Fat Replacement of Paraspinal Muscles with Aging in Healthy Adults

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ABSTRACT

DAHLQVIST, J. R., C. R. VISSING, G. HEDERMANN, C. THOMSEN, and J. VISSING. Fat Replacement of Paraspinal Muscles with Aging in Healthy Adults. *Med. Sci. Sports Exerc.*, Vol. 49, No. 3, pp. 595–601, 2017. **Purpose**: The aims of this study were to investigate the age-related changes in fatty replacement and cross-sectional area (CSA) of cervical, thoracic, and lumbar paraspinal muscles versus leg muscles in healthy adults and to test for association between muscle fat fraction and lifestyle factors. **Methods**: Fifty-three healthy adults (24–76 yr) were included. Dixon magnetic resonance imaging technique was used to determine CSA and to quantify the fat fraction of paraspinal and leg muscles. Muscle CSA and fat fractions were tested for association with age and muscle strength. The fat fractions were also tested for association with sex, body mass index (BMI), physical activity, and lower back pain. **Results**: Both paraspinal and leg fat fractions correlated directly with age ($P < 0.0001$). At all ages, fat fraction was higher in paraspinal than leg muscles. The age-related increase in fat fraction was higher in paraspinal muscles than leg muscles ($P < 0.0001$). The CSA of the muscles did not correlate with age. Knee extension strength correlated with fat fraction ($P < 0.05$), and the muscle strength of hip muscles, thigh muscles, and anterior calf muscles correlated with CSA ($P < 0.05$). Sex was associated with lumbar paraspinal fat fraction ($P < 0.05$) and BMI with thigh fat fraction ($P < 0.001$). There was no association between fat fraction and physical activity or lower back pain. **Conclusion**: The paraspinal muscles were more susceptible to age-related changes than leg muscles. Further, men had significantly lower fat fractions in lumbar paraspinal muscles, and BMI was positively associated with thigh, but not paraspinal, fat fraction. **Key Words:** MRI, MUSCLE FAT REPLACEMENT, PARASPINAL MUSCLE, AGING

It is well known that muscle mass decreases with aging because of a reduction in the number and size of muscle fibers (3). The paraspinal muscles are important postural muscles, and several studies have investigated the effect of age on the cross-sectional area (CSA) of the lumbar paraspinal muscles in both healthy adults (9,30) and patients with lower back pain (8,16). The majority of these studies have shown a significant effect of age on the lumbar paraspinal CSA (8,9,30).

When the age-related loss of muscle mass leads to decreased muscle strength and low physical performance, it is called sarcopenia (3). Sarcopenia is very common, with a prevalence that ranges from 5% to 13% in 60- to 70-yr-olds and from 11% to 50% in >80-yr-olds (3). It is associated with a higher mortality and is responsible for loss of mobility and vitality in old age (20,24). Several mechanisms have been proposed to cause sarcopenia, including imbalance between protein synthesis and breakdown, physical inactivity, mitochondrial dysfunction, and loss of motor neurons (26). Inactivity has also been proposed to be a prominent cause because exercise stimulates protein synthesis, which leads to muscle regeneration (26). The decline in muscle strength with aging often exceeds the loss of muscle mass (14), which suggests that deterioration of intrinsic contractile properties also contribute to the decline. A potential lipotoxic effect of fatty replacement of skeletal muscle with aging may be involved in this deterioration (1,24). The extent of fatty replacement of skeletal muscle has been investigated in relation to lower back pain, whiplash-associated disorders, neuromuscular diseases, obesity, and cardiovascular diseases (5,6,15,18). Studies have shown that increased paraspinal fat fraction is associated with muscle weakness (11), poorer function (16), and limitations of movement (14). Age-related changes in the paraspinal muscles of healthy adults have been investigated in a few studies (2,7,9,30). Most of these studies examined the lumbar paraspinal muscles, and studies on the cervical and thoracic parts are limited. The results are inconsistent: age seems to affect the fatty replacement of the lumbar paraspinal muscles

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(2,9,30), but not the cervical paraspinal muscles (7). Further, the actual fat percentage values show a great variation in the different studies, ranging from 2.1% to 45% in the lumbar paraspinal muscles of young adults (27,30). More studies on paraspinal muscle composition are therefore required.

The inconsistency in the previously mentioned studies could be explained by the different methods used to determine the fatty replacement of muscle. Magnetic resonance imaging (MRI) is a great method for evaluating size and fatty replacement of skeletal muscle (25). T1-weighted imaging has often been used to evaluate the quality of the skeletal muscles (30). The skeletal muscles have also been evaluated using T2-weighted imaging (9). The Dixon MRI technique is superior to both T1- and T2-weighted imaging techniques in fat fraction quantification (22). Dixon MRI provides an objective measurement that quantifies the fatty replacement in mapped muscles on a continuous and observer-independent scale. It can detect small changes in muscle fat infiltration, not detectable by T1- and T2-weighted imaging (21).

The aim of this study was to investigate the age-related changes in fatty replacement of cervical, thoracic, and lumbar paraspinal muscles in healthy adults using Dixon MRI. Furthermore, we compared the age-related changes in fatty replacement of the paraspinal muscles to the leg muscles, investigated age-related changes of the CSA of the muscles, and tested muscle fat fraction for association with sex, body mass index (BMI), muscle strength, physical activity, and lower back pain.

MATERIALS AND METHODS

Ethical approval. The Danish National Committee on Health Research Ethics approved the research protocol (approval number: H-3-2012-163 and amendment #41665), and written and oral consent to participate was obtained from all subjects.

Subjects. Fifty-five self-reported healthy adults were recruited via advertisements from the local community; 28 men and 27 women. There were 10–12 subjects represented across five decades: 20–29, 30–39, 40–49, 50–59, and 60–76 yr. Exclusion criteria were contraindications for MRI, cardiovascular disease, lung disease, diabetes and other metabolic diseases, muscular diseases, and known spine disease. Some of the data collected in approximately half of the subjects have contributed to another study as control data (5).

MRI. Scans were performed using a 3.0-T Siemens scanner (MAGNETOM Verio Tim System). The MR protocol has been described previously (5). It included axial T1-weighted images (field of view = 400–450 mm, slice thickness = 6.0 mm, distance factor = 20%, echo time = 19 ms, repetition time = 650 ms) and axial 2-point Dixon sequences (field of view = 400–450 mm, slice thickness = 3.5 mm, distance factor = 0%, echo time = 2.45 and 3.675 ms, repetition time = 5.59 ms). It has been shown that a single MRI slice can be representative of a whole muscle or muscle group to estimate muscle volume and fat infiltration (17). Furthermore, there is no evidence to suggest that volumetric assessments of muscle are better than measurements on a single CSA, as also acknowledged by Wokke et al. (31), who measured fat fraction in the whole muscle of boys with Duchenne muscle dystrophy. The fat fraction at L4 strongly associates with the total lumbar paraspinal muscle fat fraction (2). Accordingly, we used one thigh slice and one calf slice to study the lower extremity muscles and three slices of the spine corresponding to the three different parts of the spine: cervical spine at C7, thoracic at T12, lumbar at L4, thigh at the middle of the thigh, and calf at the thickest part of the calf (Fig. 1). The slices were found using bone landmarks on a localizer (5). The images were analyzed by JRD and GH on a Siemens Syngo MR Workplace using Numaris/4 B17 software. Interobserver agreement was 91% ± 1.8%. We manually traced the muscles or muscle groups on the five slices, thus determining the CSAs, and then performed the quantitative fat fraction analysis. Fat fraction was calculated as follows: fat fraction (%) = (signal fat/signal water + fat) × 100. To illustrate the quality of the lean muscle mass, we calculated a fat-free CSA, or a contractile CSA (CCSA).

At the three spine positions, we identified the erector spinae muscles and mapped them together labeled "the paraspinal muscles" (Fig. 1A–C). At the lumbar position only, we also mapped the psoas muscles (Fig. 1C). In addition, we divided the paraspinal muscles into medial and lateral parts and mapped the parts individually in a representative cohort of 16 subjects. In these 16 subjects, we also compared the left and the right sides. At the thigh position, we mapped the three compartments of the thigh: anterior (rectus femoris, sartorius, and vastus lateralis, medialis, and intermedius muscles), medial (adductor muscles and gracilis muscle), and posterior compartment (biceps, semitendinosus, and semimembranosus muscles) (Fig. 1D). At the calf position, we divided the muscles into five muscle groups: anterior (tibialis anterior and extensor digitorum longus muscles), lateral (peroneus longus and brevis muscles), medial superficial posterior (medial gastrocnemius muscle), lateral superficial posterior (lateral gastrocnemius and soleus muscles), and deep posterior compartment (tibialis posterior, flexor digitorum longus, and flexor hallucis longus muscles) (Fig. 1E).

Clinical evaluation. Body weight and length were measured, and BMI was calculated. We tested maximal isokinetic peak torque of knee extension, knee flexion, ankle plantarflexion, and ankle dorsiflexion using the Biodex System PRO 4 Dynamometer® (Biodex Medical Systems, Inc., USA). The CITEC handheld dynamometer (C.I.T. Technics, Centre for Innovative Technics, Netherlands) was used to quantify maximum voluntary contraction in the paraspinal muscles and the lower extremities of all subjects. Handheld dynamometry has been shown to be a valid and reliable instrument in muscle strength testing (29). However, the method has some limitations, especially when testing strong muscles. In our study, 80% of the subjects reached the

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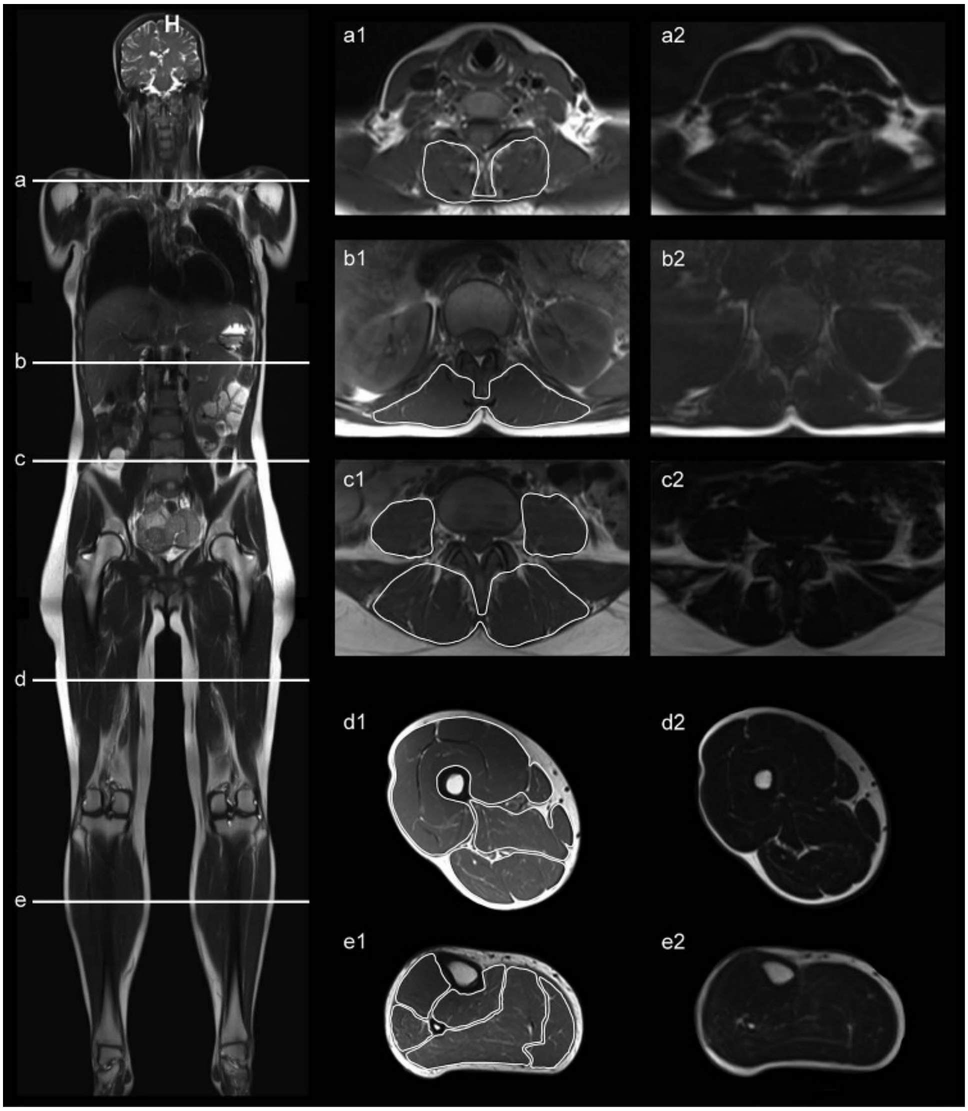

FIGURE 1—Mapping of back and leg muscles. (*Left*) The five chosen slices marked on a whole-body localizer (a–e). (*Middle*) Muscle mapping on T1-weighted images in cervical (a1), thoracic (b1), and lumbar (c1) regions of the back and the thigh (d1) and calf (e1). *Right* (a2–e2) Dixon fat images of the same regions as a1–e1.

maximum score in back extension, and this ceiling-off effect rendered back strength measures essentially useless for correlative calculations.

In addition to the mentioned strength tests, muscle strength of the back was examined with a static back extension endurance test (see Appendix, Supplemental Digital Content 1, Details on the muscle strength testing, http://links.lww.com/MSS/A781).

All subjects filled out a questionnaire on training frequency. All subjects also completed the self-administered questionnaire Low Back Pain Rating Scale, which measures different clinical aspects of lower back pain (28). In this study, we included the pain domain where the subjects were asked to grade their lower back pain on a scale from 0 to 10, with 10 being the worst pain imaginable.

Statistical analyses. A linear mixed model was used to investigate the relationship between age-related changes in fat fraction in the mapped muscles. The linear mixed model was also used to test a potential difference between the fat fractions in the mapped muscles. A P value of <0.05 was considered significant. Linear regression and Pearson correlation test were used to demonstrate association between parameters in each subject. Values are mean ± SE.

RESULTS

Subjects. Fifty-five subjects were investigated, and 53 subjects were included: 27 men (mean age = 46.6 yr, range = 24–76 yr) and 26 women (mean age = 45.2 yr, range = 24–62 yr). The reasons for exclusion were polio in childhood in one subject, which only became apparent after evaluations, and inability to complete the MRI scan because of claustrophobia in another subject. The BMI was 24.9 ± 0.5 $kg \cdot m^{-2}$ (men = 26.1 ± 0.6 $kg \cdot m^{-2}$, women = 23.5 ± 0.7 $kg \cdot m^{-2}$).

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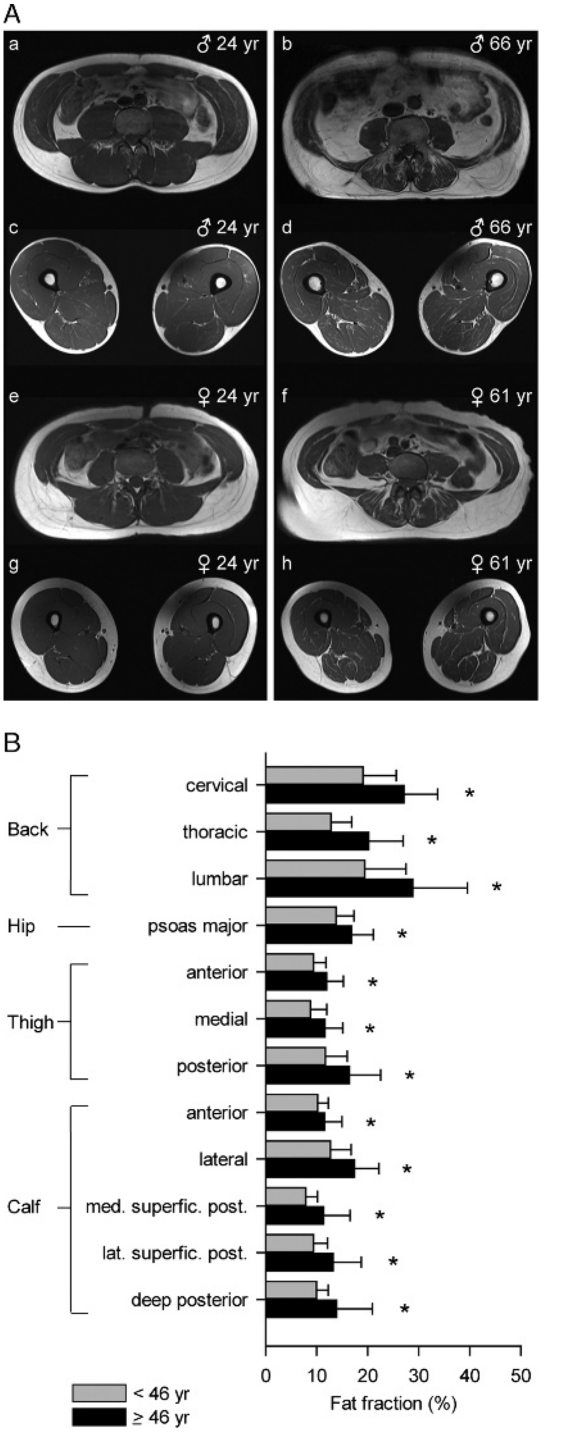

FIGURE 2—Fat fractions of muscles. A, MRIs of back and leg muscles. Axial T1-weighted images of lumbar paraspinal muscles (a, b and e, f) and thigh muscles (c, d and g, h) in younger adults (a, c, e, and g) and older adults (b, d, f, and h). B, Fat fractions of muscles in the back, hip, thigh, and calf in 53 healthy adults. *Significant difference between adults younger and older than 46 yr ($P < 0.05$). lat. superfic. post., lateral superficial posterior; med. superfic. post., medial superficial posterior.

Muscle fat fraction, CSA, and age. The muscle fat fractions of the individual muscles are illustrated in Figure 2B. We dichotomized the results at the mean age of 46 yr to illustrate that there are higher fat fractions in each individual muscle in the older subjects compared with the younger. The mean fat fraction of the thoracic paraspinal muscles was significantly lower than the cervical and lumbar paraspinal fat fractions ($P < 0.0001$). There was no difference between cervical and lumbar fat fractions ($P = 0.59$).

There was no difference in mean fat fractions between medial and lateral parts of the lumbar paraspinal muscles in the 16 subjects investigated ($P = 0.94$). The right side had significantly higher lumbar paraspinal fat fraction compared with the left side ($P < 0.05$).

There was no difference between right and left legs ($P = 0.50$).

In all subjects, the mean paraspinal fat fraction was significantly higher than the mean leg fat fraction ($P < 0.0001$), across all ages. The mean fat fraction of paraspinal, thigh, and calf muscles correlated with age ($P < 0.0001$, $R_{paraspinal} = 0.75$, $R_{thigh} = 0.66$, $R_{calf} = 0.69$; Fig. 3). The annual increase in fat fraction was 0.4% in the paraspinal muscles and 0.2% in thigh and calf muscles. This increase in fat fraction was significantly higher in the paraspinal muscles than that in the leg muscles ($P < 0.0001$; Fig. 3).

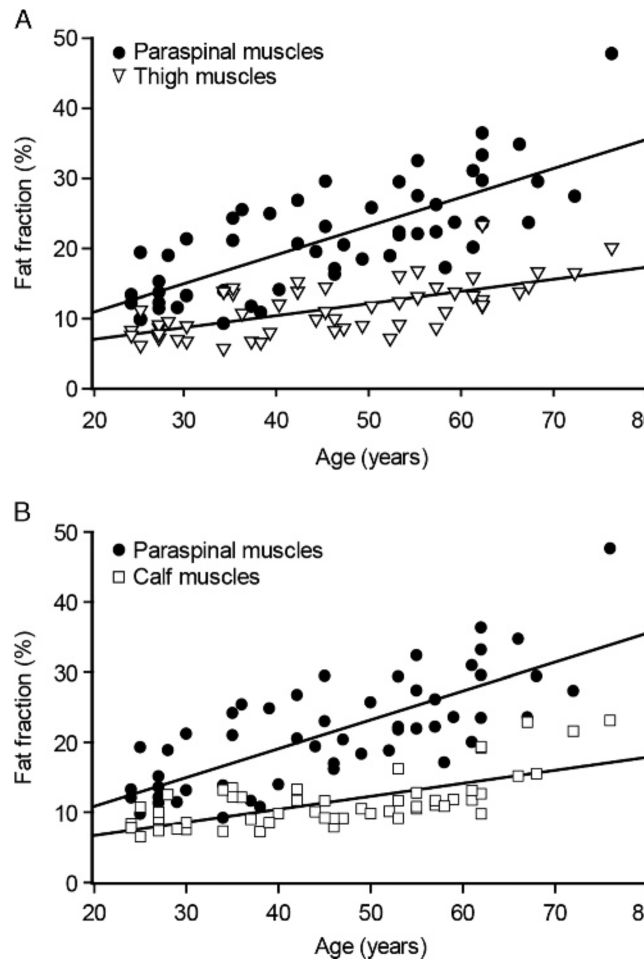

FIGURE 3—Correlations between age and muscle fat fraction. A and B, Correlations between age and muscle fat fraction in the paraspinal muscles ($R = 0.75$, $P < 0.0001$) compared with the thigh muscles (A; $R = 0.65$, $P < 0.0001$) and calf muscles (B; $R = 0.66$, $P < 0.0001$).

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There was no correlation between age and the height-adjusted CSA of the muscles.

Muscle strength. Muscle strength was investigated with the handheld dynamometer in 45 subjects and with the Biodex System PRO 4 dynamometer® in 38 subjects. The muscle strength results from the two methods correlated in knee extension ($P < 0.0001$, $R = 0.64$), knee flexion ($P < 0.0001$, $R = 0.70$), and ankle dorsal flexion strength ($P < 0.0001$, $R = 0.67$). Knee extension ($P < 0.05$, $R = -0.44$), knee flexion ($P < 0.05$, $R = -0.40$), and ankle plantarflexion strength ($P < 0.05$, $R = -0.39$) decreased with age (Fig. 4A and B). Knee extension strength examined with the Biodex System PRO 4 dynamometer® correlated with the fat fraction of the anterior compartment of the thigh ($P < 0.05$, $R = -0.44$). The muscle strength of hip muscles ($P < 0.0001$, $R = 0.57$), anterior and posterior thigh muscles ($P < 0.0001$, $R_{\text{anterior}} = 0.59$, $R_{\text{posterior}} = 0.58$), and anterior calf muscles ($P < 0.0001$, $R = 0.56$) correlated with the CSA.

The knee extension strength examined with the Biodex System PRO 4 dynamometer® correlated with the CCSA of the anterior thigh compartment ($P < 0.0001$, $R = 0.87$). The knee extension strength per CCSA decreased with age ($P < 0.05$, $R = -0.46$; Fig. 4C).

On the static back extension endurance test, the subjects could maintain their upper body lifted for 126 s. The endurance strength did not correlate with CSA or thoracolumbar fat fraction (CSA, $P = 0.75$; fat fraction, $P = 0.19$).

Sex, BMI, physical activity level, and back pain. The fat fraction of lumbar paraspinal muscles was associated with sex: men had lower fat fraction than women, 22.0% versus 26.2% ($P < 0.05$). BMI was positively associated with thigh fat fraction ($P < 0.001$), but not with paraspinal and calf fat fractions (paraspinal, $P = 0.13$; calf, $P = 0.01$).

Results from the questionnaire on training showed that 64% trained approximately 4 $h \cdot wk^{-1}$ (mean age = 43.8 yr), 15% trained 5–10 $h \cdot wk^{-1}$ (mean age = 44.0 yr), and 2% trained more than 10 $h \cdot wk^{-1}$ (1 = subject; 67 yr old). The remaining 19% did not train regularly (mean age = 47.3 yr).

In the Low Back Pain Rating Scale questionnaire, 11% of the subjects graded their worst possible pain during the last 14 d from 5 to 10, and 55% from 1 to 4. The last 34% had no lower back pain.

Neither training frequency nor severity of lower back pain correlated with the paraspinal fat fraction (training, $P = 0.96$; pain, $P = 0.62$).

DISCUSSION

In this study, we investigated the fatty replacement of paraspinal and lower extremity muscles in healthy adults. We found that the paraspinal muscles have a significantly higher mean fat fraction and age-related increase in fatty replacement compared with the lower extremity muscles. These new findings suggest that the paraspinal muscles are more susceptible to age-related changes than lower extremity muscles.

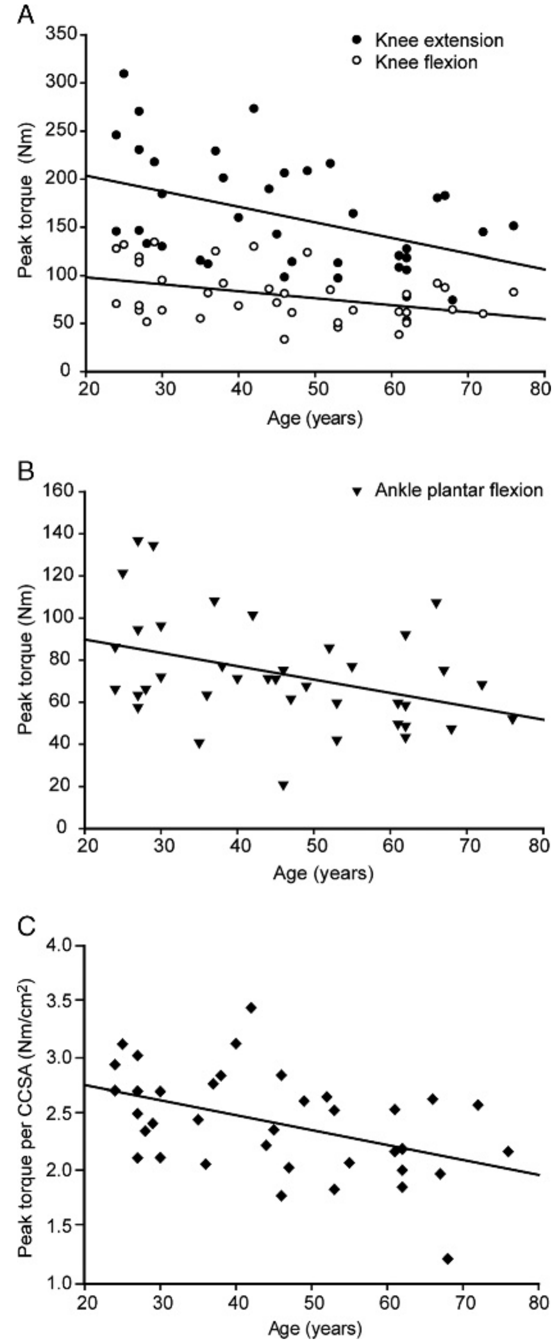

FIGURE 4—Correlation between age and muscle strength. A and B, Correlation between age and muscle strength in knee extension and flexion (A; $R_{\text{ext.}} = -0.44$, $R_{\text{flex.}} = -0.46$, $P < 0.05$) and ankle plantarflexion (B; $R = -0.39$, $P < 0.05$). C, Correlation between age and knee extension strength per CCSA ($R = -0.46$, $P < 0.05$).

We also found that men had significantly lower fat fractions in lumbar paraspinal muscles and that BMI was positively associated with thigh, but not paraspinal, fat fraction.

Most studies that have investigated age-related changes in muscle fatty replacement in healthy adults have focused on limb muscles and reported that age affects the fatty replacement (10,26). The paraspinal muscles are important postural muscles that help stabilize the spine and are important in daily

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function and mobility. The properties of the paraspinal muscles are as important as thigh muscles for daily tasks like walking, keeping balance, and rising from a chair (16). Increased paraspinal fat fraction is associated with muscle weakness (11), poorer function (16), and limitations of movement (14). Studies that have investigated the age effect on the paraspinal muscles in healthy adults have shown inconsistent results. One study reported that age does not affect the fatty replacement of the cervical paraspinal muscles (7), another study reported that age affects the fatty replacement on the right lumbar side only (30), and other studies reported that age affects all lumbar paraspinal muscles (2,9). Fortin et al. (9) investigated the lumbar paraspinal muscles in a longitudinal study of 99 healthy twin males. Using T2-weighted MRI images, they found an increase of 29%–65% in the lumbar fat content for a 15-yr follow-up period. In our study, we used the Dixon MRI technique, which is superior to other ways of quantifying muscle fat fraction (22). We assessed the fat fraction of the paraspinal muscle using three slices corresponding to the three different parts of the spine (Fig. 1), which has not been done before. The actual fat percentage values that we found were similar to those reported by Crawford et al. (2) who used the same Dixon MRI technique. This supports that the Dixon MRI technique is superior to many other MRI techniques yielding reproducible results. We found greater fat fractions in the lumbar and cervical spine compared with the thoracic spine, which might relate to the higher prevalence of spinal pathology and degeneration at these two levels. There is also greater movement and more stress in the cervical and lumbar spine compared with the thoracic spine (8). At all three paraspinal levels, as well as in the leg muscles, there was a clear increase in fat fraction with aging. The age-related increase in fatty replacement was significantly higher in the paraspinal muscles than the leg muscles.

In addition to aging, possible causes for the increases in muscle fat fraction include body weight (9) and metabolic syndrome (13). In our study, we found no association between body weight or BMI and paraspinal muscle fat fraction. This is in accordance with other reports (2,3,16). The fat fractions in thigh muscles, however, correlated with BMI. Evidence have also suggested that changing the way a muscle is used, rather than aging itself, may play an important role in the level of fat replacement of muscle. Reduced activity for 4 wk in young adults resulted in increases of fat content in lower extremity muscles by 15%–20% (23). Furthermore, increases in physical activity prevented the increase in fat content (12), and a resistance training program decreased fat content in the thigh muscles of elderly (24). These results indicate that a change in the level of physical loading of a muscle affects its gross morphology. By contrast, the association between the level of physical activity in the daily life and the paraspinal fat replacement is negligible or nonexisting (8). Familial aggregation; that is, genes and early environment, has been reported to be the strongest predictor of paraspinal fat replacement and CSA (10). Our findings, of a disassociation between physical activity and fat replacement, support these reports.

The muscle mass decrease seen with aging causes muscle weakness. In the present study, we found that knee extension, knee flexion, and ankle plantarflexion strength decreased with age (Fig. 4A and B). Our back strength results were essentially useless for correlative calculations because of the ceiling-off effect. The static back extension endurance test did not correlate with age or fat fraction. Therefore, future studies on how the age-related changes in the paraspinal muscles affect the function are needed.

As stated in the introduction, the observed decline in muscle strength with aging often exceeds the loss of muscle mass, suggesting that muscle quality, in addition to the quantity, may be responsible for the weakness. Our finding of an age-related decrease in the anterior thigh strength per CCSA (Fig. 4C) supports this notion.

Several studies have investigated changes in paraspinal muscle morphology in patients with lower back pain. The results are inconsistent; however, the current evidence supports a relationship between fat content of paraspinal muscles and lower back pain (4,5,13). A study on 854 adults and adolescents from the general Danish population found an association between lower back pain and paraspinal muscle fat content in the adults, but not in the adolescents. They suggested that pain initiates the muscle changes, and because the prevalence of lower back pain increases with age, the fat content also increases with age (18). We did not find a correlation between the paraspinal fat infiltration and lower back pain intensity. However, our study sample only included subjects who were self-reportedly healthy with only six subjects having lower back pain level higher than 4 on a scale of 1 to 10, a prevalence of lower back pain that represents the Danish background population (19).

CONCLUSION

The paraspinal muscles help stabilize the spine and are important for daily function and mobility. Well-functioning paraspinal muscles may be as important as thigh muscles for daily tasks like walking, keeping balance, and rising from a chair. Our findings show that the paraspinal muscles have a significantly higher age-related increase in fat fraction compared with lower extremity muscles. The age-related increase in paraspinal fat fraction did not correlate with BMI or physical activity, suggesting that it might be an age-related phenomenon that may be difficult to modify with interventions. However, studies have shown that changes in the level of physical loading of a muscle affect the fat fraction, suggesting that training interventions, nevertheless, could affect the muscle morphology. The paraspinal muscles should therefore be considered in the management of decreased mobility in elderly people.

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