Skeletal Radiol (2016) 45:1221–1226
DOI 10.1007/s00256-016-2405-8

SCIENTIFIC ARTICLE

Assessment of trunk muscle density using CT and its association with degenerative disc and facet joint disease of the lumbar spine

Ronnie Sebro[1] · **Liam O'Brien**[2,3] · **Martin Torriani**[4] · **Miriam A. Bredella**[4]

Received: 2 February 2016 / Revised: 24 April 2016 / Accepted: 2 May 2016 / Published online: 14 May 2016

Abstract
Objective The purpose of this study was (1) to evaluate the association of trunk muscle density assessed by computed tomography (CT) with age, gender, and BMI and (2) to evaluate the association between trunk muscle CT density and degenerative disc and facet joint disease of the lumbar spine.
Material and methods The study was IRB approved and HIPAA compliant. The study group comprised 100 subjects (mean age 44.4 ± 22.2 years, 51 % male) who underwent CT of the abdomen and pelvis without intravenous contrast. Exclusion criteria included prior abdominal or spine surgery, active malignancy and scoliosis. CTs were reviewed and the attenuation of the rectus abdominis, transverse abdominis, internal and external obliques, psoas, multifidus, longissimus and gluteus maximus were measured bilaterally at consistent levels. Degenerative disc and bilateral facet joint disease were scored using established methods. Univariate analyses were performed using linear regression. Multivariate linear regression was performed to adjust for age, gender and BMI.
Results CT density of each trunk muscle correlated inversely with age ($p < 0.001$) and BMI ($p < 0.001$). CT density of each trunk muscle correlated inversely with degenerative disc and facet joint disease in the univariate analyses ($p < 0.001$); however, only the gluteus maximus and the transverse abdominis remained significant predictors of degenerative disc and facet joint disease respectively in the multivariate analysis.
Conclusion Fatty infiltration of trunk musculature increases with age and BMI. Fatty infiltration of the gluteus maximus and transverse abdominis are associated with degenerative disc and facet joint disease, independent of age, gender and BMI.

Keywords Rectus abdominis · Transverse abdominis · Internal oblique · External oblique · Psoas · Multifidus · Longissimus · Gluteus maximus · CT · Trunk muscle · Atrophy · Degenerative disc disease · Facet joint disease

Introduction

Approximately 15–20 % of the adult population experience low back pain (LBP) annually and 50–80 % of the population will experience LBP at some time in their lives [1, 2]. Degenerative disc and facet joint disease have been thought to contribute to the etiology of LBP [3–5]. The trunk muscles are important stabilizers of the lumbar spine and trunk muscle atrophy may play a role in the development of degenerative disc and facet joint disease [6–8]. Muscle density on unenhanced computed tomography (CT) has been shown to be a good indicator of fatty infiltration [9], and is related to muscle strength and function [10, 11].

A prior study showed an association between the CT density of the multifidus muscle and spondylolisthesis of L4 on L5, and between the CT density of the erector spinae muscle and disc space narrowing at L4–L5 [12]. Another study demonstrated that posterior paraspinal muscle atrophy (estimated

✉ Miriam A. Bredella
mbredella@mgh.harvard.edu

[1] Musculoskeletal Section, Department of Radiology, University of Pennsylvania, 3737 Market Street, No. 6175, Philadelphia, PA 19104, USA

[2] Department of Mathematics and Statistics, Colby College, Waterville, ME 04901, USA

[3] School of Community and Population Health, University of New England, Portland, ME 04103, USA

[4] Musculoskeletal Imaging and Intervention, Department of Radiology, Massachusetts General Hospital and Harvard Medical School, Yawkey 6E, 55 Fruit Street, Boston, MA 02114, USA

by CT density) was correlated with facet joint osteoarthritis [13]. These prior studies have focused solely on the posterior paraspinal trunk musculature, and did not exclude subjects with conditions which would affect the CT density of the interrogated muscles such as scoliosis, prior surgery or history of active malignancy.

We hypothesized that individuals with lower CT density (lower Hounsfield units) and therefore more fatty infiltration of the trunk muscles would have more severe degenerative disc and facet joint disease of the lumbar spine. We therefore investigated the association between trunk muscle density assessed by CT and degenerative disc and facet joint disease of the lumbar spine.

Materials and methods

The study was approved by our Institutional Review Board (IRB) and was HIPAA compliant.

Subjects

We studied consecutive patients who underwent unenhanced CT of the abdomen and pelvis at our institution over a 3-month period from October 1, 2013 through December 31, 2013. Inclusion criteria were age ≥18 years and unenhanced CT of the abdomen and pelvis of diagnostic quality. Exclusion criteria were scoliosis (Cobb angle > 10° at any level) [14], pars interarticularis defects, lumbosacral transitional anatomy, anasarca, history of chronic steroids/immune modulator therapy, history of active malignancy (malignancy currently being treated with chemotherapy or radiation therapy within one year), or any prior spinal, abdominal or pelvic surgery. Histories were verified by searching a text database of all medical records available and by interpretation of the CT study. Data on each subject's age, gender, weight, height, and body mass index (BMI) were recorded.

Computed tomography

All CT studies were performed on a General Electric Discovery CT750HD CT machine using an axial slice thickness of 2.5 mm, variable mA and kVp of 120. Coronal and sagittal reformations were obtained at 3-mm slice thickness. Scoliosis was assessed on the coronal images of the CT scan, measuring the maximum Cobb angle. We included subjects with only 5 non-rib bearing lumbar type vertebral bodies (subjects without lumbosacral transitional anatomy). Subjects with lumbosacral transitional anatomy (Castellvi I, II, III or IV) were excluded [15].

Degenerative disc disease score

At each intervertebral disc level in the lumbar spine (L1–L2, L2–L3, L3–L4, L4–L5 and L5–S1), the degree of degenerative disc disease was scored using the system published by Mimura et al. [16] (Table 1). The total number (range 0–16) of osteophytes at the anterior, posterior, right and left aspect of both vertebral endplates at each disc space was assessed. The number of vertebral body sclerotic edges (range 0–2) at each intervertebral disc level was determined. The degree of intervertebral disc height loss at each level was recorded by comparing the intervertebral disc to the level immediately above and to the level immediately below [16]. These measurements were scored on an ordinal scale ranging from 0–4 with scores as follows: 0 (0 %), 1 (1–25 %), 2 (25–50 %), 3 (50–75 %) and 4 (greater than 75 %). Each disc in the lumbar spine was then graded on an ordinal scale from 0 to 4 based on the scoring system proposed by Mimura et al. [16].

Degenerative facet joint disease score

Degenerative facet joint disease of bilateral L3–L4, L4–L5 and L5–S1 facet joints was individually scored using the system published by Pathria et al. [17] (Table 2). The facet joints were graded on an ordinal scale ranging from 0–4 with 4 being the most severe (Fig. 1).

CT density of trunk muscles

For each subject, CT density of trunk muscles—in mean Hounsfield Units (HU)—was measured at the L3–L4 and L4–L5 levels. Measurements of the following muscles were assessed using the method described by Kamaz et al. [18] and Kalichman et al. [13]—external oblique, internal oblique, transverse abdominis, psoas major, multifidus, and longissimus as well as the rectus abdominis and gluteus maximus. Measurements of the CT densities of the left and right rectus abdominis were obtained at two levels. The first measurement was at the level immediately above the umbilicus and second measurement at the level immediately inferior to the umbilicus, which is usually at the L3–L4 and L4–L5 levels; however, depending on the patient's habitus, a panniculus can alter the level of the rectus abdominis musculature. The largest possible region of interest (ROI) was placed in the muscle belly of each muscle, making sure the ROI was at least 10 mm^2, and that the standard deviation (SD) of the measurement was less than 20 HU (Fig. 2). Tendons and aponeuroses were avoided and the average of the four CT density measurements for each muscle was used in the analyses. The measurement of the CT densities of the gluteus maximus was performed bilaterally at the level of the symphysis pubis and the average of these two CT density measurements was used in the analyses.

Table 1 Scoring of degenerative disc disease according to Mimura et al. [16]

Degenerative disc disease score	Disc height changes (% of adjacent disc)	Osteophytes (No. of osteophytes on 16 edges)	Endplate sclerosis
Normal	0 (100 %)	0 (0 edges)	0 (None)
I (0–1)	1 (>75)	1 (1–4 edges)	1 (one endplate)
II (2–3)	2 (50–75)	2 (5–8 edges)	2 (both endplates)
III (4–6)	3 (25–50)	3 (9–12 edges)	
IV (7–10)	4 (<25)	4 (13–16 edges)	

Statistical analysis

The degenerative facet joint disease scores were summed over all measured levels and sides in the lumbar spine. Similarly, the degenerative disc disease scores were summed over all levels in the lumbar spine. The summed degenerative disc disease score and the summed degenerative facet joint disease score were then used as the outcome variables for the analysis.

All variables were tested for normality of distribution using the Shapiro–Wilks test. Variables that were not normally distributed were log-transformed for use in our analyses. Correlations in CT density between both sides of each muscle group (left versus right), and correlations between muscles were calculated using Pearson's correlation coefficient.

Univariate linear regression models were used to predict the degenerative disc disease score and the degenerative facet joint disease score, respectively. Multivariate linear regression modeling was performed to assess whether trunk muscle CT density predicted the degenerative disc disease score and the degenerative facet joint disease score after controlling for age, gender, and BMI. $p < 0.05$ was used to denote significance. Statistical analysis was performed using R v2.9 software (www.cran.r-project.org).

Results

Our study group comprised 100 patients (49 women, 51 men). Mean age of subjects was 44.4 ± 22.2 years (range 20–89 years), mean BMI was 27.8 ± 7.4 (range 15.4–66.0). CT studies were performed for the following most common indications: suspected renal calculi 64 % ($N = 64$), generalized abdominal pain/nausea/vomiting 7 % ($N = 7$), surveillance imaging for successfully treated malignancy 6 % ($N = 6$), suspected (but negative for) retroperitoneal hematoma 5 % ($N = 5$), and others 18 % (N=18), including suspected hernia, evaluation of adrenal lesions, and suspected abdominal infection. None of the final diagnoses were thought to have affected trunk muscle fat infiltration. Descriptive summary statistics are represented in Table 3.

There was a strong inverse correlation between all of the investigated trunk muscle CT densities and age, with CT density of all muscles decreasing with age. A similar strong inverse association was identified between trunk muscle CT densities and BMI. Males had higher mean CT densities of the rectus abdominis and transverse abdominis than females after adjusting for age and BMI ($p = 0.03$).

Both sides of each measured trunk muscle were highly correlated, with correlations ranging from 0.74 ($p < 0.0001$) between the right and left psoas at L3–L4, to 0.94 between the left and right multifidus at L4–L5 ($p < 0.0001$). The CT densities of the trunk muscles were all statistically significantly positively correlated with each other. Both degenerative disk disease grades and facet degenerative joint disease scores were highly positively correlated ($r = 0.79$, $p < 0.0001$).

Univariate linear regression showed that age was the most significant predictor of degenerative disk disease ($p < 0.0001$) and facet degenerative joint disease ($p < 0.0001$) (Table 4). Males were more likely than females to have more advanced degenerative disk disease grades ($p = 0.001$) and facet degenerative joint disease scores ($p = 0.03$). Higher BMI was also associated with more advanced degenerative disk disease

Table 2 Degenerative facet joint disease scoring according to Pathria et al. [17]

Degenerative facet joint disease score	Changes of the facet joint
0	No changes
1	Joint space narrowing
2	Narrowing plus sclerosis or hypertrophy
3	Severe osteoarthritis with beginning narrowing, sclerosis and osteophytes
4	Advanced osteoarthritis with hypertrophy, narrowing, sclerosis and osteophytes

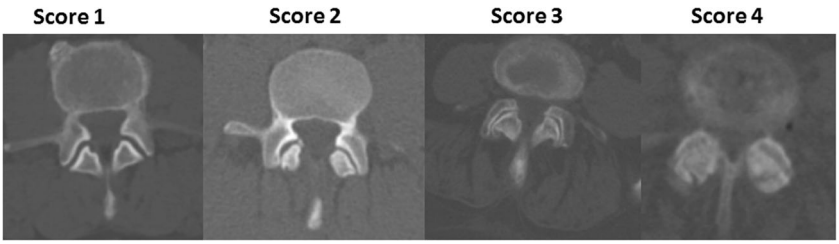

Fig. 1 Degenerative facet joint disease score

grade ($p = 0.0004$) and facet degenerative joint disease scores ($p = 0.0007$). The CT density of each of the trunk muscles showed statistically significant negative correlations with degenerative disk disease grades and facet degenerative joint disease scores.

The CT density of the gluteus maximus remained a significant predictor of degenerative disc disease score after adjusting for age, gender and BMI in the multivariate analysis. The CT densities of the other trunk muscles were not significant predictors of degenerative disc disease scores. Only the CT density of the transverse abdominis remained a significant predictor of the degenerative facet joint disease score after adjusting for age, gender and BMI (Table 5).

In the multivariate analysis, age was the only variable (of age, gender and BMI) that was consistently a statistically significant predictor of facet degenerative joint scores ($p < 0.001$). However, age and gender were statistically significant predictors of degenerative disc disease scores when models contained the CT densities of the rectus abdominis, transverse abdominis, psoas, multifidus, longissimus and gluteus muscles ($p < 0.05$ for all models). Gender was a borderline significant predictor of degenerative disc disease scores when multivariate models contained the CT densities of the internal and external obliques ($p < 0.10$).

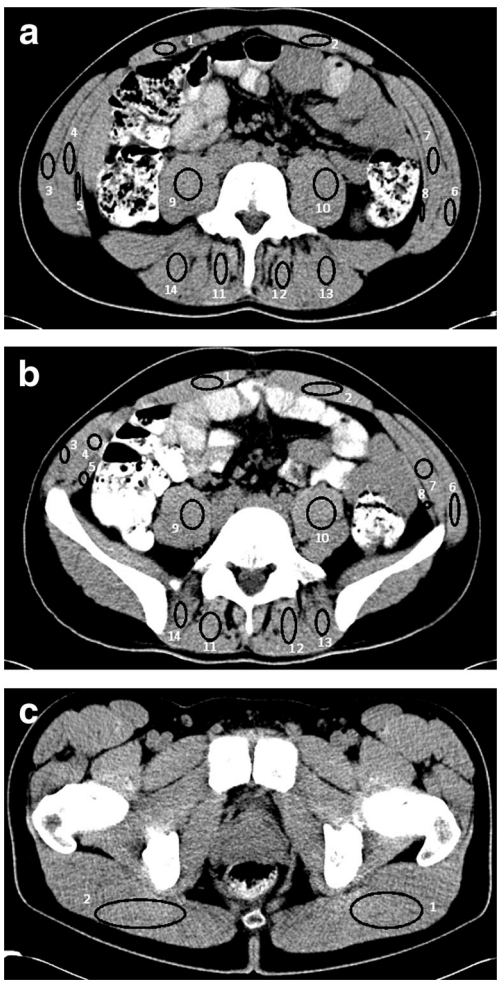

Fig. 2 **a** Measurement of muscle densities above the level of the umbilicus. *1* Right rectus abdominis, *2* Left rectus abdominis, *3* Right external oblique, *4* Right internal oblique, *5* Right transverse abdominis, *6* Left external oblique, *7* Left internal oblique, *8* Left transverse abdominis, *9* Right psoas, *10* Left psoas, *11* Right multifidus, *12* Left multifidus, *13* Left longissimus, *14* Right longissimus. **b** Measurement of muscle densities below the level of the umbilicus. *1* Right rectus abdominis, *2* Left rectus abdominis, *3* Right external oblique, *4* Right internal oblique, *5* Right transverse abdominis, *6* Left external oblique, *7* Left internal oblique, *8* Left transverse abdominis, *9* Right psoas, *10* Left psoas, *11* Right multifidus, *12* Left multifidus, *13* Left longissimus, *14* Right longissimus. **c** Measurement of muscle densities at the level of the symphysis pubis. *1* Left gluteus maximus, *2* Right gluteus maximus

Discussion

Our study shows that the CT density of the transverse abdominis is an independent predictor of degenerative facet

Table 3 Summary statistics of study cohort

Variable	Mean (SD)
Age	44.4 (22.2)
Gender (*N*, % male)	51 (51 %)
Weight (kg)	79.4 (20.1)
Body mass index (kg/m^2)	27.8 (7.4)
CT density of the rectus abdominis (HU)	41.6 (16.3)
CT density of the transverse abdominis (HU)	40.7 (12.4)
CT density of the external obliques (HU)	41.6 (15.0)
CT density of the internal obliques (HU)	50.1 (9.2)
CT density of the psoas (HU)	52.9 (7.1)
CT density of the multifidus (HU)	52.6 (11.3)
CT density of the longissimus (HU)	46.7 (13.8)
CT density of the gluteus maximus (HU)	41.4 (17.9)

Table 4 Univariate analysis predicting degenerative changes

Variable	Degenerative disc disease score correlation, *r*, (*p*-value)	Facet degenerative joint disease score correlation, *r*, (*p*-value)
Age	0.88	0.90
	($p < 0.0001$)	($p < 0.0001$)
Gender (mean difference male–female)	0.27	0.53
	($p = 0.001$)	($p = 0.032$)
BMI	0.39	0.38
	($p = 0.0004$)	($p = 0.0005$)
Rectus abdominis CT density	−0.62	−0.63
	($p < 0.0001$)	($p < 0.0001$)
Transverse abdominis CT density	−0.56	−0.66
	($p < 0.0001$)	($p < 0.0001$)
External oblique CT density	−0.59	−0.66
	($p < 0.0001$)	($p < 0.0001$)
Internal oblique CT density	−0.52	−0.62
	($p < 0.0001$)	($p < 0.0001$)
Psoas CT density	−0.60	−0.59
	($p < 0.0001$)	($p < 0.0001$)
Multifidus CT density	−0.61	−0.61
	($p < 0.0001$)	($p < 0.0001$)
Longissimus CT density	−0.67	−0.68
	($p < 0.0001$)	($p < 0.0001$)
Gluteus maximus CT density	−0.48	−0.55
	($p < 0.0001$)	($p < 0.0001$)

joint disease after adjusting for age, gender and BMI. In addition, CT density of the gluteus maximus is an independent predictor of degenerative disc disease after adjusting for age, gender and BMI. The CT densities of the other trunk muscles were not significant predictors of either degenerative facet joint disease or degenerative disc disease scores after adjusting for age, gender and BMI.

We found that the fat infiltration of each trunk muscle, evidenced by lower CT density, significantly increases with age and BMI. Males had higher mean CT densities of the ventral trunk musculature (rectus abdominis and transverse abdominis muscles) after adjusting for age and BMI than women. Overall, age was the strongest predictor of fat infiltration of the trunk musculature in both univariate and multivariate analyses. We also found that gender predicts the degenerative disc disease score in our multivariate analyses, suggesting that gender may play a role in the development of degenerative disc disease. However, gender was not a significant predictor of the degenerative facet joint disease scores.

The CT density of a muscle reflects the degree of fat content of the muscle, but it is also an indirect measure of the number and area of muscle fibers, as well as the density of contractile material [19]. Muscles are intermixed with fat and muscle fibers. There is a negative correlation between the muscle fat and fiber content, so that a decrease in muscle fibers will be correlated with an increase in fat between muscle fibers [19]. Therefore, we hypothesized that fat content of the lumbar spine stabilizers should be associated with lumbar degenerative disc and facet joint disease.

Our results are similar to previous studies, which showed that the mean CT density of the trunk muscles decreases with age [11, 18]. Kalichman et al. 2013 [13] found that decreased density of the longissimus and multifidus was associated with facet arthropathy at L4–L5. We did not find any association between the fat infiltration of the multifidus and degenerative disc and facet joint disease after adjusting for age, gender and BMI. In our study, increased fat infiltration of the transverse abdominis and gluteus maximus musculature were associated with degenerative changes of the lumbar spine (degenerative disc disease and facet degenerative joint disease), suggesting a role of these muscles in the development of degenerative disc and facet joint disease.

There is likely a complex interplay between the trunk musculature and development of degenerative disc disease and facet degenerative joint disease. The trunk musculature likely work in concert with each other and there are strong positive correlations between each muscle trunk group in the degree of

Table 5 Multivariate analysis predicting degenerative changes adjusting for age, gender and BMI

CT density	Degenerative disc disease score *p*-value	Degenerative facet joint disease score *p*-value
Rectus abdominis	0.76	0.93
Transverse abdominis	0.89	0.019*
External oblique	0.13	0.98
Internal oblique	0.33	0.21
Psoas	0.76	0.72
Multifidus	0.63	0.89
Longissimus	0.70	0.86
Gluteus maximus	0.05*	0.78

* $p \leq 0.05$

fatty infiltration. A large longitudinal study with detailed assessment of subject symptoms, as well as quantitative assessment of muscle fat either with magnetic resonance imaging (MRI) or CT, would be required to further establish the relative contributions of each of the trunk muscles to the development of lumbar spine degenerative changes.

Our results have potential clinical implications. As exercise is associated with decreased fatty infiltration of muscles [19], exercises geared towards strengthening and increasing the tone of the trunk muscles, in particular the transverse abdominis and gluteus maximus, may help prevent development of degenerative changes of the lumbar spine.

Strengths of our study include the large number of subjects and the detailed assessment of each trunk muscle and utilization of accepted scoring/grading of the degenerative disc disease and facet degenerative joint disease; however, our study had the following limitations. First, the cross-sectional retrospective study design limits our ability to ascertain causality. Second, our results are subject to measurement variability within and between muscles, and the areas sampled may not be truly representative of the entire muscle, in particular the transverse abdominis, which was the smallest muscle studied. Third, the unenhanced CT may not be able to provide enough information for us to detect small differences in muscle densities between trunk muscles. Finally, we did not perform a detailed clinical exam to assess for underlying etiologies of low back pain at the time of the study.

In conclusion, fat content of the trunk musculature increases with age and BMI. Fatty infiltration of the gluteus maximus and transverse abdominis are associated with degenerative disc and facet joint disease respectively, independent of age, gender and BMI. Further work is required to determine how the trunk musculature works together and the exact contributions of each muscle to the development of lumbar spine degenerative changes.

Compliance with ethical standards

Funding This study was supported by the Ralph Schlaeger Research Award.

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was waived for individual participants included in the study. The study was approved by the local Institutional Review Board (IRB) and HIPAA compliant.

References

1. Buselli P, Bosoni R, Buse G, et al. Effectiveness evaluation of an integrated automatic termomechanic massage system (SMATH® system) in nonspecific sub-acute and chronic low back pain: a randomized double blinded controlled trial, comparing SMATH therapy versus sham therapy: study protocol for a randomized controlled trial. Trials. 2011;12:216.
2. Rubin DI. Epidemiology and risk factors for spine pain. Neurol Clin. 2007;25(2):353–71.
3. Atlas SJ, Deyo RA. Evaluating and managing acute low back pain in the primary care setting. J Gen Intern Med. 2001;16(2):120–31.
4. Borenstein D. Does osteoarthritis of the lumbar spine cause chronic low back pain? Curr Rheumatol Rep. 2004;6(1):14–9.
5. Risbud MV, Shapiro IM. Role of cytokines in intervertebral disc degeneration: pain and disc content. Nat Rev Rheumatol. 2014;10(1):44–56.
6. Pezolato A, Encide de Vasconcelos E, Defino HLA, Nogueira-Barbosa MH. Fat infiltration in the lumbar multifidus and erector spinae muscles in subjects with sway-back posture. Eur Spine J. 2012;21(11):2158–64.
7. Regev GJ, Kim CW, Tomiya A, et al. Psoas muscle architectural design, in vivo sarcomere length range, and passive tensile properties support its role as a lumbar spine stabilizer. Spine (Phila Pa 1976). 2011;36(26):E1666–74.
8. Penning L. Psoas muscle and lumbar spine stability: a concept uniting existing controversies—critical review and hypothesis. Eur Spine J. 2000;9(6):577–85.
9. Goodpaster BH, Kelley DE, Thaete FL, He J, Ross R. Skeletal muscle attenuation determined by computed tomography is associated with skeletal muscle lipid content. J Appl Physiol (1985). 2000;89(1):104–10.
10. Visser M, Kritchevsky SB, Goodpaster BH, et al. Leg muscle mass and composition in relation to lower extremity performance in men and women aged 70 to 79: the health, aging and body composition study. J Am Geriatr Soc. 2002;50(5):897–904.
11. Anderson DE, D'Agostino JM, Bruno AG, Demissie S, Kiel DP, Bouxsein ML. Variations of CT-based trunk muscle attenuation by age, sex, and specific muscle. J Gerontol A Biol Sci Med Sci. 2013;68(3):317–23.
12. Kalichman L, Hodges P, Li L, Guermazi A, Hunter DJ. Changes in paraspinal muscles and their association with low back pain and spinal degeneration: CT study. Eur Spine J. 2010;19(7):1136–44.
13. Kalichman L, Klindukhov A, Li L, Linov L. Indices of paraspinal muscles degeneration: reliability and association with facet joint osteoarthritis: feasibility study. J Spinal Disord Tech. 2013.
14. Kim H, Kim HS, Moon ES, et al. Scoliosis imaging: what radiologists should know. Radiographics. 2010;30(7):1823–42.
15. Castellvi AE, Goldstein LA, Chan DP. Lumbosacral transitional vertebrae and their relationship with lumbar extradural defects. Spine. 1984;9(5):493–5.
16. Mimura M, Panjabi M, Oxland T, Crisco J, Yamamoto I, Vasavada A. Disc degeneration affects the multidirectional flexibility of the lumbar spine. Spine. 1994;19:1371–80.
17. Pathria M, Sartoris DJ, Resnick D. Osteoarthritis of the facet joints: accuracy of oblique radiographic assessment. Radiology. 1987;164(1):227–30.
18. Kamaz M, Kireşi D, Oğuz H, Emlik D, Levendoğlu F. CT measurement of trunk muscle areas in patients with chronic low back pain. Diagn Interv Radiol. 2007;13(3):144–8.
19. Jones DA, Rutherford OM, Parker DF. Physiological changes in skeletal muscle as a result of strength training. Q J Exp Physiol. 1989;74:233–56.