Available online at www.sciencedirect.com
ScienceDirect
Metabolism Clinical and Experimental 58 (2009) 1663–1668
Metabolism
Clinical and Experimental
www.metabolismjournal.com

Reproducibility of dual-energy x-ray absorptiometry total and regional body composition measurements using different scanning positions and definitions of regions

Martina Lohman[a,b,*], Kaj Tallroth[a,c], Jyrki A. Kettunen[c], Markku T. Marttinen[a]

[a]ORTON Orthopaedic Hospital, ORTON Foundation, 00280 Helsinki, Finland
[b]University of Pittsburgh Medical Center, Pittsburgh PA-15213, USA
[c]ORTON Research Institute, ORTON Foundation, 00280 Helsinki, Finland

Received 2 February 2009; accepted 27 May 2009

Abstract

Repeated dual-energy x-ray absorptiometry (DEXA) measurements are often performed both in clinical work and in research studies. The aims of the present study were to investigate the repeatability of DEXA total body measurements, to clarify the effect of the scanning positioning of the subject, and to compare the reliability of DEXA measurements of the extremities between automatically and manually defined regions of interest (ROIs). Three DEXA measurements of the total body composition, that is, fat tissue mass, lean tissue mass (LM), and bone mineral content, were performed on 30 male volunteers (mean age, 45.2 years) in addition to measurements of bone mineral density. Using a narrow fan-beam Lunar Prodigy densitometer (GE Lunar, Madison, WI), 3 DEXA scans (2 supine and 1 prone) of the total body were performed. For regional measurements of the right arm and leg, ROIs were set automatically and manually in the supine-supine and supine-prone positions. Repeatability of total body DEXA measurements was excellent for bone mineral content (r = 0.99), LM (r = 0.99), fat tissue mass (r = 1.00), and bone mineral density (r = 0.98) in supine scanning. Change of position from supine to prone slightly decreased the reproducibility of total body measurements. Reproducibility of regional measurements was inferior to total body results; especially in the upper extremity, the repeated automatic LM measurements in supine-supine positions produced r values as low as 0.74 but increased to 0.93 after manual adjustment of the ROIs. To obtain maximal reliability of the composition measurements, we recommend manual checking of machine-made ROIs and, if needed, manual adjustment to avoid measurement errors.
© 2009 Elsevier Inc. All rights reserved.

1. Introduction

Dual-energy x-ray absorptiometry (DEXA) was originally developed for the measurement of bone density. Along with the evolution of sophisticated software, DEXA is nowadays also suitable for estimation of body composition in terms of evaluating the ratio between fat, muscle, and bone in different parts of the body [1-7] with minimal radiation exposure, equivalent to 0.1 μGy [4]. At present, there are 3 main manufacturers of DEXA scanners; but the results for interequipment reproducibility are not always comparable [8]. Therefore, it is commonly recommended that especially follow-up examinations should be performed preferably on 1 scanner, or at least the same type of scanner, as differences in measurement results have been reported even with the use of apparently identical equipment [9].

For consecutive measurements on 1 scanner, the repeatability has been reported to be good [10]. Given the obvious benefits of DEXA examinations, that is, being safe (with nonsignificant radiation dose), fast, noninvasive, and relatively inexpensive, the use of DEXA for total body measurements has continuously increased both in clinical settings and in research use. Precision errors of 1.8% have been reported for bone mineral content (BMC), 1.5% for lean tissue mass (LM), and less than 1.5% for fat mass (FM) [7,10-12].

In common clinical practice, the subject is lying supine during scanning. Theoretically, however, composition of the body should be the same regardless of the position of the

The research was done at ORTON Orthopaedic Hospital, Tenholantie 10, 00280 Helsinki, Finland.

None of the authors have any conflicts of financial interest. No financial support has been obtained.

* Corresponding author. Department of Radiology, University of Pittsburgh Medical Center, Pittsburgh, PA 15213-2582, USA. Tel.: +1 412 648 6062; fax: +1 412 692 2615.
E-mail address: martina.lohman@fimnet.fi (M. Lohman).

0026-0495/$ – see front matter © 2009 Elsevier Inc. All rights reserved.
doi:10.1016/j.metabol.2009.05.023

subject. To our knowledge, the reliability of consecutive DEXA total body measurements in different body positions has previously been reported in only 1 publication [13].

Single DEXA measurements of regional body composition have been performed in elite athletes [14]; and consecutive follow-up measurements, in obesity-related research [15,16] as well as after fasting [17]. In evaluations of the effect of training on body composition, both single [18] and consecutive follow-up measurements [14,18-21] of regional body composition have been reported.

In addition, regional scanning has been reported in some neurologic conditions, such as spinal cord injury [22] and paraplegia, both of which can affect the composition of the extremities asymmetrically [23].

For such studies, information about the tissues without the confounding effect of other body parts is needed. According to the DEXA equipment manufacturers, the software programs for modern scanners are capable of separating one body region from the rest of the body during the measurement. Few authors have however investigated the reliability of such regional assessments of body part composition [1,10,13].

The aim of the present study was 3-fold: firstly, to investigate the repeatability of DEXA total body measurements; secondly, to clarify the effect of the scanning positioning of the subject; and, thirdly, to compare the reliability of DEXA measurements of the extremities between automatically and manually defined regions of interest (ROIs). We hypothesized that FM, LM, BMC, and bone mineral density (BMD) could be accurately determined using repeated DEXA.

2. Materials and methods

2.1. Subjects

Thirty men were recruited to participate in this study carried out at ORTON Orthopaedic Hospital, Helsinki. The subjects represented a normal distribution of Finnish adult (mean age, 45.2 years; range, 22-61 years) men, some being slim, some athletic, and some obese (mean body mass index, 26.5; range, 17.8-33.9). None of the subjects was too large to fit into the DEXA scanning area. The aim of the study was explained to the participants, and their written consent to participation was obtained. The Ethics Committee of the Hospital District of Helsinki and Uusimaa approved the study protocol.

2.2. DEXA examinations

For the DEXA examinations, a narrow fan-beam Lunar Prodigy densitometer (GE Lunar, Madison, WI) was used. This scanner incorporates a constant potential x-ray source at 76 kV and a K-edge filter (cerium) to achieve a congruent beam of stable dual-energy radiation: 38 keV and 70 keV. The total body scanning time was 6 to 7 minutes. As the x-ray beam passes through the subject, the beam undergoes attenuation by the tissues. The Lunar Prodigy software version 8.80 uses a series of complex algorithms to determine the amount of BMC, LM, and FM, enabling automatic calculation of the regional body composition for different anatomical regions. The calibration of the DEXA scanner with a phantom was performed not only weekly, as recommended by the manufacturer, but every working day to enhance reproducibility and stability of data.

For this study, 3 DEXA scans with total body composition measurements including automatically defined ROIs for extremity measurements were performed. After the first scanning in supine position, the subjects were asked to stand up and then to lie down again to be repositioned for the second scan in prone position. After this, the subjects stood up and lay down again for the third, repeated scan in supine position. The DEXA examinations were performed by 1 of 2 experienced radiology technologists specially trained for these examinations.

The body composition for each subject was calculated automatically by the DEXA machine. The results were reported as kilograms for BMC, LM, and FM. Bone mineral

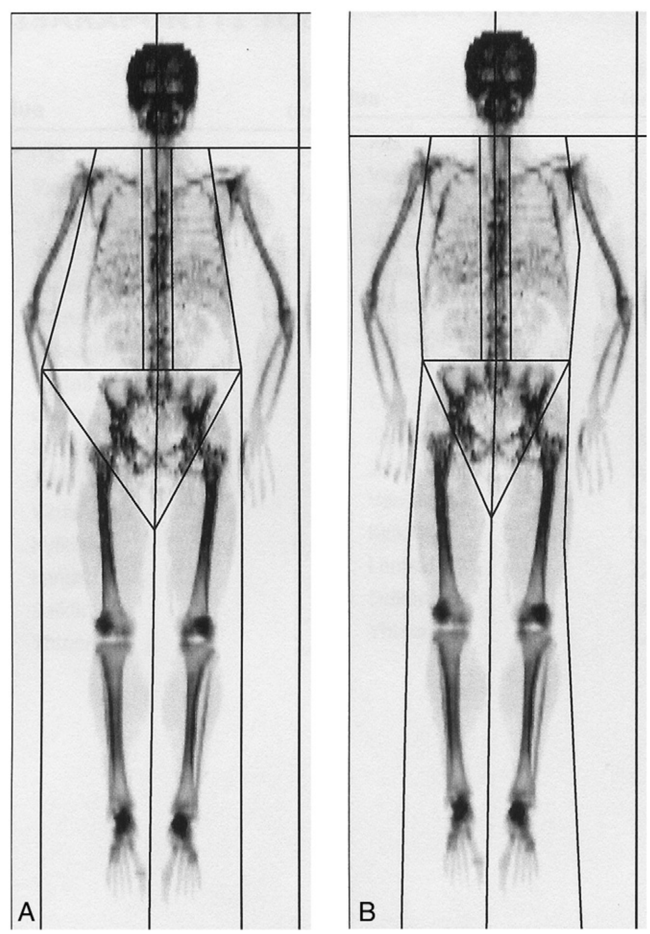

Fig. 1. Difference between automatic (A) and manual (B) ROI definitions. In (A) the ROI for the arms are asymmetric and the right hand and wrist are excluded from the region. The ROIs for the legs are cut at different levels at the hips. In (B) the ROIs are set symmetrically.

Table 1
Comparison of tissue composition measurements of the total body and of the extremities using automatically set regions in 30 subjects scanned supine and prone

Location of measurement	1st measurement in supine position		Supine vs supine		Supine vs prone	
	Mean	SD	r[a]	SD of the measurement errors[b]	r[a]	SD of the measurement errors[b]
Total body						
Bone mass (kg)	3.339	0.407	0.99	0.039	0.98	0.063
LM (kg)	59.248	6.784	0.99	0.666	0.99	1.156
FM (kg)	20.194	7.423	1.00	0.451	0.95	1.791
BMD (g/cm^2)	1.3	0.1	0.98	0	0.98	0.1
Upper limb (right)						
Bone mass (kg)	0.250	0.037	0.95	0.009	0.87	0.025
LM (kg)	3.579	0.635	0.74	0.319	0.70	0.936
FM (kg)	0.949	0.432	0.92	0.149	0.90	0.262
BMD (g/cm^2)	1.0	0.1	0.92	0.032	0.83	0.141
Lower limb (right)						
Bone mass (kg)	0.644	0.094	0.98	0.011	0.98	0.034
LM (kg)	9.874	1.251	0.98	0.169	0.92	0.373
FM (kg)	2.953	1.066	0.99	0.092	0.98	0.180
BMD (g/cm^2)	1.5	0.1	0.98	0	0.93	0

[a] Correlation for measurements in repeated supine vs supine and supine vs prone position.
[b] Standard deviation of the measurement errors.

density was measured in grams per square centimeters. The perceptual ratio of fat, muscle, and bone was calculated for every subject in the 3 examinations. Both the second supine measurement (third scan) and the prone measurement (second scan) were correlated to the first supine measurement in this study (first scan).

Repeatability (variety of measurements repeated under exactly the same conditions) of the examination results in supine position was calculated from the first and third scanning measurements. To evaluate the reproducibility (variety of measurements repeated under different conditions) of the supine vs prone examinations, the results from the first (supine) and second (prone) scans were compared.

We then compared the results of the regional measurements based on automatically defined ROIs (Fig. 1A) with those based on manually set ROIs of the right arm and the right leg in the supine-supine and supine-prone positions (Fig. 1B). The manually set ROIs were formed to include the whole extremity in question. The ROI for the arm was cut proximally at the coracoid process, and the ROI of the leg was cut at a line along the lower ramus and the opening of the acetabulum.

2.3. Statistical analysis

Repeatability of the measurements was calculated using Pearson r values. Calculations of the standard deviation of the measurement errors between repeated measurements were based on the analysis of variance. Plotting of difference against means [24] was used to describe differences between repeated measurement values. The statistical analysis was

Table 2
Comparison of tissue composition measurements of the extremities with manually set regions in 30 subjects scanned supine and prone

Location of measurement	1st measurement in supine position		Supine vs supine		Supine vs prone	
	Mean	SD	r[a]	SD of the measurement errors[b]	r[a]	SD of the measurement errors[b]
Upper limb (right)						
Bone mass (kg)	0.255	0.038	0.97	0.007	0.88	0.015
LM (kg)	3.703	0.593	0.93	0.152	0.72	0.495
FM (kg)	1,050	0.506	0.97	0.096	0.85	0.195
BMD (g/cm^2)	1.0	0.1	0.92	0.032	0.92	0.044
Lower limb (right)						
Bone mass (kg)	0.652	0.090	0.98	0.014	0.97	0.017
LM (kg)	10.171	1.286	0.95	0.279	0.90	0.445
FM (kg)	3.077	1.095	0.98	0.147	0.97	0.232
BMD (g/cm^2)	1.5	0.1	0.98	0	0.93	0.031

[a] Correlation for measurements in repeated supine vs supine and supine vs prone position.
[b] Standard deviation of the measurement errors.

performed using SPSS 15.0 for Windows statistical software (SPSS, Chicago, IL).

3. Results

Repeatability of the DEXA measurements was generally better in supine-supine than in supine-prone positions. For total body measurements of BMC, LM, FM, and BMD, reproducibility of both supine-supine and supine-prone measurements was excellent, with r values of 0.95 to 1.00 (Table 1). For the lower extremity, reproducibility was excellent in supine-supine positions (r = 0.98-0.99) and was slightly inferior in supine-prone positions (r = 0.92-0.98). When comparing the automatically calculated measurements, reproducibility for the upper extremity was inferior to that for the total body and the lower extremity. In supine-supine positions, reproducibility was 0.74 to 0.95; and in supine-prone positions, 0.70 to 0.90.

Measurement errors were generally higher in supine-prone than in supine-supine positions for measurements both of the total body and of the extremities, irrespective of whether measurements were performed with automatically (Table 1) or manually set ROIs (Table 2).

The correlations in terms of r values of the total body measurements were always superior to the corresponding measurement values of the upper extremity when the ROIs were automatically set (Table 1). Manual adjustment of the ROI increased reproducibility of most of the measurements of the upper extremity, from r values of 0.92 to 0.97 in supine-supine and from 0.72 to 0.92 in supine-prone positions (Table 2). In the lower extremity, the effect of manual ROI adjustment was less consistent. Fig. 1 shows the difference between automatic (Fig. 1A) and manual (Fig. 1B) ROI definitions for one subject.

The difference between 2 supine measurements of the right arm in each single subject is graphically illustrated, according to the method described by Bland and Altman, for the machine-made measurements in Fig. 2 and for the manually determined ROIs in Fig. 3. Variations between the 2 measurement values were clearly larger when the ROIs were automatically determined.

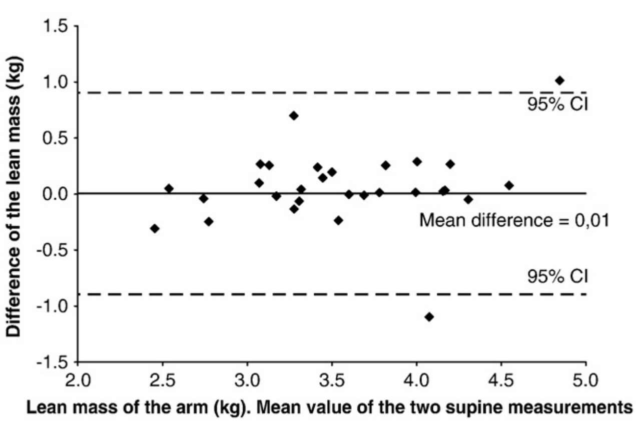

Fig. 2. Difference between 2 supine measurements of the right arm for the machine-made measurements.

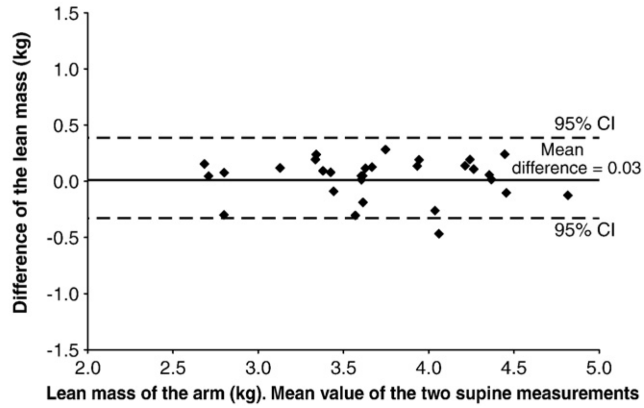

Fig. 3. Difference between 2 supine measurements of the right arm for the manually determined ROIs.

4. Discussion

Our present study showed that BMC, LM, FM, and BMD can be excellently determined using repeated DEXA scans in the supine position. In addition, the reproducibility of DEXA total body composition measurements is accurate in consecutive examinations performed in the standardized supine position and in the supine-prone positions. However, for regional measurements, manual adjustment of the ROIs is needed to ensure an impeccable measurement.

In previous research, variation in measurement results has been noted when comparing results obtained with scanners from different manufacturers [8], scanners from a single manufacturer [25], or even scanners of exactly the same type and version [9]. Accordingly, it is advisable not to use more than 1 scanner and software version in follow-up studies of the same subject. If several scanners are to be used for multicenter studies, they should be cross-calibrated [8,25]. The reproducibility of whole-body density measurements has not previously been studied with the use of a Lunar Prodigy scanner. According to the manufacturer, the Lunar Prodigy scanner used in this study incorporates a patented algorithm for beam hardening in subjects with high body fat by means of a specific adjustment for each region, mainly depending on tissue thickness and fat percentage. Furthermore, the software handles tissue adjacent, above, and below bone using a specific interpolation system to identify bone pixels when calculating BMD for the whole body.

Lambrinoudaki et al [13] compared changes in the mean values of body composition in supine and prone positions and found differences in the observed measurement values. Furthermore, in our study, there was more variation between repeated values in supine-prone than in supine-supine measurements. Although the mean difference of the right arm LM in each single subject was small, whether calculated automatically or manually, the 95% confidence intervals were narrower in manual compared with automatic measurements (Figs. 2 and 3).

In our study, the position change from supine to prone slightly increased measurement errors and weakened the reproducibility of most measurements. Overall, the reproducibility of the measurements of different anatomical regions was inferior compared with total body results; and interindividual variation was observed. Especially in the arm, however, manual adjustment of the ROI increased the reproducibility. We have not found any articles addressing the importance of manual adjustment of the different anatomical regions of the body or regarding the importance of a correct initial placement of the subject's arms along the body.

The area included in the scan field was marked on the examination table of our scanner, and all our subjects fitted within the limits of the table. Obese subjects may occasionally be too wide for the table, and the ankles and feet of tall subjects may dangle over the table end. Moreover, a change in body shape affects the contact area on the table and may influence the scan results. Especially in obese subjects, the shape of the body may be affected by the positioning; and the subjects having most variability between the repeated measurements tended to be those with higher body mass indexes. Because of the small sample size, there was no statistical power to study this in more detail. The actual scanning differs thus from a test situation using the phantom, which maintains its shape independent of positioning. In one prior study, placing additional lard over the scanning regions had an impact on the measurement of fat as well as that of bone density [26]. The reliability and repeatability of soft tissue DEXA measurements with the subject in a standard position are considered relatively good in the extremities, though slightly inferior to total body measurements. However, in a clinical study, Salomone et al [1] considered the reliability and repeatability of fat tissue DEXA measurements with the subject in a standard position to be relatively good in the extremities, though slightly inferior to total body measurements. In our study, repositioning of the subject may have altered the shape and position of the soft tissues and may thus explain some of the variation noted in the limb measurements. A lower reproducibility in the limbs probably reflected the difficulty in maintaining standard limb positioning, but also the problems encountered with the existing DEXA software in determining the ROI areas (Fig. 1A). This is especially significant for the upper extremity because of its smaller size that allows a variety of positions on the scan table.

According to the user manual of the DEXA scanner, regional measurements can be performed either automatically by the machine or manually by adjusting the regions to be analyzed. In our study, the reproducibility of the automatic measurement results for the extremities was generally inferior to that for the total body measurements. Hence, it seems important that appropriate positioning of the extremities is always ensured by means of conducting a visual check of the automatically defined ROIs and, should these not appear optimal, performing manual adjustment of the regions as needed.

Both Hologic (Bedford, MA) and Lunar have introduced a new "compare feature" into the software that allows analyses of repeated scans by comparison to the original scan made on an individual. This provides for identical placements of ROIs between 2 scans, making follow-up scans more reproducible [19,20]. The precision (reproducibility) of this technique has been evaluated by Calder et al [19] in a group of 21 young women. The coefficients of variation were 2.0% for the trunk, 2.0% for the legs, and 5.7% for the arms. Unfortunately, this method cannot be used in investigations and comparison of different individuals, healthy and diseased extremities, and groups of subjects.

Another factor related to the positioning of the subject is geometry. The Prodigy scanner used in this study uses a fan-beam technique that may create minor geometric distortions. In DEXA examinations, 3-dimensional structures are projected onto a 2-dimensional plane. If the subject is lying prone instead of supine, a slight geometrical projective error occurs because of changes in the distance of the different anatomical regions in relation to the scanner.

One limitation in our study was the study material, consisting solely of healthy white men. In subjects with a limited range of motion in the extremities or those with posttraumatic conditions, the positioning may be problematic; and the scanning results may hence be less good. Subjects who have recently undergone surgery cannot always lie supine, for example, because of operation wounds and hardware, in which case the measurements have to be performed in the prone position.

Dual-energy x-ray absorptiometry offers advantages over traditional body composition measurements, such as quickness of scan (only 6-7 minutes for total body assessment), clinical convenience, minimal radiation exposure, and evaluation of total and regional body composition. As the measurements are mostly performed by specialized technologists, information about the importance of correct positioning should be stressed in their training. Raw data are saved on the workstation in most scanners, and ROIs can later be manually adjusted if needed.

In conclusion, the repeatability of DEXA total body composition measurements in this study was excellent in consecutive examinations performed in the standardized supine position, whereas the outcome of reproducibility tests in supine-prone examinations was slightly poorer. The reproducibility of the regional DEXA measurements, regardless of positioning, was inferior. Therefore, we consider it necessary to adjust manually the ROIs for the upper extremities both in clinical practice and in research investigations.

References

[1] Salamone LM, Fuerst T, Visser M, Kern M, Lang T, Dockrell M, et al. Measurement of fat mass using DEXA: a validation study in elderly adults. J Appl Physiol 2000;89:345-52.

[2] Prior BM, Cureton KJ, Modlesky CM, Evans EM, Sloniger MA, Saunders M, et al. In vivo validation of whole body composition estimates from dual-energy x-ray absorptiometry. J Appl Physiol 1997;83:623-30.

[3] Kohrt WM. Preliminary evidence that DEXA provides an accurate assessment of body composition. J Appl Physiol 1998;84:372-7.

[4] Mazess RB, Barden HS, Bisek JP, Hanson J. Dual-energy x-ray absorptiometry for total-body and regional bone-mineral and soft-tissue composition. Am J Clin Nutr 1990;51:1106-12.

[5] Frisard MI, Greenway FL, Delany JP. Comparison of methods to assess body composition changes during a period of weight loss. Obes Res 2005;13:845-54.

[6] Albanese CV, Diessel E, Genant HK. Clinical applications of body composition measurements using DXA. J Clin Densitom 2003;6:75-85.

[7] Haarbo J, Gotfredsen A, Hassager C, Christiansen C. Validation of body composition by dual energy x-ray absorptiometry (DEXA). Clin Physiol 1991;11:331-41.

[8] Reid DM, Mackay I, Wilkinson S, Miller C, Schuette DG, Compston J, et al. Cross-calibration of dual-energy x-ray densitometers for a large, multi-center genetic study of osteoporosis. Osteoporos Int 2006;17:125-32.

[9] Lantz H, Samuelson G, Bratteby LE, Mallmin H, Sjostrom L. Differences in whole body measurements by DXA-scanning using two Lunar DPX-L machines. Int J Obes Relat Metab Disord 1999;23:764-70.

[10] Kiebzak GM, Leamy LJ, Pierson LM, Nord RH, Zhang ZY. Measurement precision of body composition variables using the Lunar DPX-L densitometer. J Clin Densitom 2000;3:35-41.

[11] Chan GM. Performance of dual-energy x-ray absorptiometry in evaluating bone, lean body mass, and fat in pediatric subjects. J Bone Miner Res 1992;7:369-74.

[12] Svendsen OL, Haarbo J, Heitmann BL, Gotfredsen A, Christiansen C. Measurement of body fat in elderly subjects by dual-energy x-ray absorptiometry, bioelectrical impedance, and anthropometry. Am J Clin Nutr 1991;53:1117-23.

[13] Lambrinoudaki I, Georgiou E, Douskas G, Tsekes G, Kyriakidis M, Proukakis C. Body composition assessment by dual-energy x-ray absorptiometry: comparison of prone and supine measurements. Metabolism 1998;47:1379-82.

[14] Fleck SJ, Mattie C, Martensen Iii HC. Effect of resistance and aerobic training on regional body composition in previously recreationally trained middle-aged women. Appl Physiol Nutr Metab 2006;31:261-70.

[15] Volek JS, Gomez AL, Love DM, Weyers AM, Hesslink Jr R, Wise JA, et al. Effects of an 8-week weight-loss program on cardiovascular disease risk factors and regional body composition. Eur J Clin Nutr 2002;56:585-92.

[16] Coupaye M, Bouillot JL, Poitou C, Schutz Y, Basdevant A, Oppert JM. Is lean body mass decreased after obesity treatment by adjustable gastric banding? Obes Surg 2007;17:427-33.

[17] Karila TA, Sarkkinen P, Marttinen M, Seppala T, Mero A, Tallroth K. Rapid weight loss decreases serum testosterone. Int J Sports Med 2008;29:872-7.

[18] Chilibeck PD, Calder A, Sale DG, Webber CE. Twenty weeks of weight training increases lean tissue mass but not bone mineral mass or density in healthy, active young women. Can J Physiol Pharmacol 1996;74:1180-5.

[19] Calder AW, Chilibeck PD, Webber CE, Sale DG. Comparison of whole and split weight training routines in young women. Can J Appl Physiol 1994;19:185-99.

[20] Chilibeck PD, Calder AW, Sale DG, Webber CE. A comparison of strength and muscle mass increases during resistance training in young women. Eur J Appl Physiol Occup Physiol 1998;77:170-5.

[21] Treuth MS, Ryan AS, Pratley RE, Rubin MA, Miller JP, Nicklas BJ, et al. Effects of strength training on total and regional body composition in older men. J Appl Physiol 1994;77:614-20.

[22] McDonald CM, Abresch-Meyer AL, Nelson MD, Widman LM. Body mass index and body composition measures by dual x-ray absorptiometry in patients aged 10 to 21 years with spinal cord injury. J Spinal Cord Med 2007;30(Suppl 1):S97-S104.

[23] Jones LM, Goulding A, Gerrard DF. DEXA: a practical and accurate tool to demonstrate total and regional bone loss, lean tissue loss and fat mass gain in paraplegia. Spinal Cord 1998;36:637-40.

[24] Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;1:307-10.

[25] Crabtree NJ, Shaw NJ, Boivin CM, Oldroyd B, Truscott JG. Pediatric in vivo cross-calibration between the GE Lunar Prodigy and DPX-L bone densitometers. Osteoporos Int 2005;16:2157-67.

[26] Svendsen OL, Haarbo J, Hassager C, Christiansen C. Accuracy of measurements of body composition by dual-energy x-ray absorptiometry in vivo. Am J Clin Nutr 1993;57:605-8.