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ORIGINAL ARTICLE

Change in fatty infiltration of lumbar multifidus, erector spinae, and psoas muscles in asymptomatic adults of Asian or Caucasian ethnicities

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Abstract

Purpose Fatty infiltration (FI) is a feature of degenerating muscle that predominates in the low lumbar spine, associates with pain, and is confounded by age, spinal degeneration, and curvature. We determined rates for decline of lumbar muscle quality according to ethnicity, muscle, and spinal level in asymptomatic subjects.

Methods Cross-sectional simulation study assessing aggregated data; 650 Asians aged 20–89 years versus 80 Caucasians aged 20–62 years. Change in lumbar multifidus, erector spinae (ES), and psoas fat content were computed using synthetic data and Monte Carlo simulations. General linear regression models and multivariate adaptive regression splines enabled estimation of yearly decline rates [with 95% confidence intervals (CI)].

Results ES at L1–5 (total) shows steeply reduced density (rate; CI) for Asians in older (>53.3 years) adulthood (−0.32; −0.27 to −0.36/year). For Asians, multifidus (−0.18; −0.15 to −0.20/year) and psoas (−0.04; −0.03 to −0.06/year) also decline, while ES in younger ≤53.3 years) adults does not (0.06; 0.01–0.12/year). Caucasian multifidus declines (increasing FI % rate; CI) insignificantly faster (L1–5; 0.23; 0.10–0.36%/year) than ES (0.13; 0.04–0.22%/year). Multifidus decline does not differ between ethnicities. ES in older Asians generally declines fastest across ethnicities and muscles, and particularly in the low lumbar levels. Low lumbar levels show higher rates of decline in Asians, with mixed level-dependencies apparent in Caucasians.

Conclusions Decline in lumbar muscle composition may differ between ethnicities and muscles. ES and low lumbar levels appear increasingly susceptible in Asians. Longitudinal studies examining rate of change to muscle composition may provide distinction between spinal conditions.

Keywords Lumbar spine · Multifidus · Erector spinae · Psoas · Rate of change · Fatty infiltration

Abbreviations

APCT	Abdomen and pelvis computer tomography
CI	95% confidence intervals
ES	Erector spinae
FI	Fatty infiltration
LBP	Low back pain
MRI	Magnetic resonance imaging

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Background

Fatty infiltration (FI) in skeletal muscle represents declining muscle structure and quality [1, 2] and has been identified in lumbar paravertebral muscles of people with [3–7] and without [8–11] low back pain (LBP). The etiology of FI in muscles of the axial skeleton remains poorly understood despite an apparent increased interest

in its clinical significance in relation to neck and LBP disorders [8, 12–15]. Complicating our understanding in the lumbar spine is its association with age [7–9, 11, 16], spinal curvature [6, 17, 18], lumbar level [3, 6, 17], posture [19], and other degenerative phenotypes or pathologies including facet joint osteoarthritis [5, 20], spondylolisthesis [5], disc narrowing [5, 21], type 2 Modic change [21], disc herniation [22], and degenerative lumbar kyphosis [17]. The relevance of paravertebral muscle FI to spinal pain conditions therefore continues to puzzle investigators, compounded by surprisingly few studies describing normative muscle decline in asymptomatic people that have not been selected on the basis of control-matching to patients with lumbar spine disorders [8, 9, 11].

Yearly rate of decline is a newly proposed parameter [13] to describe temporal change of adult lumbar muscle composition occurring concurrent with spinal column features. Based on Monte Carlo simulations of published age-aggregated data [8, 9, 23], different decline rates were reported for various spinal features typifying degeneration of the lumbar spine [13]. These results indicate that muscle composition declines (characterized by increasing FI) at similar rates to the development of age-related disc protrusion, annular fissures, and spondylolisthesis, yet slower than the loss of disc signal in particular. It is plausible that the different rates coincide with the expected degenerative cascade originally proposed by Kirkaldy-Willis et al. [24] and further supported by Haig [10].

While a trend for different rates of increasing fatty infiltration (FI) with age between multifidus, erector spinae (ES), and psoas was shown, conclusions were drawn on the basis of the only two studies reporting age-aggregated data in asymptomatic people that used similar MRI-based quantification methods [8, 9]. However, these studies had a combined sample of just over one hundred cases, and no representation into older adulthood (e.g., samples aged <63 years). Apparently simultaneously, a Korean study reported FI in lumbar paraspinal muscles of asymptomatic people using computed tomography (CT) and based on an impressive sample of 650 cases [11]. In common with the Crawford et al. [8] study examining a Caucasian sample and used in the previous simulation study [13], Lee et al. [11] provide age-aggregated normative values for muscle density in lumbar muscles according to spinal level. Therefore, to better understand the effect of age on change to FI within the lumbar paravertebral muscles, and to inform the generalizability of studies describing lumbar muscle fat content using different modalities (CT and MRI), we aimed to examine whether FI in lumbar muscles showed differential rates of decline according to muscle, spinal level, age group, and/or between Caucasian and Asian ethnicities.

Methods

We employed Monte Carlo simulations using established methods [13] to derive a relative yearly rate of change in muscle fat content based on absolute published age-group-specific FI data for lumbar paravertebral muscles, which was undertaken separately for the studies of Crawford et al. [8] and Lee et al. [11]; in summary, the data from the two studies were not pooled but relatively compared. Crawford et al. [8] presented mean fat signal fraction (%) and standard deviation values for multifidus and ES (bilateral average) for both genders separately according to ages 20–29, 30–39, 40–49, and 50–62 (women: 39.0 ± 11.6, 21–62 years; men: 40.0 ± 11.2, 20–61 years) using ten asymptomatic Swiss subjects per gender per decade ($n = 80$); their method involved semi-automated segmentation of two-point Dixon-sequenced magnetic resonance imaging (MRI) based on full volume analysis (multi-slice) of each lumbar level spanning the superior vertebral end-plates of two adjacent vertebra (L1–S1). Lee et al. [11] present mean values for muscle density of multifidus, ES, and psoas (bilateral average) in Asians of both sexes combined according to young (20–39; mean 32.7 ± 5.3 years), middle (40–59; mean 53.3 ± 5.2 years), and old (60–90; mean 77.8 ± 8.1 years) age groups ($n = 650$). Personal communication [25] with the corresponding author identified sample sizes for each age group (young = 191, middle = 210, old = 249). Their method employed cross-sectional CT scans of the abdomen and pelvis (APCT) at the five lumbar disc levels (single 3 mm slice) between L1 and S1 to determine mean muscle density (in Hounsfield units). While different, these methods are the two most commonly used to quantify spinal muscle composition [26], with that of MRI perhaps being contemporarily favoured on the basis of improved soft-tissue contrast, lack of ionizing radiation exposure, and automation methods.

In order to accommodate different methods of the source studies, we applied simulations separately to determine absolute rates of change for each muscle according to lumbar level per ethnic dataset. Both source published values provided bilateral averages for each muscle and level; the Crawford et al. [8] data for different sexes were combined like that of Lee et al. [11]. In brief, simulation involved deriving 10,000 samples of age-specific normal random variates with sample size, mean, and standard deviations drawn equivalent to the original studies. General linear regression models (Gaussian) were then used to estimate marginal effects of age with corresponding CIs.

Likelihood ratio test was used to make comparison between saturated models using original age-group variables, with models employing a linear age predictor derived from the mid-points of each study's age groups. Formative

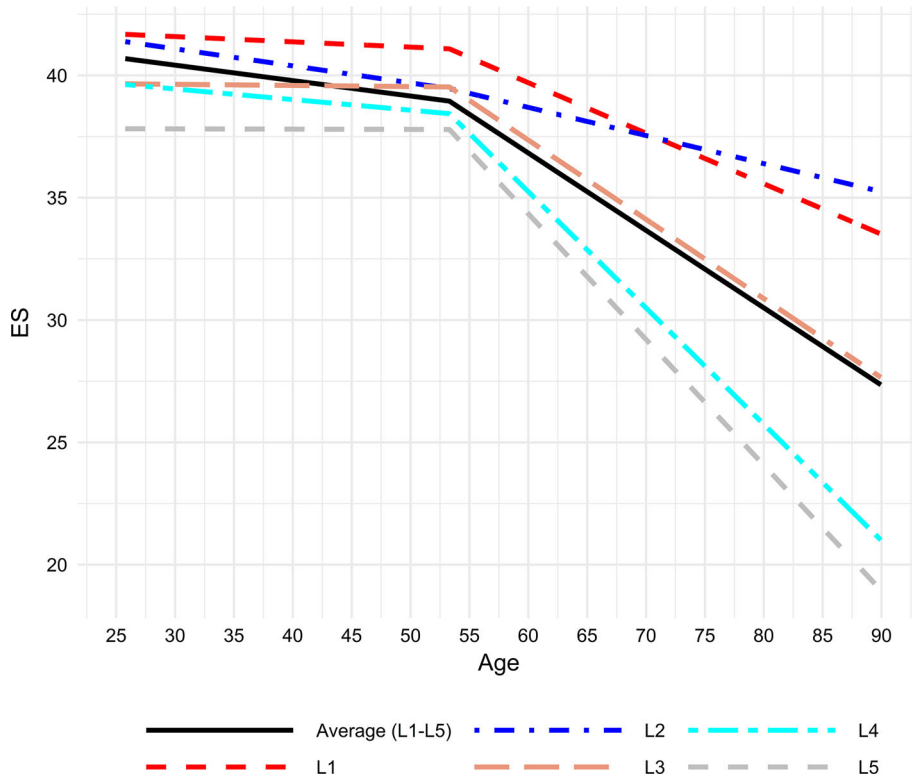

Fig. 1 Asian erector spinae density (based on Lee et al. [11]) according to age and lumbar level indicating different decline rates in younger (≤53.3 years) and older (>53.3 years) subjects

tests showed violated linearity assumption in Korean ES data only. Hence, we employed multivariate adaptive regression splines (MARS) to the Korean ES data and reported age-group-specific decline rates for younger (≤53.3 years) and older (>53.3 years) subjects separately. Essentially, MARS breaks the predictor into two (or more) groups and models linear relationships between the predictor and outcome in each group. In effect, it creates piecewise linear modelling of isolated portions of the original data; visually, the cut-points (at 53.3 years) for a predictor appear as a "hinge" or "hockey stick" (Fig. 1). We report marginal effects of a one-year change (and CIs) in age for reducing muscle density [11] or increasing FI [8] in MF, ES, and psoas (Asians only) muscles; marginal effects per year were used to depict a relative rate of decline for each muscle and according to separate lumbar levels.

Statistical analyses, including simulations, were carried out in Stata 14.1 (StataCorp, College Station, TX, USA) and R (The R Foundation for Statistical Computing, Vienna, Austria), where figures were also constructed. Package earth 4.4.7 was used for the estimation of MARS [27].

Results

Yearly rates of change in muscle fat content determined for the Asian (from Lee et al. [11]) and Caucasian (from Crawford et al. [8]) cohorts are presented in Table 1. Density (rate; CI) for ES (average L1–5) showed the highest yearly rate of decline in older Asians (−0.316; −0.364 to −0.269/year), yet ES muscle density slightly increased in the younger Asian group (0.063; 0.005–0.121/year) (Figs. 1, 2). In Asians, multifidus (−0.175; −0.201 to −0.148/year) and psoas (−0.042; −0.057 to −0.027/year) also demonstrated a declining density per year, with ES in older Asians declining faster than other muscles at L4 and L5, and multifidus declining faster than psoas and ES in younger Asians (Fig. 2). Multifidus decline (characterized by increased FI % rate; CI) for L1–5 in Caucasians (0.228; 0.099–0.358/year) was shown to be higher but not statistically different to ES (0.126; 0.035–0.216/year), and showed wider variability at L4 and 5 (Fig. 3). Yearly rate of change according to ethnicity and muscle group (Fig. 4) demonstrated level-dependent differences where ES in older Asians declined faster than: all other muscles at L4 and L5; all but multifidus in Asians at L3; and, all but multifidus in Caucasians at L1 (Fig. 4). Multifidus rate of change did not differ between ethnicities; however, it showed faster decline at L5 than ES in young Asians, and in Psoas (only Asians) (Fig. 4). Psoas (only Asians) demonstrated less variable rates of decline at all lumbar levels, and a lower decline rate than multifidus in both ethnicities, and ES in younger Asians and Caucasians (Fig. 4). Level-dependence of rate of change appeared less obvious in Caucasians for multifidus and ES than in older Asians (Fig. 4).

Table 1 Yearly rate of change coefficients (with 95% CIs) for lumbar paravertebral muscles determined from simulations based on muscle density in Asians reported by Lee et al. [11], and percent fatty infiltration for Caucasians reported by Crawford et al. [8] according to average (L1–5) and each lumbar level

Lumbar	Crawford et al. [8] (20–62 years)			Lee et al. [11] (20–90 years)[a]		
	Coef	95% CI		Coef	95% CI	
		Lb	Ub		Lb	Ub
Level						
	Multifidus					
L1–5	0.228	0.099	0.358	0.175	0.148	0.202
L1	0.217	0.095	0.340	0.094	0.041	0.148
L2	0.222	0.112	0.332	0.098	0.041	0.155
L3	0.218	0.091	0.344	0.170	0.103	0.236
L4	0.220	0.068	0.371	0.222	0.166	0.279
L5	0.256	0.093	0.419	0.291	0.222	0.360
	Psoas					
L1–5				0.043	0.027	0.058
L1				0.041	0.006	0.076
L2				0.041	0.006	0.076
L3				0.039	0.005	0.074
L4				0.049	0.013	0.085
L5				0.043	0.013	0.074

Lumbar	Crawford et al. [8] (20–62 years)			Lee et al. [11] (≤53.3 years)			Lee et al. [11] (>53.3 years)[a]		
	Coef	95% CI		Coef	95% CI		Coef	95% CI	
		Lb	Ub		Lb	Ub		Lb	Ub
Level	Erector spinae								
L1–5	0.126	0.035	0.216	−0.063	−0.121	−0.005	0.316	0.269	0.364
L1	0.072	0.011	0.134	−0.022	−0.123	0.080	0.207	0.092	0.321
L2	0.104	0.034	0.173	−0.070	−0.242	0.103	0.115	−0.068	0.298
L3	0.129	0.047	0.212	−0.005	−0.053	0.044	0.324	0.224	0.424
L4	0.172	0.020	0.325	0.043	−0.165	0.079	0.476	0.386	0.565
L5	0.198	−0.010	0.406	0.001	−0.030	0.028	0.514	0.441	0.587

Lb lower bound, *Ub* upper bound

[a] All values multiplied by −1 to allow comparison between studies, i.e. muscle density decrease interpreted as FI increase

Discussion

We used Monte Carlo simulations based on published age-aggregated data to determine representative rates of change to paravertebral muscle composition in asymptomatic adults of two ethnicities and according to lumbar level. Rate of declining muscle composition appears to differ between Asians and Caucasians, the muscles studied, and according to age, wherein ES at the low lumbar spine in older Asians appears particularly susceptible to a year-on-year reduction in muscle density. A mounting literature attests to the influence of various spinal phenotypes on paravertebral muscle fat content [5, 17, 19, 21, 28], with the present study being one of the first to indicate that ethnicity may also play a role. As such, and in order to better appreciate the generalisability of muscle FI results attained globally, multi-centre studies examining changes to lumbar (if not paraspinal) muscle composition [1] in asymptomatic spines across various ethnic groups and using standardized methods appear warranted. This is not only applicable to studies examining muscle tissues, but also those informing our understanding of normative patterns for degenerative change in the spinal column at large [13, 23].

Our observation indicating a steeper rate of decline for erector spinae in older Asians appears to centre on the age range of participants in the Lee et al. [11] study, where a marked decline from age 53 (as the age-group mid-point) was shown (Fig. 1). Our results for ES based on the Crawford et al. [8] study (20–62 years) revealed greater decline in similarly aged Caucasians than for the younger Asians; however, differences were only significant for the upper lumbar levels, largely due to wider variability shown in the Caucasian decline rates at the lowest lumbar levels.

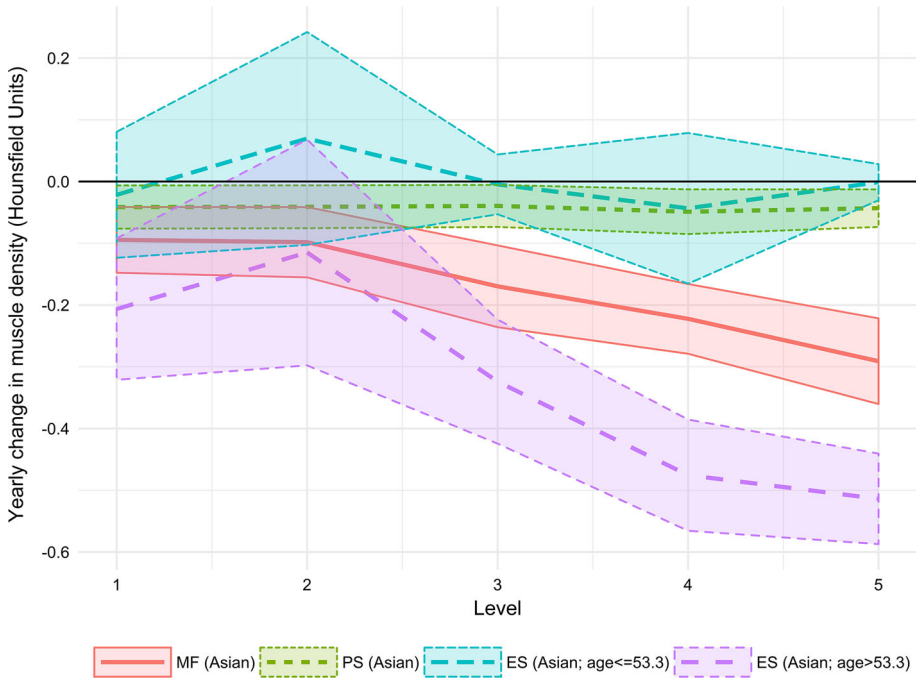

Fig. 2 Yearly rate of change (and 95% CIs) of lumbar paravertebral muscle density determined for Asians based on Lee et al. [11] according to lumbar level

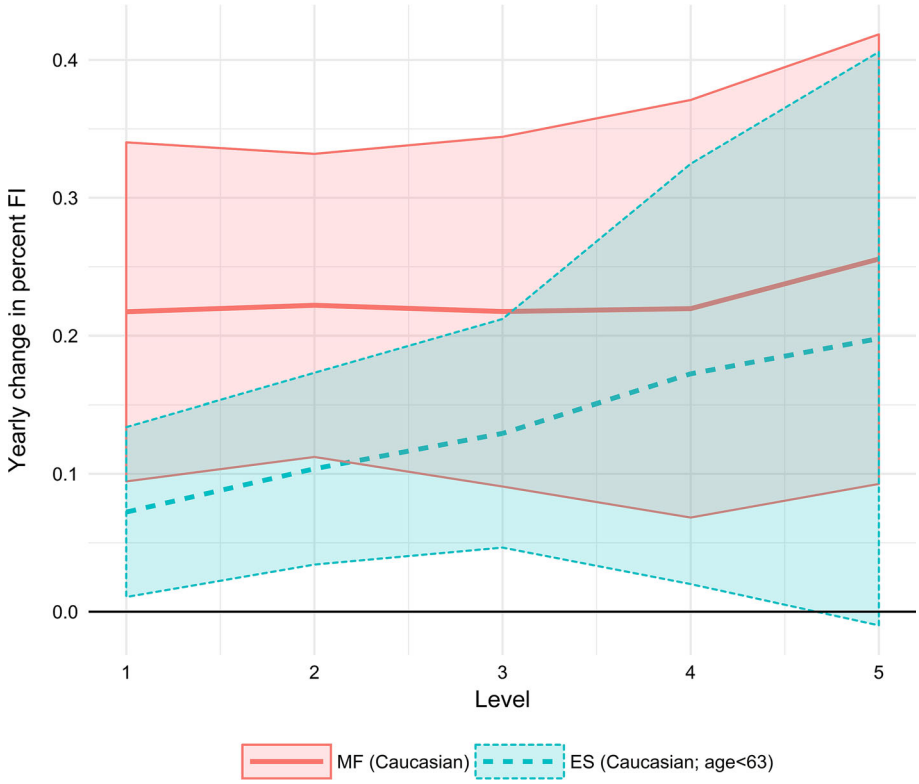

Fig. 3 Yearly change (and 95% CIs) to lumbar paravertebral muscles determined for Caucasians based on percent muscle fatty infiltration reported by Crawford et al. [8] according to lumbar level

This observation may relate to several cases in the smaller Crawford et al. [8] sample being 53 years or older, and could be a reflection of the methodological differences between the two source studies. However, it appears more likely that ES is subject to a changing rate of decline into older age, which should be examined further in Caucasians and other ethnicities. In their prospective study examining a Danish cohort using T1-weighted MRI, Hebert et al. [16] reported 28.8, 28.7, and 31.6% multifidus fat content at ages 40, 45, and 49 years of age, respectively; this suggests a non-linear decline in the forties that accelerates in the latter half of the decade. Furthermore, using Dixon MRI,

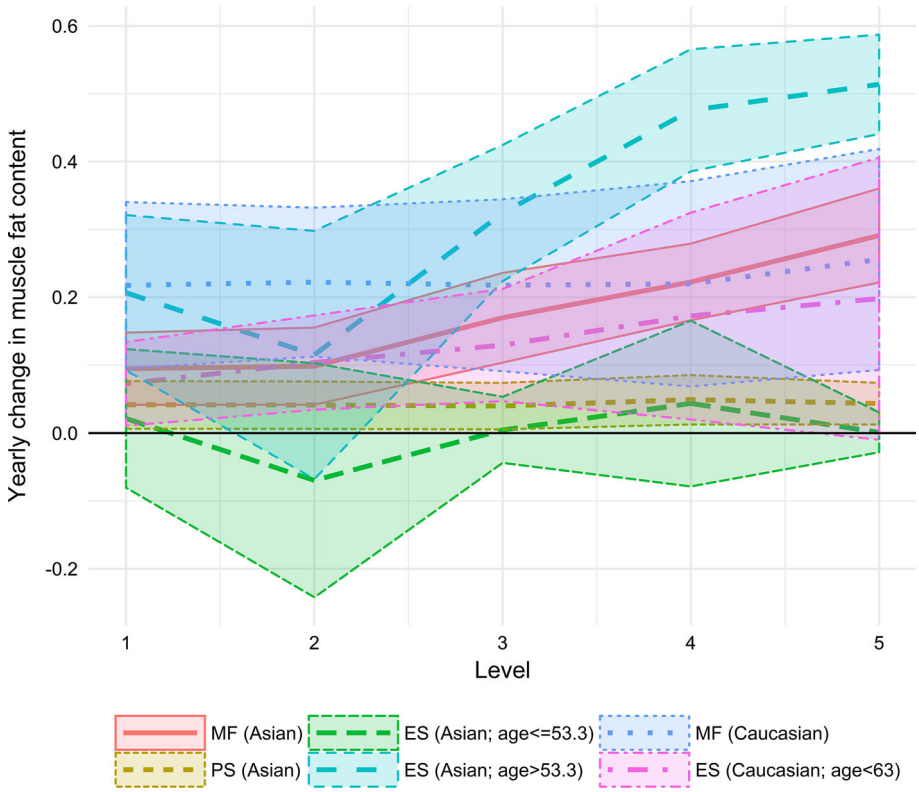

Fig. 4 Yearly change (and 95% CIs) of lumbar paravertebral muscles fat content for Asians [11] and Caucasians [8] according to lumbar level. Change for each ethnicity (per study) were determined separately and are presented together, with results from Lee et al. [11] inverted to reflect increasing proportion of fatty content

Dahlqvist et al. [29] show significantly fattier paravertebral muscles for healthy Danish cases aged 46 or more, than those younger, and particularly in the lumbar and cervical spines compared to thoracic. While the latter investigators segmented multifidus and ES together, age-associated decline in muscle composition agrees with other studies examining lumbar paravertebral muscles [8, 9, 30]. Of question for the clinical meaningfulness of this age-dependent observation is at what age this steeper decline is triggered, and therefore potentially preventable with early intervention? Crawford et al. [8] report significant decline (increasing fat content) in asymptomatic men in their thirties and women in their fifties, each compared to the twenties, while Dahlqvist et al. [29] show a linear decline from the twenties, both pointing to relatively early observable degeneration in and throughout adulthood.

In their somewhat unique study, Chang et al. [31] describe lumbar paravertebral muscle density in six NASA astronauts and show a reduction to 83% of pre-flight baseline when imaged within 2 days after their 6 month mission. Remarkably, muscle density improved to 94% after a period of terrestrial recovery (mean 46 days). These apparently dramatic changes with weightlessness secondary to microgravity exposure and then reloading for on-land activities, point to the capacity for healthy lumbar paravertebral muscles to be modified with (un)loading and/or (in)activity. Whether targeted interventions can modify the distribution of fat content in lumbar paravertebral muscles of patients with low back pain requires investigation in longitudinal studies, and particularly to establish optimal time periods to expect measureable and meaningful change.

In agreement with Crawford et al. [13], our results indicate that psoas undergoes significantly slower decline (~0.04%/year) than multifidus (>0.18%/year) and erector spinae (>0.13%/year; value excludes younger Asians where decline was not shown). While specific values are not reported for psoas, Fig. 2 in the Dahlqvist et al. [29] study shows lower fat content in psoas than for the lumbar paravertebral muscles, which confirms the findings of earlier studies suggesting less propensity for FI in the primary hip flexor than muscles of the spine [9, 11]. Fortin et al. [30] report reduced muscle density in lumbar paravertebral muscles in male twins aged over 40 years after a 15 years follow-up that, assuming linear decline, indicate lower yearly rates of decline for multifidus (0.21% at L3/4 and L5/S1) than ES (0.30% at L3/4 and 0.40% at L5/S1). Their sample was partly LBP-symptomatic, which may account for the slightly higher rates described by the present and Crawford et al. [8] studies. Furthermore, differences in fat content noted between lumbar paravertebral muscles across several studies [8, 9, 11, 13, 29, 30, 32] suggest a non-uniform decline between muscles that may be important in understanding the etiology of muscle FI and any implications for targeted (and likely level- and/or muscle-differential) management strategies. Differential

patterns of FI distribution may have biomechanical consequences whereby subtle, and more obvious, differences in motor function [33–37] may be partially explained by the overall muscle composition.

While it is generally agreed that higher fat content occurs in the lower compared to upper lumbar levels [6, 8, 11, 30], our results indicate a mixed pattern between muscles in terms of yearly change (Fig. 4). Older Asians show a propensity for faster decline in ES at L4 and L5 that is not observed in younger Asians, and a mounting decline in multifidus caudally across all ages, with significance between L4 and 5 compared to L1 and 2. In contrast, Caucasians show no appreciable level-dependence for multifidus, and an increasing caudal rate for ES that is not significant; further, wider variability in rate of change at the lowest two lumbar levels in Caucasians warrants further exploration across larger samples. Level differences between ethnicities may be a function of the differences in sample size between studies, but could be related to ethnic-differential spinal curvature that results in 'different' loading/function/muscle activity at each level (e.g., sway back versus lordotic). The clinical meaning of this observation may require elaboration in future studies, particularly for informing rehabilitative interventions targeting the low lumbar levels as the common source of, or contributor to, pain, disability, and dysfunction.

Our study has limitations that should inform interpretation. The cross-sectional nature of both source studies [8, 11] limits the generalizability of our results wherein secular changes are not accounted for. Similarly, we welcome further investigations that examine other ethnicities and older Caucasian cohorts to provide an improved representation of the global populations affected by back pain [38] and potentially normatively reducing spinal muscle composition. Importantly, in endeavouring to isolate the age at which lumbar spinal muscle tissues first show signs of degeneration, we consider adolescent populations to be underrepresented in the literature and requiring urgent investigation to better understand muscle quality baselines. With non-ionizing imaging methods like MRI being popular and available, we foresee fewer barriers toward the ethics of recruiting children or youth for research imaging studies. Alternatively, existing abdominal imaging (particularly APCT) datasets that include the lumbar spine may be explored across ethnicities for this purpose. The variability of findings may be explained through source datasets that are purportedly 'asymptomatic' and wherein healthy subject selection criteria and definitions differ. While our methods are statistically robust, comparing studies using different imaging modalities [17, 39, 40], regions of interest [26], and quality descriptors (density and fat %) to determine muscle fat content is an approach that would benefit from clarification with longitudinal studies examining its utility. Furthermore, we strongly encourage a global approach to standardizing the quantification of lumbar muscle fat content [24] in order to homogenise the reporting of this seemingly important variable in spinal health.

Conclusions

Rate of change to lumbar muscle fat content may differ between ethnicities. ES declines faster in older than younger Asian adults and should be examined within a similarly aged group of Caucasians and other ethnicities. Declining muscle composition occurs slowest in psoas and is similar between MF and ES. The faster decline seen at L4 and L5 in older Asians compared to the upper lumbar levels appears to accelerate with age and suggests an increasing susceptibility to fatty infiltration in the lowest levels. Rate of decline of muscle tissues and other spinal features is a promising parameter that may provide distinction between people with and without spinal disorders, with applicability to longitudinal studies examining effect of interventions.

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Compliance with ethical standards

Conflict of interest Authors RC and TV declare they have no conflicts of interest. Author JE is in receipt of an NIH research Grant (2014-19) for a cervical spine investigation, and provides consultation outside the submitted work as part-owner/investor in a medical consulting startup.

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