to lower-leg muscles on the paretic side, the MT values of all muscles were significantly lower and the EI values of the TA and Gas were significantly higher in the stroke survivors than in the healthy older adults. These results are almost consistent with those of the study by Berenpas F et al., showing lower MT values of the Gas and higher EI values of the Gas and TA on the paretic side in stroke survivors than in healthy older adults\(^7\). These results may be associated with muscle phenotypic abnormalities after stroke. Basic pathological studies have shown specific loss of slow-twitch fibers in paretic side\(^6\). The lower-leg muscles showed a high proportion of slow-twitch, whereas the thigh muscles showed a high proportion of fast-twitch\(^25\). Therefore, the decrease in the MT values and increase in the EI values of lower-leg muscles may represent a specific loss of muscle fibers and relative increase in intramuscular noncontractile tissues after stroke.

We hypothesized that the quantity and quality of the abdominal muscles altered in the stroke survivors than in the healthy older adults because the isometric strength of abdominal muscles was significantly lower in stroke survivors than in healthy older adults\(^10,11\). However, none of the abdominal muscles showed decrease in the MT values or increase in the EI values and the MT values of the RA on the non-paretic side was higher in stroke survivors than in healthy older adults. Furthermore, the abdominal muscles were spared after stroke because they were bilaterally innervated\(^26,27\); therefore, quantitative or qualitative changes in

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**Figure 1.**

Ultrasound images of VL and Gas on the paretic, non-paretic side in stroke survivor, and healthy older adults.
the abdominal muscles may not occur in stroke survivors. A review reported that reduced activity, delayed onset, and reduction in the synchronized activation of trunk muscles were observed in stroke patients. Therefore, even if the MT or EI values of the abdominal muscles are maintained, these muscles in stroke survivors may experience dysfunction due to altered muscle activity. However, this study did not assess trunk muscle activity, strength, or function. Further studies are needed to explore MT, EI, and muscle activity on the trunk strength or function in stroke survivors.

Previous studies have reported that there is a significant negative association between MT and EI on quadriceps femoris in healthy older adults. A previous study of acute stroke patients by Maeda et al. reported a significant negative association between MT and EI of the quadriceps femoris. These previous findings suggest that quantitative and qualitative changes of individual muscles are associated with each other. However, our study investigated the chronic phase of stroke patients and revealed that no muscle shows a negative correlation. Conversely, a significant positive correlation was observed between TA and Sol. Thus, in hemiplegic patients, the relationship between muscle quantitative and qualitative changes may differ by muscles and by period since onset.

In many previous studies, changes in muscle quantity and quality on the paretic side after a stroke have been investigated using muscles on the non-paretic side as references. However, the results of this study demonstrated that there are also changes in muscle quantity and quality on the non-paretic muscles, and that the degree of these changes is site-specific. Additionally, it has been reported that muscle strength training improves both muscle mass and quality. The results of this study have significance in clarifying the target muscles for muscle training and exercise therapy for improving muscle mass and muscle quality on both paretic and non-paretic sides. However, the EI value is dependent on differences in devices and the measurement parameters, such as frequency or gain; hence, a clear criterion for the EI value has not been established. Therefore, the results of the current study, i.e., difference in EI between stroke survivors and healthy controls, should be interpreted with caution.

In this study, MT and EI in stroke survivors was compared with those in healthy older adults who matched by age, BMI, and sex. However, because of the small sample size of this study, the effects of age, gender, and physique on the difference between stroke patients and healthy older adults may not be completely eliminated. In addition, MT and EI in healthy controls in this study do not necessarily represent the standard values of the age ranges. The physical activity level of study participants is closely associated with MT and EI in older adults and in stroke patients, but was not measured in this study. In general, the physical activity level in stroke patients is lower compared to that in healthy older adults. It is possible that the difference in MT and EI between stroke survivors and healthy older adults in this study is associated with a difference in physical activity levels. Further studies are needed to clarify this significance. Additionally, it is necessary to explore the association of EI with neuro-muscular symptoms specific to stroke, such as decreasing contractile function or spasticity.

The present study has some limitations. First, selection bias may have been introduced because our study participants were over 60 years old and were recruited while they were receiving rehabilitation services in the Japanese long-term care insurance system. Thus, the external validity should be examined in future studies. Second, the number of participants was small; thus, type 2 errors may be present. Third, in this study, rest periods before ultrasound measurements were not applied, although fluid shifts in response to changes in body position and exercise could affect MT and EI.

Conclusion

Our study showed that site-specific changes in muscle quantity and quality occur in stroke survivors. Our data provide variable information for assessment and intervention to improve muscle function in stroke survivors.

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