

CASE REPORT

Lower extremity muscle structure in incomplete spinal cord injury: a comparison between ultrasonography and magnetic resonance imaging

Andrew C Smith^{1,2}, Kristen Jakubowski², Marie Wasielewski², Sabrina SM Lee² and James M Elliott²

INTRODUCTION: Ultrasound (US) measures of muscle thickness are used in the management and monitoring of muscle changes during rehabilitation, but it is unknown how this measure compares to magnetic resonance imaging (MRI) measures of muscle cross-sectional area (CSA) in patients with spinal cord injury (SCI).

CASE PRESENTATION: Six participants with incomplete SCI underwent US imaging and MRI of their gastrocnemius and tibialis anterior (TA) muscles.

DISCUSSION: Significant correlations were found between US muscle thickness and MRI CSA in the gastrocnemius ($R=0.91$, $P < 0.001$), and TA muscles ($R=0.58$, $P < 0.05$). US muscle thickness in the gastrocnemius and TA of patients with incomplete SCI may be used as a cheaper alternative measure of CSA as measured using MRI, and this measure may be clinically useful to track progress in muscle gains during rehabilitation.

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INTRODUCTION

Following spinal cord injury (SCI), aside from reductions in muscle recruitment, deficits in motor function may also be secondary to changes in muscle mass and structure below the level of injury.^{1–4} In rehabilitation research, magnetic resonance imaging (MRI) is often used to quantify reductions in lower limb muscle cross-sectional area (CSA) in SCI,⁵ but not without excessive and potentially unnecessary costs. Ultrasonography (US) has also been used to study distal skeletal muscle thickness changes in this patient population,⁶ providing a potentially more practical and cost-effective alternative to MRI. Although evidence has established a moderate level of reliability for US measures of muscle size (thickness and estimated cross-sectional area, and volume) in healthy human populations, there is limited evidence in clinical populations.⁷ As pathological muscle alterations occur in SCI distal to the injury site, such as increased muscle fat infiltration,^{4,8} it is unknown whether US measures of skeletal muscle thickness are accurate in this patient population; thus, concurrent validity using MRI should be established. Accordingly, the purpose of this preliminary study was to compare MRI measures of CSA with US measures of lower-extremity muscle thickness in participants with incomplete SCI. We hypothesized that these two measures would be significantly correlated.

METHODS

Participant characteristics

Participants were recruited from the Rehabilitation Institute of Chicago's Spinal Cord Injury database, in accordance with Northwestern University IRB #STU00087983 and the Declaration of Helsinki. Six male individuals with chronic cervical incomplete SCI participated (average age = 41 ± 13 years old). Three

individuals were classified using the American Spinal Cord Injury Association Impairment Scale (AIS) as AIS C C5–8 level, 1 participant was classified as AIS D C1–4 level and one participant was classified as AIS D C5–8 level. All participants were able to ambulate for at least 10 m using assistive devices. See Table 1 for details on participant characteristics.

Magnetic resonance imaging

All MRI was performed on a 3.0 Tesla Prisma magnetic resonance scanner (Siemens, Erlangen, Germany). Participants were imaged in supine with knees in extension and ankles at their desired comfortable position. For leg muscle, CSA quantification, scans included both lateral and medial gastrocnemius muscles combined and tibialis anterior (TA) muscles of both legs. The specific MRI parameters included the following: TR = 6.59 ms, TE1 = 2.45 ms TE2 = 3.675 ms, flip angle = 12° , bandwidth 1 = 510, bandwidth 2 = 660 Hz/Px and an imaging matrix of 448×266 . A read field of view of 320–340 mm was used with a 16-channel body array surface coil, and 60 slices per slab with a slice thickness of 5 mm and a slice oversampling of 6.7% were acquired. The acquisition time was 4:12 min with a rectangular view of 60%, four averages and an in-plane resolution of 0.5 mm. Localizer scans were used to obtain the MRI data in the axial plane perpendicular to the tibia.

Analysis of the lower-extremity MRI data was performed using customized imaging analysis scripts created in MATLAB (Version 2014b, MathWorks, Natick, MA, USA) to determine cross-sectional area by manually defining regions of interest (ROI). ROI were defined in the gastrocnemius and TA by contouring each muscle within its fascial borders. Each outline of the individual muscles yielded a CSA value. To best approximate the peak CSA at the muscle belly, the average individual muscle CSA value was calculated as the CSA average across five slices above and five slices below the slice with the maximum area (see Figure 1). The

¹Regis University School of Physical Therapy, Denver, CO, USA and ²Department of Physical Therapy and Human Movement Sciences, Northwestern University, Chicago, IL, USA. Correspondence: Dr AC Smith (asmith034@regis.edu)

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Table 1. Participant characteristics and data

Participant	Age (years)	Height (cm)	Weight (kg)	Time since injury (years)	Level of injury	ASIA Impairment Scale	Ultrasound gastroc thickness (mm)		MRI gastroc CSA (mm ²)		Ultrasound TA thickness (mm)		MRI TA CSA (mm ²)	
							L	R	L	R	L	R	L	R
iSCI1	53	185	82.1	6	C5	C	15.8	11.9	1098.0	1002.4	30.9	28.4	816.7	799.3
iSCI2	57	178	79.4	8	C3	D	17.6	14.5	2055.3	1402.5	31.1	35.6	788.7	1148.5
iSCI3	31	178	72.6	4	C5	D	15.5	16.9	1398.9	1165.4	28.8	25.7	723.0	881.3
iSCI4	50	168	83.9	2	C6	D	18.5	20.1	2007.2	2245.9	34.0	34.2	963.1	891.7
iSCI5	30	193	115.7	4	C6	C	22.6	19.5	2759.1	2186.3	32.8	27.2	761.8	778.0
iSCI6	27	191	86.2	4	C5	C	12.3	14.7	1021.2	1240.1	30.4	27.6	916.0	831.3

Abbreviations: ASIA, American Spinal Cord Injury Association; Gastroc, gastrocnemius muscle;; L, left leg; R, right leg; TA, tibialis anterior muscle.

combined CSA measurement for the medial and lateral gastrocnemius was used for the analyses. The inter-rater reliability using this method has been demonstrated to be high in this patient population in the major leg muscles, with an ICC (2,1) value range of 0.94–0.99.⁹

Ultrasound imaging

US images were captured (Aixplorer SuperSonic Imagine, Aix-en-Provence, France) while the participant was instructed to sit in a comfortable position with their knee at 20 ° extension and ankle in a relaxed position, at a 90 ° angle. This angle was chosen to standardized testing conditions between participants. It has been previously demonstrated that muscle thickness does not significantly vary at different ankle angles.¹⁰ Participants were asked to remain relaxed with the gastrocnemius and TA passive. This position was chosen to mimic the knee and ankle positions in the MRI machine. Image acquisition of the TA and medial, and lateral gastrocnemius was performed for both legs (five images per muscle). The transducer was positioned at the mid-belly region of the respective muscle and aligned with the fascicles as viewed from the B-mode image (see Figure 1). Ultrasound muscle thickness has been shown to be an accurate measure of muscle morphometry.¹¹

A custom-written MATLAB program was used to measure muscle thickness from the US images. Muscle thickness was measured by digitizing the distance between the superficial and deep aponeuroses in the medial and lateral gastrocnemius, as well as in the TA. An average thickness was calculated between trials for each muscle, and the values for the medial and lateral gastrocnemius were averaged to get a gastrocnemius approximation similar to that obtained using MRI.

Statistical analysis

All statistical analyses of the data were performed using IBM SPSS (Version 21, Armonk, NY, USA). Linear regression analyses were conducted to evaluate correlations between MRI cross-sectional area and US muscle thickness. Significance was set at $P \leq 0.05$.

RESULTS

Significant positive linear correlations were found between the MRI cross-sectional area and US muscle thickness in the gastrocnemius muscle ($R=0.91$, $P \leq 0.001$, see Figure 2), as well as in the TA ($R=0.58$, $P < 0.05$, see Figure 3).

DISCUSSION

Our results suggest that US measures of muscle thickness in the gastrocnemius and tibialis anterior of patients with incomplete SCI may be used as a surrogate measure of CSA as measured using MRI. These results are in accordance with similar findings comparing ultrasound muscle thickness to MRI CSA in the quadriceps muscles of healthy young adults¹² and patients with patellofemoral pain.¹³ This is beneficial for situations where MRI measures cannot be obtained due to a lack of access to a MRI machine, or if the status of a patient is not conducive for undergoing MRI.

Interestingly, we found relatively weaker correlation in the TA compared with the gastrocnemius. We believe this may be due to a relatively smaller range of values in this muscle. Moreover, it is important to consider the morphology differences of the two muscles. Although the gastrocnemius muscles are much larger than the TA in cross-sectional area,¹⁴ the thickness of the TA is greater. Thus, the shape of the two muscles likely has a role in explaining the differences in the strength of correlation between thickness and CSA.

As a preliminary study, one inherent limitation is our relatively smaller sample size. This study is part of a project containing a

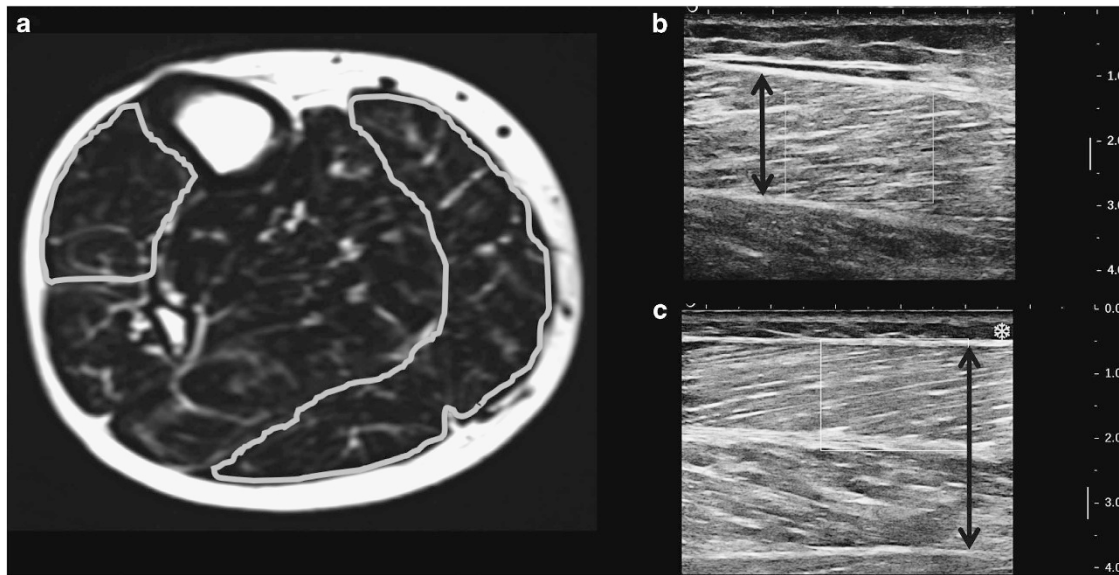


Figure 1. (a) A magnetic resonance image of the tibialis anterior (left outline) and gastrocnemius muscles (right outline) for one representative participant. (b) An ultrasound measure of the muscle thickness of the gastrocnemius muscle for one representative participant. (c) An ultrasound measure of the muscle thickness of the tibialis anterior muscle for one representative participant.

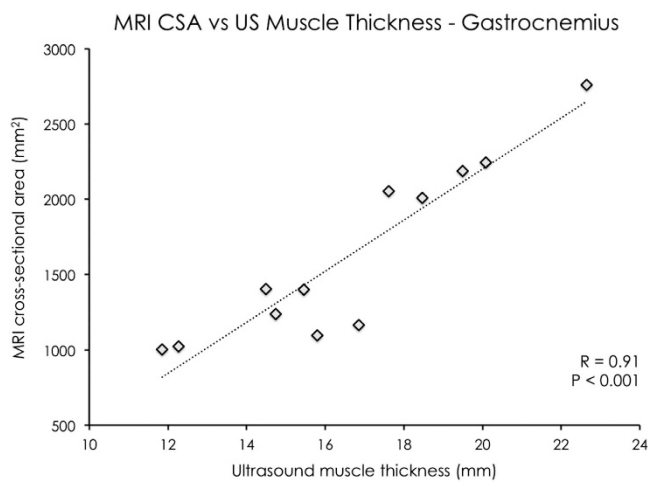


Figure 2. Linear plot of US muscle thickness versus MRI cross-sectional area in the gastrocnemius muscle. A significant linear correlation was found ($R = 0.91$, $P < 0.001$).

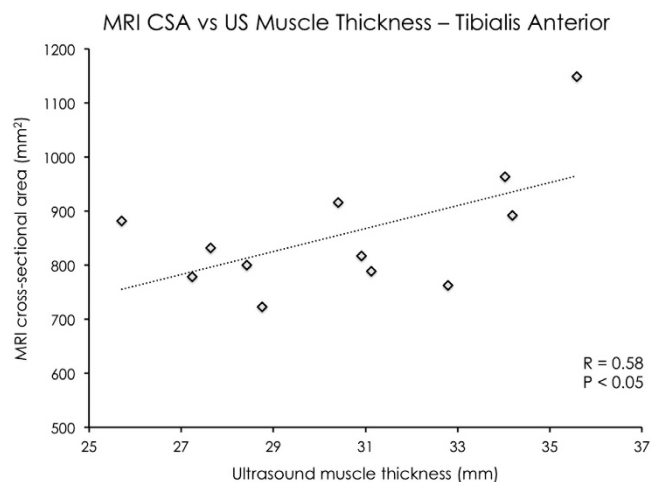


Figure 3. Linear plot of US muscle thickness versus MRI cross-sectional area in the tibialis anterior muscle. A significant linear correlation was found ($R = 0.58$, $P < 0.05$).

larger heterogeneous participant pool, but in favor of consistency, we chose participants with a more homogeneous incomplete SCI clinical presentation for this current study.

CONCLUSION

In participants with incomplete SCI, US measures of gastrocnemius and TA muscle thickness are comparable to measures obtained from MRI. Measures of muscle thickness with US may be clinically useful toward making an informed prognosis of functional recovery, informing management and monitoring gains in muscle mass during rehabilitative intervention. The cost-effectiveness of such needs to be trialed before definitive conclusions toward impacting practice can be made.

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COMPETING INTERESTS

JME—Relevant activities outside the submitted work: board membership, consultancy, other (35% ownership/investment interest in medical consultancy start-up: Pain ID LLC), payment for lectures. The remaining authors declare no conflict of interest.

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