Associations Between Muscle Mass, Muscle Morphology and Bone Health in Older Men With Sarcopenia: A Cross-sectional Study

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Abstract

Background: The aim of this study was to explore the association between muscle mass, morphology, bone mineral density, and physical function in community-dwelling older men with sarcopenia.

Methods: A total of 151 men, 60 years or older were included in this study. Body composition was measured by dual-energy X-ray absorptiometry (DXA). Low bone mineral density was diagnosed if T-score was equal to or below -1.0 SD of mean young men reference range. Sarcopenia was diagnosed according to European Working Group on Sarcopenia in Older People (EWGSOP) criteria: low muscle mass and low muscle strength or low physical performance. Physical performance was evaluated by short physical performance battery. Microbiopsy of *musculus vastus lateralis* was performed with disposable muscle microbiopsy system. The perimeter and cross-section area of muscle fibers were calculated using image analysis software in whole slide images; type of fiber and their distribution were evaluated as well. Relationship between variables were examined using Spearman's and Pearson's correlations. The level of significance (p-value) of < 0.05 was considered as statistically significant.

Results: Mean age of the subjects was 72.9 ± 8.02 years. Sarcopenia was diagnosed in 45 (29.8%) men. In the sarcopenia group, 25 muscle biopsies were examined. The average muscle fiber length was 217.47 ± 25.22 microm and average fiber cross-sectional area was 2446 ± 608.87 microm^2. In 9 sarcopenic men with T-scores equal or below -2.5, the muscle fiber area had a significant correlation with balance test ($r = 0.73$, $p = 0.025$). Multiple significant correlations were found between bone mineral density, lean mass, appendicular lean mass, arm and leg lean mass, gait speed, balance test and handgrip strength.

Conclusions: In men with sarcopenia, low lean muscle mass was associated with low femoral neck and hip BMD, and lower muscle strength. In sarcopenic men with osteoporosis, lower muscle fiber area was associated with lower scores of balance test.

Trial registration: study protocol has been approved by Lithuanian regional biomedical research ethics committee (No. 158200-03-208-75).

Background

In 1989, Rosenberg described age-related loss of lean body mass as sarcopenia [1]. Although, there is no one unifying definition of sarcopenia, all current ones include low muscle mass and function, be it either muscle strength or physical performance, or both [2]. Depending on the definition used, the prevalence of sarcopenia varies between 10–40% [3]. Sarcopenia is associated with such negative outcomes as falls, increased hospitalization, functional decline and death [4, 5].

One of the hallmark components of sarcopenia is muscle mass. Muscle consists of different types of fiber (type I and type II). With ageing, the number and size of fibers, especially type II, decreases [6, 7]. Furthermore, age related changes lead to fiber atrophy [8]. This in turn may lead to muscle atrophy and reduced muscle mass.

Bone mineral density (BMD) is used to assess bone health. Furthermore, BMD is a component of body composition measurements [9]. Low BMD is also a risk factor for osteoporosis and fractures [10]. It is known that there are associations between fat mass, lean muscle mass and BMD [11]. Moreover, these associations continue to persist in longitudinal studies [12, 13]. A loss of muscle or bone tissue, affects musculoskeletal system. It was believed that bone and muscle interact only on biomechanical level, meaning that force produced by muscles impacts bone strength and density [14]. Also, a relationship between bone health, muscle strength and physical performance exists [12]. However, a new theory is now emerging that links bone and muscle transformations at biochemical level [15]. Despite that there are only a few studies, which looked at association between muscle changes and bone health.

Therefore, the aim of this study was to explore associations between muscle mass, morphology, bone mineral density and physical functions in community-dwelling elderly males with sarcopenia.

Methods

Criteria for participation in this cross-sectional study include men who have attended the National Osteoporosis Center in Vilnius, Lithuania. Inclusion criteria were: age 60 years and older, voluntary consent to participate in the study. Exclusion criteria were: an objection to any procedure, large dose of radiation received over the past 12 months, malignant tumours of various localizations, mental disorders, muscle diseases (hereditary and inflammatory), current/past use of any medications likely to affect muscle, bone and fat metabolism. This study protocol has been approved by Lithuanian regional biomedical research ethics committee (No. 158200-03-208-75). All subjects gave their written informed consent prior to enrolment.

Body composition was assessed by dual-energy X-ray absorptiometry (iDXA, GE Lunar, USA). Bone mineral content (BMC) and bone mineral density (BMD) were evaluated from total body measurements. Lumbar spine (L1–L4, in the anterior-posterior direction) and left hip (total hip and femoral neck) BMD was also measured. Absolute value of BMD and T-score were evaluated and analysed. Total body fat mass, total lean mass, appendicular lean mass, arm and leg lean mass were measured as well. Fat distribution was assessed using the android and the gynoid region of interest defined by the manufacturer, located respectively in the abdominal and in the hip area. Appendicular skeletal muscle mass calculation was based on the sum of muscle mass in all four limbs. Bone mineral density was evaluated according to World Health Organization criteria [16].

In this research, diagnosis of sarcopenia was confirmed according to the European Working Group on Sarcopenia in Older People (EWGSOP), with its criteria proposed in 2010: low muscle mass and low muscle strength or low physical performance [17]. A skeletal muscle mass index was calculated by dividing appendicular skeletal muscle mass by the subjects' height squared. The cut-off of 7.26 kg/m^2 for skeletal muscle mass index in men was used [18]. Muscle strength was assessed by handgrip strength which was measured using a mechanical handheld dynamometer (Presision, Druck, Germany). Participants were asked to sit upright and hold the dynamometer in their non-dominant hand. Men were asked to squeeze dynamometer three times as tightly as possible, and the highest result was recorded. The cut-off of 30 kg was used as the diagnostic criterion [19]. Both devices, DXA machine and dynamometer, were calibrated following the manufacturer's instructions. Physical performance was evaluated by short physical performance battery (SPPB) composed of three tests: balance, 4-m gait speed and chair stand [20, 21]. Gait speed slower or equal to 0.8 m/s was used as diagnostic criterion for sarcopenia [19]. For microbiopsy, each subject was asked to lay down on the medical functional bed with the thigh area uncovered. The skin of microbiopsy area (*musculus vastus lateralis*, about 15 cm above the patella) was disinfected and local anesthesia was applied. A piece of muscle was taken using a disposable muscle microbiopsy system with 14–16 G and 10 cm long needle for muscle microbiopsy (Bard Monopty Disposable core biopsy instrument, USA). A sterile dressing was applied on the puncture site. After the muscle biopsy sample was obtained, it was kept surrounded by melting ice and transported to the laboratory immediately. In laboratory, unfixed muscle was frozen for 30 sec and kept in liquid nitrogen. Thereafter, all collected samples were cryosectioned at 10 μm of thickness for hematoxylin/eosin, adenosine triphosphatase histochemical and immunohistochemical merosine (Monoclonal Mouse Anti-Human Merosin Laminin Alpha 2 Chain) staining. Furthermore, the perimeter of myocites marked by merosin, annotated manually and cross-section area of muscle fiber was calculated using the Aperio software (Image Scope, USA). The samples of skeletal muscles were also stained with adenosine triphosphatase and various types of fibers, as well as their distribution were evaluated.

Statistical analysis was performed using IBM SPSS Statistics Windows software version 18 (IBM, New York). All data were expressed as mean, standard deviation (SD) or frequencies (number, percentage), as appropriate. Where the data were skewed or not normally distributed, median and interquartile ranges were used. Distribution of continuous variables was assessed by the Shapiro–Wilk test. Normally distributed continuous variables were compared using independent sample T-test if categorical variable was dichotomous. Mann-Whitney U test was used to compare independent groups for non-parametric dichotomous variables. Chi-square test was used to compare categorical variables. Relationship between normally distributed continuous variables were examined using Spearman's correlation and between non-parametric variables Pearson's correlation. A correlation above 0.81 was considered as excellent, between 0.61 and 0.80 very good, between 0.41 and 0.6 as good, between 0.21 and 0.4 acceptable, and less than 0.20 was considered insufficient [22]. The level of significance (p-value) of < 0.05 was considered to be statistically significant.

Results

A total of 151 men participated in this study. According to EWGSOP criteria, sarcopenia was defined in 45 (29.8%) men. Basic descriptive characteristics of the study population are shown in Table 1.

Table 1
Basic descriptive characteristics of study population (mean ± SD)

Characteristics	All subjects (n = 151)	No sarcopenia (n = 106)	Sarcopenia (n = 45)	p-value*
Age, years	72.9 ± 8.02	70.33 ± 6.47	79.09 ± 8.05	< 0.001
Height, cm	172.73 ± 6.73	173.56 ± 6.56	170.74 ± 6.79	0.006
Weight, kg	81.5 ± 13.85	84.56 ± 13.44	74.15 ± 12.05	< 0.001
BMI, kg/m^2	27.24 ± 4.07	28.01 ± 4	25.4 ± 3.66	0.001
Total fat mass, kg	24.75 ± 8.83	25.86 ± 8.87	21.99 ± 7.91	0.01
Android fat mass, kg (median [IQR])	2.57 [1.8–3.22]	2.71 [2.03–3.44]	2.3 [1.5–3.04]	0.023
Gynoid fat mass, kg (median [IQR])	3.35 [2.77–4.06]	3.5 [2.96–4.17]	3.06 [2.27–3.67]	0.006
Lean mass, kg	54.01 ± 6.61	55.88 ± 6.06	49.37 ± 5.7	< 0.001
Appendicular lean mass, kg	24.32 ± 3.68	25.5 ± 3.34	21.51 ± 2.88	< 0.001
Arm lean mass, kg	6.78 ± 1.12	7.12 ± 1	5.85 ± 0.9	< 0.001
Leg lean mass, kg	17.61 ± 2.69	18.42 ± 2.47	15.66 ± 2.13	< 0.001
SMMI, aSM/m^2	8.13 ± 0.94	8.44 ± 0.82	7.37 ± 0.78	< 0.001
Handgrip strength, kg	31.54 ± 10.37	35.76 ± 8.66	21.39 ± 6.32	< 0.001
Balance test, s (median [IQR])	10 [10–10]	10 [10–10]	10 [7.65–10]	< 0.001
5 chair stands, s	15.18 ± 5.45	14.18 ± 4.1	17.17 ± 7.61	0.017
Gait speed, m/s (median [IQR])	0.88 [0.72–1]	1 [0.85–1.08]	0.66 [0.57–0.77]	< 0.001
SPPB, score (median [IQR])	9 [8–9]	9 [8–9]	8 [7.5–8.5]	< 0.001
Whole body BMD, g/cm^2	1.19 ± 0.14	1.22 ± 0.13	1.11 ± 0.14	0.001
Lumbar spine BMD, g/cm^2	1.22 ± 0.23	1.2 ± 0.23	1.17 ± 0.33	0.157
Femoral neck BMD, g/cm^2	0.92 ± 0.15	0.97 ± 0.14	0.83 ± 0.12	< 0.001
Total hip BMD, g/cm^2	1.03 ± 0.16	1.04 ± 0.15	0.91 ± 0.13	< 0.001
Whole body T-score (median [IQR])	-0.1 [-1–0.85]	0.1 [-0.7–1.1]	-1.1 [-1.7–0.1]	< 0.001
Lumbar spine BMD T-score (median [IQR])	-0.4 [-1.3–1.3]	-0.4 [-1.2–1.3]	-0.6 [-1.55–0.6]	0.17
Femoral neck BMD T-score (median [IQR])	-1.2 [-1.9 – -0.4]	-0.9 [-1.6 – -0.1]	-1.9 [-2.57 – -1.3]	< 0.001
Hip BMD T-score (median [IQR])	-0.6 [-1.5–0.2]	-0.35 [-1–0.5]	-1.5 [-2.1 – -0.75]	< 0.001
T-score ≤-1.0, number (%)	97 (64.2)	58 (54.7)	39 (86.7)	< 0.001
Whole body BMC, kg	3 ± 0.47	3.11 ± 0.44	2.73 ± 0.45	< 0.001
Number of comorbidities (median [IQR])	1 [1–2]	1 [1–2]	1 [1–2]	0.503
Number of medications (median [IQR])	1 [1–2]	1 [1–2]	1.5 [1–3]	0.277

BMI – body mass index, SMMI – skeletal muscle mass index, aSM – appendicular skeletal muscle mass, IQR – interquartile range, BMD – bone mineral density, BMC – bone mineral content, SPPB – short physical performance battery, * p-value comparing non-sarcopenic and sarcopenic groups

Sarcopenic men were older, with lower weight and BMI as well. Moreover, mean BMI score in all groups belong to pre-obesity status. In addition to this, lean mass, appendicular lean mass, arm lean mass, leg lean mass, and skeletal muscle mass index, handgrip strength, and gait speed were lower in sarcopenic men. Fat mass was also lower in older men with sarcopenia. Whole body, femoral neck and total hip BMD as well as whole body, femoral neck and total hip T-score and BMC were higher in non-sarcopenic men; however, no difference was

found between lumbar spine BMD and T-score in non-sarcopenic and sarcopenic men. The largest proportion of men with T-score equal to or below − 1.0 was found in the sarcopenic group, where more than 86 percent of men could be classified as having osteopenia.

When analyzing bone health measures and body composition in older men with sarcopenia, it was found that multiple associations exist between bone health and body composition (Table 2).

Table 2
Correlations between specific bone health measures and body composition parameters in sarcopenic men.

Bone health measures	Lean mass	Appendicular lean mass	Arm lean mass	Leg lean mass	SMMI
Femoral neck BMD	r = 0.418	r = 0.5	r = 0.576	r = 0.435	r = 0.347
	p = 0.006	p = 0.001	p < 0.001	p = 0.004	p = 0.024
Hip BMD	r = 0.374	r = 0.475	r = 0.489	r = 0.431	r = 0.372
	p = 0.013	p = 0.001	p = 0.001	p = 0.004	p = 0.014
Whole body BMD	r = 0.37	r = 0.44	r = 0.451	r = 0.382	r = 0.382
	p = 0.015	p = 0.003	p = 0.002	p = 0.011	p = 0.012
Femoral neck T-score	*r* = 0.446	*r* = 0.52	*r* = 0.564	*r* = 0.411	*r* = 0.362
	p = 0.003	p < 0.001	p < 0.001	p = 0.007	p = 0.018
Total Hip T-score	*r* = 0.417	*r* = 0.505	*r* = 0.538	*r* = 0.422	*r* = 0.398
	p = 0.005	p = 0.001	p < 0.001	p = 0.005	p = 0.008
Whole body T-score	*r* = 0.37	*r* = 0.442	*r* = 0.457	*r* = 0.382	*r* = 0.382
	p = 0.015	p = 0.003	p = 0.002	p = 0.011	p = 0.012

SMMI – skeletal muscle mass index, aSM – appendicular skeletal muscle mass, BMD – bone mineral density, BMC – bone mineral content, r – Pearson r, *r* – Spearman r

As shown in Table 2, acceptable and good positive correlations were found between some bone health measures and body composition parameters. Furthermore, positive correlations were also found between fat mass and hip BMD (r = 0.31, p = 0.043) as well as whole body BMD (r = 0.372, p = 0.014). In addition, gynoid fat mass was positively associated with whole body T-score (r = 0.317, p = 0.038). An acceptable correlation was found between lumbar spine T-score and SMMI (r = 0.323, p = 0.035).

Bone health measures in sarcopenic men were not only associated with body composition, but with physical performance as well. SPPB score positively correlated with femoral neck BMD and T-score (r = 0.223, p = 0.008; r = 0.219, p = 0.009, respectively). Gait speed was positively associated with femoral neck T-score and hip T-score (r = 0.45, p = 0.002;r = 0.39, p = 0.007, respectively). A relationship was found between balance test and T-score of femoral neck (r = 0.45, p = 0.002) and hip (r = 0.3, p = 0.04). Balance test was also associated with femoral neck BMD (r = 0.442, p = 0.003), BMC (r = 0.445, p = 0.003) and whole body T-score (r = 0.368, p = 0.015). No correlations were found between 5 chair stand test results and any bone health measure. Handgrip strength had positive associations with femoral neck BMD, hip BMD, whole body T-score and BMC (r = 0.386, p = 0.011; r = 0.385, p = 0.01; r = 0.419, p = 0.005; r = 0.387, p = 0.011, respectively). Correlations between handgrip strength and femoral neck and hip T-scores are shown in Fig. 1.

Some of the body composition parameters were associated with physical performance tests. Gait speed had positive correlation with appendicular lean mass (r = 0.323, p = 0.037) and arm lean mass (r = 0.327, p = 0.035). Moreover, balance test was associated with appendicular lean mass and arm lean mass as well (r = 0.347, p = 0.024; r = 0.384, p = 0.012, respectively), as with SMMI (r = 0.334, p = 0.031). Skeletal muscle mass index also had an acceptable positive correlation with handgrip strength (r = 0.342, p = 0.027). No associations were found between leg lean mass and gait speed (p = 0.056) or balance (p = 0.054), and between 5 chair stand test and body composition parameters.

A few body composition parameters were associated with handgrip strength (Fig. 2).

Out of 45 men with sarcopenia, 38 agreed to undergo a procedure of muscle biopsy. Eight out of those men had contraindications for biopsy: 2 were taking anticoagulants at the time and 6 had a confirmed case of arrhythmias. Out of 30 muscle microbiopsies performed, 25 samples were informative, because 2 microbiopsies had insufficient samples and 3 had higher than the accepted count for altered fibers. A picture of muscle morphology sample can be seen in Fig. 3.

On average, muscle fiber length was 217.47 ± 25.22 microm, the smallest length was 183.47 microm and the longest – 255.83 microm. Fiber cross-sectional area varied from 139 to 6116 microm^2. Average fiber cross-sectional area was 2446 ± 608.87 microm^2. The number of type I fibers counted was 168.75 ± 89.35 and of type II fibers, it was 126.25 ± 74.87. Type I fibers made up 57.28% of all fibers.

No significant correlations were found between muscle fiber length and whole body, lumbar spine, femoral neck or hip BMD ($p = 0.18$, $p = 0.43$, $p = 0.19$, $p = 0.65$, respectively) or bone mineral content ($p = 0.25$). Muscle fiber area did not correlate with bone health measures (BMD and BMC) as well. No correlations between muscle fiber length or area and T-score in whole body, lumbar spine, femoral neck or hip were found as well. Body composition parameters, such as fat mass, android and gynoid fat mass, lean mass, appendicular lean mass, arm and leg lean mass were also not associated with muscle fiber length or muscle fiber area. Moreover, no correlations were found between muscle fiber length or area and physical performance (balance test, 5 chair stands and gait speed) or muscle strength (handgrip strength).

In nine sarcopenic men with T-score ≤ 2.5, muscle fiber area had a good positive correlation with results of balance test ($r = 0.73$, $p = 0.025$). No other associations were found between muscle fiber length or area and bone health measures, body composition, physical performance or muscle strength. In other 16 men, no correlations were found between muscle morphology, BMD, body composition, physical performance and muscle strength.

Discussion

The results of our study show that associations between bone health measures, body composition, physical performance and muscle strength are intertwined within the groups. Multiple significant correlations exist between bone mineral density, lean mass, appendicular lean mass, physical performance and handgrip strength. However, only one association was found between muscle morphology and physical performance measure.

In this study, we found that lean mass, appendicular lean mass, arm and leg lean mass, and skeletal muscle mass index, which is calculated by dividing appendicular lean mass from subject's height squared, had positive associations with femoral neck, hip and whole body BMD and T-score. Also, SMMI was associated with lumbar spine T-score as well. Some of these results are similar to those found by Verschueren et al. [23]. They found that higher appendicular lean mass and skeletal muscle mass index were associated with higher BMD scores in whole body, femoral neck, total hip and lumbar spine. It should be noted that their study included not only older, but middle-aged men as well. Moreover, in Hertfordshire Sarcopenia Study, it was found that appendicular lean mass was associated with whole body BMD, lumbar spine BMD and femoral neck BMD [24]. Turning to body composition association with T-score, in Swiss study, men with sarcopenia, which was characterized as skeletal muscle mass index lower or equal to 7.26 kg/m^2, had significantly lower femoral neck T-score compared to men, who had higher skeletal muscle mass index [25]. Furthermore, Intriago and colleagues found that in older adults with osteoporosis lean mass, appendicular lean mass and SMMI were lower than in older adults without sarcopenia [26]. However, the majority of participants in that study were women. Conversely to the previously mentioned findings, one cross-sectional study in China found no differences between skeletal muscle mass index in older adults and T-score [27]. It should be noted that in this study,BMD was not measured by the DXA, but by the quantitative ultrasound at calcaneus. Also, this study included both older men and women. We not only found associations between bone health measures and lean mass, but with fat mass as well. Whole body and hip BMD were correlated with fat mass and whole body T-score was associated with gynoid fat mass. A cross-sectional study in non-sarcopenic older women found that fat mass was associated with femoral neck, hip and lumbar spine BMD [28]. Contrary to this, a cross-sectional study in older Korean women found no relationship between fat mass and femoral neck or hip BMD [29].

In our study, gait speed and balance test were associated with femoral neck and hip T-scores, balance test alone had correlations with BMC and whole body T-score in older men with sarcopenia. Furthermore, gait speed and balance test were related to appendicular lean mass and arm lean mass. Balance test and SMMI were also correlated. Surprisingly, leg lean mass did not correlate with gait speed or balance test, which is odd knowing that legs play a major role in gait speed and balance test assessment.

Handgrip strength, which acts as a proxy for muscle strength assessment, in our study was associated with bone health measures and body composition parameters. Femoral neck and hip BMD and T-score as well as whole body T-score and BMC were correlated with handgrip strength. In older Chinese adults, higher handgrip strength was associated with lower risk of osteoporosis [27]. Although, in older Chinese women with osteoporosis, handgrip strength was correlated with femoral neck, hip and lumbar spine BMD, in the same study such correlations were not found in men's group [30]. As mentioned earlier, handgrip strength was also associated with lean mass, appendicular lean mass, arm and leg lean mass and SMMI. In Sweden, community-dwelling older men with moderate and severe sarcopenia positive correlation was found between SMMI and handgrip strength [31]. In older adults without sarcopenia, higher fat free mass was associated with higher handgrip strength [32]. No correlations were found between muscle morphology (muscle fiber length and muscle fiber area)

and bone health measures (BMD and BMC). However, in Hertfordshire, Sarcopenia study unadjusted analysis revealed associations between type I fiber area and femoral neck BMC, whereas after the adjustment for age and height, these associations were not significant [24]. Furthermore, they found that type II fiber area was associated with femoral neck BMD and BMC before and after the adjustment. In addition, they did not observe any significant correlations between types I or II fiber area and whole body or lumbar spine BMD or BMC. Other studies conducted in osteoporotic women also found that total hip and femoral neck BMD values correlated with the percentage of type II fiber atrophy [33]. The information about associations between muscle morphology and bone health measures is scarce, therefore, it is difficult to define the relationship between muscle fibers and bone health measures. In this study, we found that men with sarcopenia and T-score below − 2.5 muscle fiber area had positive correlation with the balance test performance. In our opinion, we are the first to report on this association. Nonetheless, the sample in which this connection was found was very small and more in depth studies are needed to confirm this association.

We also found that in this study larger proportion of men with sarcopenia had osteopenia compared to non-sarcopenic men. A cross-sectional study in geriatric inpatient population found that prevalence of osteoporosis was significantly higher in men with sarcopenia than in men without sarcopenia [34]. Older Chinese men with sarcopenia, diagnosed according to Asian Working Group for Sarcopenia guidelines, had higher prevalence of osteopenia than non-sarcopenic men [35].

Our study has some limitations. First, the number of study participants is probably not large enough to show significant relationships between certain variables. Second, muscle fibers from the microbiopsy cannot be ideally orientated in the same cutting direction (e.g. perpendicular), which gives additional variation in morphometry (fiber area, perimeter). This explains why there was no correlation between muscle morphology and bone health measures.

Conclusions

In conclusion, the results of our study show that men with sarcopenia lower lean muscle mass was associated with lower femoral neck and hip BMD, and with lower muscle strength. In sarcopenicmen, physical performance was associated with appendicular lean mass, femoral neck and hip T-scores. Also, relationships were found between higher muscle strength,femoral neck and hip BMD. In sarcopenic men with T-score $\leq$ 2.5, lower muscle fiber area was associated with lower scores of balance test.

Abbreviations

BMD – bone mineral density

BMC – bone mineral content

EWGSOP - European Working Group on Sarcopenia in Older People

SPPB - short physical performance battery

SD - standard deviation

BMI – body mass index

SMMI – skeletal muscle mass index

aSM – appendicular skeletal muscle mass

IQR – interquartile range

Declarations

Ethics approval and consent to participate

Study protocol has been approved by Lithuanian regional biomedical research ethics committee (No. 158200-03-208-75). All subjects gave their written informed consent prior to enrolment.

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author.

Competing interests

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Authors' contributions

AM, VA, MT, and AL participated in the conception, design, conduct and data collection of the study. JK and DP conducted statistical analyses. AM and JK wrote the first draft version of the manuscript; VA, MT and AL contributed to and reviewed final version of the manuscript. All authors read and approved the final manuscript.

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Figures

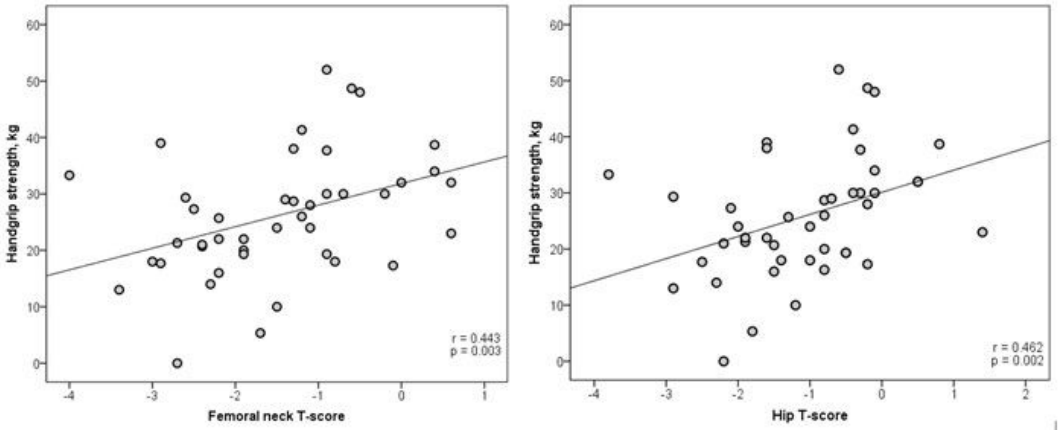

Figure 1

Spearman correlations between handgrip strength and total femoral neck T-score (left) and hip T-score (right)

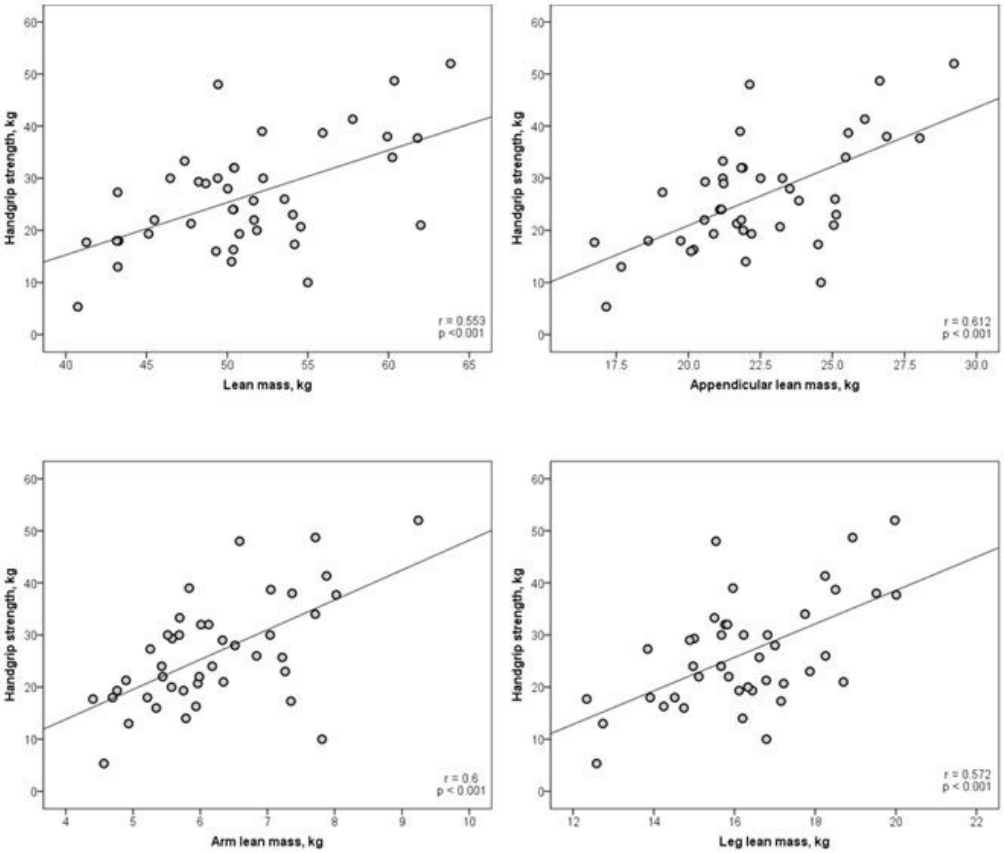

Figure 2

Pearson correlations between handgrip strength and lean mass (top left), appendicular lean mass (top right), arm lean mass (bottom left) and leg lean mass (bottom right)

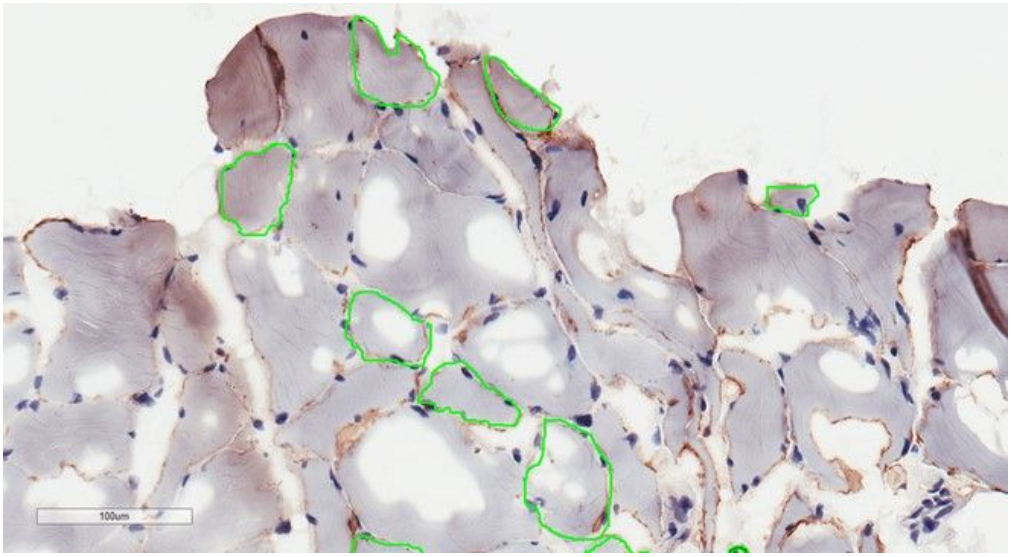

Figure 3

Microscopical view of the skeletal muscle biopsy stained with Merosin and with manual annotations (green line) of sarcolemma at visually the most perpendicularly orientated cross sectioned and at least artefactually damaged myocytes