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ORIGINAL RESEARCH ARTICLE

Computed Tomography-Based Muscle Attenuation and Electrical Impedance Myography as Indicators of Trunk Muscle Strength Independent of Muscle Size in Older Adults

ABSTRACT

Anderson DE, Bean JF, Holt NE, Keel JC, Bouxsein ML: Computed tomography-based muscle attenuation and electrical impedance myography as indicators of trunk muscle strength independent of muscle size in older adults. Am J Phys Med Rehabil 2014;93:553–561.

Objective: The aim of this study was to examine the associations of computed tomography-based x-ray attenuation and paraspinal electrical impedance myography measures of trunk muscles with absolute and relative (normalized by body weight) trunk extension strength, independent of muscle cross-sectional area.

Design: This is a cross-sectional study of mobility-limited community-dwelling older adults (34 women, 15 men; mean [SD] age, 78.2 [7.2] yrs) recruited from within an existing prospective research cohort. Trunk extension strength, computed tomography-based trunk muscle cross-sectional area and attenuation at L4 level, and paraspinal electrical impedance myography measures were collected.

Results: Attenuation was positively correlated with absolute and relative strength for multiple muscle groups (r = 0.32–0.61, $P < 0.05$). Paraspinal electrical impedance myography phase was positively correlated with paraspinal attenuation ($r = 0.30$, $P = 0.039$) and with relative strength ($r = 0.30$, $P = 0.042$). In multivariable linear regressions adjusting for sex and cross-sectional area, attenuations of the anterior abdominal muscles (semipartial $r^2 = 0.11$, $P = 0.013$) and combined muscles (semipartial $r^2 = 0.07$, $P = 0.046$) were associated with relative strength.

Conclusions: Although attenuation was associated with relative strength, small effect sizes indicate limited usefulness as clinical measures of muscle strength independent of muscle size. However, there remains a need for additional studies in larger and more diverse groups of subjects.

Key Words: Muscle Strength, Multidetector Computed Tomography, Myography, Aged

Aging is accompanied by well known declines in muscular strength, power, and physical function. Although declining strength is partially caused by decreases in muscle size, strength declines more rapidly than muscle lean mass[1] or cross-sectional area (CSA)[2] in older adults. This suggests that a decline in muscle quality, often defined as muscle strength per unit CSA, is an important factor in age-related loss of muscle strength. However, there is currently no simple, muscle-specific clinical measure of muscle quality. Such a measure would be of interest both for the evaluation of muscle impairment and monitoring of rehabilitation in older adults as well as for research into the mechanisms underlying the loss of strength and function with aging.

Lower x-ray attenuation by muscles in computed tomographic (CT) scans, measured in Hounsfield units (HU), indicates lower tissue density and is associated with increased levels of fat within the muscle tissue.[3] Low muscle attenuation in the trunk is associated with poor physical function, faster loss of physical function over time, more severe low back pain, and increased thoracic kyphosis in older adults.[4–6] In addition, muscle attenuation in the thigh is associated with knee extension strength independent of muscle size.[7] Overall, these studies point to trunk muscle attenuation as likely to be associated with trunk strength independent of muscle size and thus related to muscle quality, but this relationship has not been previously examined.

Electrical impedance myography (EIM) is a recently developed bioimpedance-based technique for noninvasive evaluation of muscle structure and composition.[8] In EIM, low-intensity electrical alternating current is applied to a muscle using two noninvasive surface electrodes. Resulting voltages on the surface of the skin are detected and analyzed to produce EIM measurements. Common values measured in EIM include resistance (R), the resistance of the tissue to current flow; reactance (X), the obstruction of current caused by capacitance or charge storage in the tissue; and phase angle ($\Theta = \arctan[X/R]$), which is a measure of the ratio of capacitive to resistive properties of the tissue.[8] These properties depend on tissue structure and composition. For example, loss or atrophy of muscle fibers and increased adipose content both increase resistance and decrease reactance. In addition, these measurements may vary across a wide variety of applied current frequencies and in different orientations with respect to muscle fiber directions. Thus, EIM can provide measures of intrinsic changes in muscle or differences between healthy and diseased muscle. For example, EIM phase measured in the upper and lower limbs can discriminate between children with Duchenne muscular dystrophy and healthy controls and is correlated with ultrasound measures of muscle and physical function.[9] EIM technology, analysis, and clinical applications are areas of ongoing research, and with additional development, EIM may become a useful clinical tool for diagnosing and monitoring disease-induced changes in muscles.[8]

Because it is fast, noninvasive, and relatively inexpensive to perform, EIM might provide a clinically useful measurement of muscle quality if any of its outcome measures are associated with muscle strength independent of muscle size. Previous studies examining lower extremity muscles have found that phase (measured at a frequency of 50 kHz) is positively correlated with strength in patients with myositis[10] and declines with age[11] and with disuse.[12] However, EIM measures of the paraspinal muscles have not been previously compared with trunk extension strength, nor has the relationship between EIM measures and CT-based muscle attenuation been previously examined.

The primary aim of this pilot study was to examine three potential indicators of muscle quality for associations with trunk extension strength independent of muscle size: x-ray attenuation in CT scans, phase angle from EIM, and reactance from EIM. It was hypothesized that in multivariable linear regression models, absolute trunk extension strength would be positively associated with both muscle CSA and attenuation, as measured in L4-level trunk muscles, and, similarly, that absolute strength would be associated with both paraspinal CSA (from CT) and paraspinal EIM measures. It was also hypothesized that in multivariable linear regression models, relative trunk extension strength (strength as a percentage of body weight [BW]) would be associated with muscle attenuation but not with trunk muscle CSA and, similarly, that relative strength would be associated with paraspinal EIM measures but not with paraspinal CSA. Finally, it was hypothesized that paraspinal muscle attenuation and paraspinal EIM measures would be strongly correlated with each other.

METHODS

Study Design and Participants

This study was designed as an ancillary pilot study within the Boston Rehabilitative Impairment Study of the Elderly (Boston RISE), a prospective cohort study based at Spaulding Rehabilitation Hospital in Boston, MA. As detailed elsewhere,[13] the

Boston RISE cohort consists of 430 community-dwelling primary care patients 65 yrs or older who were at risk for decline in mobility skills as manifested by either self-reported difficulty or task modification when walking one-half mile or climbing one flight of stairs. The Boston RISE participants who had successfully completed trunk extension strength measurements in a follow-up assessment visit were recruited to undergo CT scanning for this study. This study was approved by the institutional review board of Spaulding Rehabilitation Hospital, and all participants provided written informed consent before participation.

Strength Assessment

Quasi-static trunk extension strength was measured as the one-repetition maximum (1RM) on a customized trunk extension machine (Keiser Pneumatic Lower Back; Keiser Corporation, Fresno, CA), as described elsewhere.[14] Briefly, each participant first sat on the machine and practiced repetitions at a low level of resistance (133 N, 30 lbs) until they were comfortable with the machine and movement. The participant then performed extension repetitions beginning with a resistance of 222 N (50 lbs), and resistance was increased (or decreased if necessary) with each subsequent repetition until the participant was unable perform the task or said that he/she had reached his/her maximum and did not wish to attempt a higher resistance. Repetitions were performed in a slow, steady motion, limited to a 15-degreerange of motion centered on a neutral spine position. The highest resistance completed successfully was recorded as the 1RM trunk extension strength. The mean (SD) number of repetitions used to determine 1RM was 6.2 (1.8), with a range of 3–10. Intrarater reliability determined for this measure within the Boston RISE study was excellent (r = 0.96). Strength outcome variables were measured as 1RM extension force (in newtons) and measured 1RM extension force normalized by BW (in percentage of BW).

CT Imaging and Image Analysis

After recruitment, the participants made a single visit to an imaging center for CT scanning. A volumetric CT scan including vertebral levels L3–L5 was acquired using a 16-slice multidetector scanner (LightSpeed Pro 16; General Electric, Milwaukee, WI). Scans had a nominal slice thickness of 1.25 mm and a nominal in-plane pixel size of 0.98×0.98 mm.

Muscle CSA (square centimeter) and attenuation (HU) were determined in the midvertebral slice of the L4 vertebral level. Because trunk extension involves significant activation of muscles besides the lumbar paraspinal muscles,[15,16] all the muscles visible in the cross-section were examined, separated into the following muscle groups: anterior abdominal muscles (rectus abdominis, external oblique, and internal oblique), posterior abdominal muscles (psoas major and quadratus lumborum), and paraspinal muscles (erector spinae and multifidus), as well as the combination of all muscles. The outer boundaries of each muscle were contoured using an image processing program (Analyze; Biomedical Imaging Resource, Mayo Clinic, Rochester, MN).[17] Attenuation values were adjusted on the basis of a five-chamber phantom (Model 3 CT Calibration Phantom; Mindways Software, Inc, Austin, TX) scanned with each participant. Muscle CSA and attenuation were calculated from voxels within the contours of the muscles on the right and left sides combined, with voxels outside the range of −50 to 150 HU excluded before calculations to exclude tissue that is clearly outside the range of normal muscle that may have fallen within the contour. The authors have previously found good overall interreader and intrareader reliability for muscle CSA and attenuation measurements using this approach.[18]

Electrical Impedance Myography

Paraspinal muscle EIM measurements were obtained in each participant using a handheld measurement device (Skulpt, Inc, Boston, MA). Measurements were performed at the level of the iliac crests (approximately level with the L4 vertebra), on both the right and the left side of the spine. The mean of the left- and right-side measurements of phase angle (measured at 50 kHz) and reactance (also measured at 50 kHz) was chosen as the EIM measurements of interest. Phase angle was selected because it is a commonly reported EIM measurement that has been previously related to muscle strength and aging,[10,11] whereas reactance was selected because it is less affected by subcutaneous fat thickness,[19] which could be significant in the trunk. Previous studies have found good repeatability of EIM measurement, with test-retest variability of approximately 5% in the quadriceps[10] and 11.9% in the wrist extensors.[20]

Statistical Analysis

Strength and muscle outcome variables were checked for normality (Shapiro-Wilk W test). Bivariate associations between L4-level trunk muscle CSA and attenuation were examined for each muscle group as well as between these muscle measures and strength measures. Then, multivariable linear regression models were created, with trunk extension force (absolute or relative) as the dependent variable and sex, trunk muscle CSA, and attenuation as independent variables. Standardized coefficients were calculated to indicate how many standard deviations strength would change per standard deviation change in the predictor variables. Squared semipartial correlation coefficients were calculated to determine the unique contribution of each variable to the overall prediction of strength. Bivariate associations between muscle CSA, attenuation, and EIM measures were examined for the paraspinal muscles as well as between EIM measures and strength. Then, multivariable linear regression models were created, with trunk extension force (absolute or relative) as the dependent variable and sex, paraspinal muscle CSA, and EIM phase or reactance as independent variables. Statistical analyses were performed in JMP (SAS Institute Inc, Cary, NC), with significance set at $\alpha = 0.05$.

RESULTS

Participants

A total of 51 participants (36 women and 15 men) took part in this study. Valid trunk extension measurements were obtained in 49 participants (34 women and 15 men), and analyses were limited to these participants. Of these, usable abdominal CT scans were obtained in 48 participants (33 women and 15 men), and paraspinal EIM measurements were obtained in 47 participants (32 women and 15 men). Participant characteristics are summarized in Table 1. The men were, on average, approximately 4.7 yrs older than the women and were taller and stronger and had larger muscle CSA.

Associations Between CT-Based Muscle Measures and Strength

All CT muscle measures and strength measures were normally distributed. In bivariate associations, CT-based trunk muscle attenuation was positively correlated with muscle CSA in anterior abdominal, paraspinal, and combined muscle groups ($r = 0.38$–0.63, $P < 0.05$, Table 2). Furthermore, in bivariate associations, muscle CSA and attenuation were positively correlated with absolute trunk extension strength for all muscle groups ($r = 0.32$–0.61, $P < 0.05$, Table 2). Relative trunk extension strength was positively correlated with paraspinal muscle CSA ($r = 0.34$, $P = 0.033$, Table 2), but this association did not reach significance for the anterior abdominal, posterior abdominal, or combined muscle groups. However, relative trunk extension strength was positively correlated with attenuation of the anterior abdominal and combined muscle groups ($r = 0.33$–0.38, $P < 0.05$, Table 2), but this association did not reach significance for the posterior abdominal or paraspinal groups.

TABLE 1 Mean (standard deviation) characteristics of study participants, including trunk strength and CT-and EIM-based trunk muscle measurements

Characteristic	All (n = 49)	Women (n = 34)	Men (n = 15)
Age, yrs	78.2 (7.2)	76.8 (6.2)	81.5 (8.5)[a]
Weight, kg	75.9 (16.1)	74.6 (18.2)	78.7 (9.6)
Height, m	1.62 (0.09)	1.59 (0.07)	1.69 (0.08)[a]
BMI, kg/m^2	29.1 (5.9)	29.8 (6.8)	27.4 (2.7)
Strength, N	541 (148)	495 (122)	645 (154)[a]
Strength, %BW	73.6 (17.5)	69.5 (17.7)	83.0 (13.3)[a]
Anterior abdominal muscles			
CSA, cm^2	44.6 (11.2)	39.8 (8.1)	55.2 (9.9)[a]
Attenuation, HU	28.3 (9.3)	26.6 (9.7)	32.1 (7.5)
Posterior abdominal muscles			
CSA, cm^2	28.2 (8.1)	24.9 (5.4)	35.5 (8.3)[a]
Attenuation, HU	41.2 (7.3)	41.2 (7.4)	41.3 (7.3)
Paraspinal muscles			
CSA, cm^2	33.2 (7.8)	31.6 (7.5)	36.6 (7.7)[a]
Attenuation, HU	26.5 (12.5)	25.3 (13.2)	29.1 (10.9)
EIM phase, degrees	2.82 (0.80)	2.82 (0.80)	2.82 (0.84)
EIM reactance, Ω	2.78 (0.93)	2.90 (0.97)	2.52 (0.83)
Combined muscles			
CSA, cm^2	106.0 (23.1)	96.3 (17.0)	127.3 (20.4)[a]
Attenuation, HU	31.3 (8.8)	30.1 (9.2)	34.0 (7.5)

[a]Significant sex difference ($P < 0.05$).

BMI, body mass index.

TABLE 2 Pearson correlation coefficients for associations between muscle CSA, attenuation, absolute trunk extension strength (newton), and relative trunk extension strength (percentage of BW) in trunk muscle groups at the L4 level

Muscle Group	CSA *vs.* Attenuation	CSA *vs.* Absolute Strength	Attenuation *vs.* Absolute Strength	CSA *vs.* Relative Strength	Attenuation *vs.* Relative Strength
Anterior abdominal	0.38[a]	0.47[a]	0.39[a]	0.15	0.38[a]
Posterior abdominal	0.27	0.55[a]	0.33[a]	0.25	0.20
Paraspinal	0.63[a]	0.55[a]	0.32[a]	0.34[a]	0.23
Combined	0.50[a]	0.61[a]	0.40[a]	0.28	0.33[a]

[a]Significant correlation ($P < 0.05$).

In multivariable linear regression models predicting absolute trunk extension strength from sex, CSA, and attenuation (Table 3), sex and CSA were significant in the paraspinal and combined muscle models ($P < 0.05$) and neared significance in the posterior abdominal muscle models. Attenuation was not significant, although it neared significance, for the anterior abdominal model ($P = 0.081$) and the posterior abdominal model ($P = 0.056$). Standardized coefficients for these near-significant attenuation values indicate that 1-SD greater attenuation is associated with approximately 0.25-SD greater absolute strength, and semipartial r^2 values indicate that these attenuation values uniquely explained approximately 5% of the variance in absolute trunk extension strength when accounting for sex and CSA.

TABLE 3 Separate multivariable linear regression analyses predicting absolute trunk extension strength (newton) as a function of sex, muscle CSA, and muscle attenuation or EIM measurements

	Intercept	Sex	CSA	Attenuation or EIM	Model r^2
Anterior abdominal attenuation					
Estimate	326.55	−43.71	2.74	3.85	0.32
Standardized estimate		−0.27	0.20	0.24	
P	0.005	0.100	0.233	0.081	
Semipartial r^2		0.04	0.02	0.05	
Posterior abdominal attenuation					
Estimate	188.27	−45.07	5.67	5.09	0.38
Standardized estimate		−0.28	0.31	0.25	
P	0.111	0.073	0.060	0.056	
Semipartial r^2		0.05	0.05	0.05	
Paraspinal attenuation					
Estimate	276.26	−53.94	8.78	−0.22	0.40
Standardized estimate		−0.34	0.46	−0.02	
P	0.002	0.008	0.005	0.905	
Semipartial r^2		0.10	0.12	0.00	
Combined muscle attenuation					
Estimate	182.92	−28.28	2.72	2.59	0.40
Standardized estimate		−0.18	0.42	0.15	
P	0.109	0.253	0.019	0.271	
Semipartial r^2		0.02	0.08	0.02	
Paraspinal EIM phase					
Estimate	300.88	−47.82	9.60	−19.44	0.43
Standardized estimate		−0.30	0.50	−0.09	
P	0.005	0.019	0.000	0.429	
Semipartial r^2		0.08	0.22	0.03	
Paraspinal EIM reactance					
Estimate	219.92	−50.32	9.33	13.23	0.43
Standardized estimate		−0.32	0.48	0.08	
P	0.025	0.016	0.000	0.491	
Semipartial r^2		0.08	0.21	0.03	

TABLE 4 Separate multivariable linear regression analyses predicting relative trunk extension strength (percentage of BW) as a function of sex, muscle CSA, and muscle attenuation or EIM measurements

	Intercept	Sex	CSA	Attenuation or EIM	Model r^2
Anterior abdominal attenuation					
Estimate	79.45	−9.27	−0.47	0.64	0.30
Standardized estimate		−0.52	−0.32	0.35	
P	<0.001	0.003	0.073	0.013	
Semipartial r^2		0.15	0.05	0.11	
Posterior abdominal attenuation					
Estimate	59.93	−8.30	−0.18	0.51	0.21
Standardized estimate		−0.46	−0.09	0.22	
P	<0.001	0.011	0.627	0.125	
Semipartial r^2		0.13	0.00	0.04	
Paraspinal attenuation					
Estimate	58.84	−6.14	0.43	0.08	0.22
Standardized estimate		−0.34	0.20	0.06	
P	<0.001	0.019	0.270	0.725	
Semipartial r^2		0.11	0.02	0.00	
Combined muscle attenuation					
Estimate	69.53	−8.02	−0.12	0.60	0.24
Standardized estimate		−0.45	−0.16	0.32	
P	<0.001	0.013	0.408	0.046	
Semipartial r^2		0.12	0.01	0.07	
Paraspinal EIM phase					
Estimate	48.18	−5.67	0.52	3.54	0.24
Standardized estimate		−0.32	0.24	0.15	
P	0.001	0.032	0.099	0.271	
Semipartial r^2		0.09	0.05	0.02	
Paraspinal EIM reactance					
Estimate	55.60	−5.85	0.55	0.59	0.22
Standardized estimate		−0.33	0.25	0.03	
P	<0.001	0.033	0.088	0.817	
Semipartial r^2		0.09	0.06	0.00	

In multivariable linear regression models predicting relative trunk extension strength from sex, CSA, and attenuation (Table 4), sex was a significant factor in all models ($P < 0.05$), whereas CSA was not a significant factor. Both anterior abdominal attenuation ($P = 0.013$) and combined muscle attenuation ($P = 0.046$) were significantly associated with relative strength. Standardized coefficients for these significant attenuation values indicate that 1-SD greater attenuation is associated with approximately 0.24- to 0.32-SD greater relative strength, and semipartial r^2 values indicate that these attenuation values uniquely explained from 7% to 11% of the variance in relative trunk extension strength when accounting for sex and CSA.

Associations of Paraspinal EIM Measures with Paraspinal CT Measures and Strength

EIM phase was positively correlated with paraspinal muscle attenuation ($r = 0.30$, $P = 0.039$, Fig. 1) and with relative trunk extension strength ($r = 0.30$, $P = 0.042$) but was not associated with paraspinal muscle CSA or absolute trunk extension strength. EIM reactance was not associated with paraspinal muscle CSA, paraspinal muscle attenuation, absolute trunk extension strength, or relative trunk extension strength.

In multivariable linear regression models predicting absolute trunk extension strength from sex, paraspinal muscle CSA, and EIM measurements (Table 3), sex and CSA were both significant in models including either EIM phase or reactance ($P < 0.05$). However, neither phase nor reactance was a significant predictor of absolute trunk extension strength. Semipartial r^2 values indicate that EIM phase or reactance uniquely explained only approximately 3% of the variance in absolute trunk extension strength when accounting for sex and CSA.

In multivariable linear regression models predicting relative trunk extension strength from sex, paraspinal muscle CSA, and EIM measurements (Table 3), sex remained a significant predictor

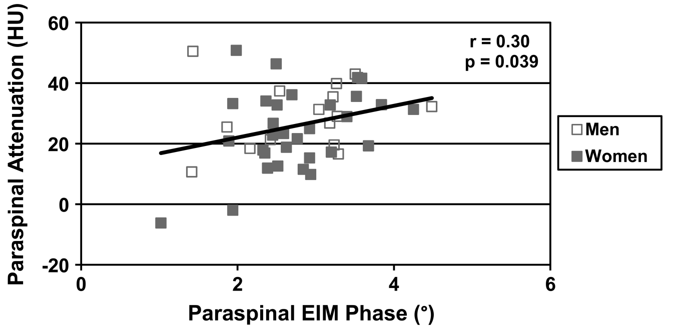

FIGURE 1 *Scatterplot showing bivariate association between paraspinal muscle attenuation and paraspinal EIM phase. Regression line is shown for all subjects (men and women combined).*

($P < 0.05$), whereas CSA was no longer significant (although with $P < 0.10$). Neither phase nor reactance was a significant predictor of relative trunk extension strength. Semipartial r^2 values indicate that EIM phase or reactance uniquely explained only 0%–2% of the variance in relative trunk extension strength when accounting for sex and CSA.

DISCUSSION

This study examined CT-based muscle attenuation and paraspinal EIM measurements as potential measures of muscle quality by relating them to trunk extension strength independent of muscle size in older adults. Overall, the results provide only partial support for the hypotheses made. In bivariate associations, trunk muscle attenuation measures were modestly correlated with absolute trunk extension strength, comparing favorably with the previously reported association ($r = 0.20$) between midthigh muscle attenuation and knee extensor strength in older adults.[7] As might be expected, trunk muscle CSA was more strongly correlated with absolute trunk extension strength, than relative strength, indicating that correlations between CSA and strength are largely caused by size, with larger individuals having larger muscles and greater strength. Thus, correlations of attenuation with relative strength support the idea that muscle attenuation is an indication of muscle strength independent of size. However, muscle CSA and attenuation were also correlated with each other, making their independent contributions to trunk extension strength more difficult to ascertain.

Multivariable linear regressions accounting for muscle CSA support the hypothesis that relative trunk extension strength is positively associated with muscle attenuation independent of CSA, but the associations varied by muscle group. The strongest attenuation measure (anterior abdominal) uniquely accounted for approximately 11% of the variation in relative strength, similar to the variance in physical performance of older adults explained by trunk muscle attenuation in the Health, Aging, and Body Composition study.[4] With a relatively small effect size, it does not seem that muscle attenuation would be a useful clinical measure of trunk muscle quality; however, the authors were limited to examining associations with trunk extension strength in this sample of older adults with mobility difficulties.

EIM phase was weakly correlated with relative strength ($r = 0.30$), which was weaker than previously reported correlations between EIM phase of the quadriceps and strength measures ($r = 0.67$–0.77).[10] The reason for this difference between results in the quadriceps and paraspinal muscles is not clear. It could be caused by differences in EIM measurements between the quadriceps and paraspinal muscles, the musculoskeletal complexity of trunk extension strength, or some other unknown factor. Paraspinal muscle EIM phase also showed a weak correlation with paraspinal muscle attenuation. It is possible that this association is indicative of an underlying factor that affects both muscle attenuation and EIM phase. For example, both attenuation and EIM phase should decrease with increased adipose content of the muscle tissue. However, the association found was not sufficiently strong to indicate that the two are measuring equivalent properties of muscle. Additional study of EIM is needed to understand its potential and limitations for evaluating trunk muscles.

Among the attenuation measures examined, attenuation of the anterior abdominal muscles was the most consistently related to trunk extension strength, whether or not independent of CSA. Although combined muscle attenuation showed similar trends in association with muscle strength, this was likely caused by the contribution of the anterior abdominal muscles to combined muscle attenuation. Thus, the results do support the hypothesis that trunk extension strength is positively associated with trunk muscle attenuation independent of size. Finding this association primarily in the anterior abdominal muscles and not elsewhere is unexpected, mainly because the obvious action of the anterior abdominal muscles is trunk flexion rather than extension. However, it must be noted that the abdominal muscles play an important biomechanical role during trunk extension. Electromyography studies show significant co-contraction of the abdominal oblique muscles during trunk extension exertions.[15,16] Furthermore, contraction of the abdominal muscles increases intra-abdominal pressure (IAP), and co-contraction naturally increases IAP during extension exertions.[21] Biomechanical modeling studies show that coactivation of the abdominal muscles and increased IAP increase the stability of the lumbar spine,[22,23] which is important because of the inherent instability of the structure. Furthermore, increased IAP may produce a net extension moment on the lumbar spine and reduce spinal compressive loading.[24] Thus, the anterior abdominal muscles minimally play an important role in lumbar stability during extension exertions and may in fact add to trunk extension strength via increased IAP. Therefore, it is not implausible that anterior abdominal muscle strength significantly affects trunk extension strength.

Study Limitations

This study has several important limitations. First, the sample size was relatively small and had limited power to detect associations given the effect sizes found. Power analysis indicates that approximately 15 additional participants would have been necessary for the near-significant anterior abdominal attenuation in the multivariable regression examining absolute strength to reach significance. However, for EIM phase in the multivariable regression examining relative strength, an additional 100 participants would be required. The combination of small sample and effect sizes limited the ability to draw conclusions in this study. Second, EIM measurements were limited to EIM phase and reactance from the paraspinal muscles, which were collected at a single frequency and in a single direction relative to the muscle fibers. These basic EIM measurements were selected because of their use in previous studies. However, improvement of EIM technology and analysis paradigms is an active area of research,[8] and it is likely that future studies will identify EIM-based measurements that are more strongly associated with muscle strength or function. Furthermore, EIM measures in muscles besides the paraspinal muscles could provide different results, although not all muscles are readily accessible for surface measurement. Third, measured trunk extension strength was used as a surrogate measure for trunk muscle strength but may not have represented it well for several reasons. The extension arm on the strength testing machine could not be adjusted for participant stature, which could have disadvantaged some participants and/or biased the measurements. Trunk extension is biomechanically complex and likely depends on factors besides paraspinal muscle strength, including anterior abdominal muscle function, IAP, and neuromuscular coordination. Furthermore, some individuals in this study may have had limited extension strength because of comorbidities (e.g., arthritis, back pain) that are not directly related to muscular strength, but exploring this was beyond the scope of this small pilot study. Thus, a variety of factors could have affected measured strength and reduced its associations with muscle measurements. Finally, the Boston RISE cohort consists of older adults with self-reported mobility problems. Although this is an important population in which clinical measures of muscle quality are needed, the results will not necessarily extend to other populations or extrapolate across a broader range of strength and muscle measurement values. Additional studies are needed to evaluate the associations between CT- and EIM-based muscle measures and trunk muscle strength in larger populations of young and healthy older adults as well as to more carefully examine the effect of other factors such as sex, body mass index, and comorbidities.

CONCLUSIONS

In conclusion, this pilot study is the first to examine both CT-based muscle attenuation and EIM measurements as potential measures of trunk muscle quality by comparing them to absolute and relative trunk strength independent of muscle size. The results indicate that muscle attenuation and EIM phase are associated with trunk extension strength, accounting for approximately 10%–20% of the variation in strength. There is some evidence that these relationships are independent of muscle size, with significant results found for attenuation of the anterior abdominal muscles. However, given the small effect sizes found and the limitations of this study, the usefulness of these measures as clinical measures of muscle quality has not been established. Nonetheless, there remains a need for further research into how these measures relate to trunk strength and function in healthy women and men of all ages as well as those with musculoskeletal disorders and conditions.

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