DISSERTATIONES KINESIOLOGIAE UNIVERSITATIS TARTUENSIS
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BONE MINERAL VALUES IN YOUNG FEMALES WITH DIFFERENT PHYSICAL ACTIVITY PATTERNS: ASSOCIATION WITH BODY COMPOSITION, LEG STRENGTH AND SELECTED HORMONAL PARAMETERS

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Dissertation is accepted for the commencement of the Degree of Doctor of Philosophy in Exercise and Sport Sciences on 27 September 2007 by the Council of the Faculty of Exercise and Sport Sciences, University of Tartu, Tartu, Estonia

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Commencement: hall of the Council of the University of Tartu, Ülikooli St. 18, Tartu, on 14 December 2007 at 11 a.m.

Publication of this dissertation is granted by the University of Tartu

ISSN 1406–1058
ISBN 978–9949–11–760–4 (trükis)
ISBN 978–9949–11–761–1 (PDF)

Tartu Ülikooli Kirjastus
www.tyk.ee
Tellimus nr 447

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STUDY II **Sööt T., Jürimäe T., Jürimäe J.** Areal bone density in young females with different physical activity patterns: relationships with plasma leptin and body composition. *Journal of Sports Medicine and Physical Fitness*, 2007, 47(1): 65–69.

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LIST OF ABBREVIATIONS AND DEFINITIONS OF TERMS

The following abbreviations and special terms are used in this study protocol

Abbreviation or special term	Explanation
BMC	Bone mineral content
BMD	Bone mineral density
BMI	Body mass index
CMJ	Counter movement jump
DLBMC	Dominant leg bone mineral content
FFM	Fat free mass
FM	Fat mass
IGF-1	Insulin-like growth factor-1
ISOK	Maximal knee extension isokinetic strength at angular velocity of 60 $deg \cdot s^{-1}$
ISOM	Maximal knee extension isometric strength
LBMC	Legs bone mineral content
LBMD	Legs bone mineral density
L2–L4	Lumbar spine bone mineral density at site L2–L4

1. INTRODUCTION

Bone is a metabolically active tissue with continuous remodelling occurring throughout its life (Cohen et al. 1995). Different kind of physical loading might have different effects on BMD. Loss of muscle mass, muscle strength and bone mass with advancing age is associated with osteoporotic skeletal fractures (Sinaki et al. 1996). Because of difficulties in the restoration of lost bone and the lack of effective means to restore lost bone, prevention through physical activity and changes in lifestyle should involve a major proportion of female population (Sinaki et al. 1996).

It is well known that physical activity is an important factor in attaining peak bone mass (Kohrt et al. 2004). The intensity, duration and type of the physical activity are affecting BMD. The influence of high intensity exercise to bone health depends on the nature of the physical activity and the effects of different exercises are more pronounced at the lumbar spine than at the femoral neck (Wallace and Cumming 2000). The basic mechanisms of these effects are not fully understood, especially in young females with different physical activity patterns.

Despite a multitude adverse effects including cardiovascular diseases and diabetes, obesity is associated with higher BMD and lower fracture rates (Frost 1997). Excessive FM, consistent with obesity, induces greater mechanical loading on the skeleton that contributes to the increase in BMD and BMC. However, the distribution of FM is heterogeneous and depot-dependent effects on BMD are also possible (Zhong et al. 2005). The increase in body FM in obesity is also accompanied by the increase in FFM, which may also have an influence on the BMD (Davis et al. 1996). Accordingly, in addition to mechanical loading, different body composition parameters may have an influence on BMD in young females.

Osteoporosis is prevalent in female athletes whose bone mass has fallen below the “critical threshold“ (Snow-Harter 1994). It is well studied that female athletes with unregular menstrual cycle run the risk of decreasing BMD to such an extent that stress fractures may occur under minimal impact loading of the bone (Cumming 1996). As a rule, extremely high running training loads may have a detrimental effect on bone health via different hormonal mechanisms (Chilibeck et al. 1995). Heinonen et al. (1995) suggested that resistance training provides a more effective osteogenic stimulus than endurance running. Therefore, a normal ovulatory cycle is necessary (Petit et al. 1999). In addition to specific sex hormones, other hormonal factors have been postulated to be involved in the development of BMD in young females.

The novelty of present study is the complex investigation what was undertaken to assess the association of bone mineral values with different anthropometric, body composition, leg strength and blood hormonal characteristics in young females. Moreover, studied females were divided into four specific

groups according to their daily physical activity patterns to assess relationships between above-mentioned different characteristics intra-group, and to compare these female groups also with each other.

2. REVIEW OF LITERATURE

2.1. Anthropometry, body composition and bone mineral values

BMC and BMD attained by young females are considered to be determinants of their risk of osteoporotic fractures in later life (Hui et al. 1988). Specifically, the risk of osteoporosis is affected by the peak bone mass attained before the age of 20 years (Bailey et al. 1996). With aging, the composition of bone marrow shifts to favour the presence of adipocytes, osteoclast activity increases, and osteoblast function declines, resulting in osteoporosis (Rosen and Bouxsein 2006). Several studies have investigated the influence of specific anthropometrical parameters such as body height, body mass and BMI to the BMC and BMD values in young females. Low body mass has been found to be a significant risk factor in the development of osteoporosis; on the other hand, obesity has been mentioned as a significant confounder of BMD (Holbrook and Barrett-Connor 1993). In the 20-44-year-old group of females, Boyanov et al. (2001) did not find any anthropometrical models to characterize BMD values except for the prediction of trabecular BMD level by body mass. Young et al. (2001) indicated that in young females, the predicted average increase in total body BMC appeared to be 0.5% per centimetre in body height. Bone mass was influenced by the body height in a group of 6–32-year-old women in the study by Lin et al. (2003). Finally, relatively few studies have investigated the impact of the specific anthropometrical parameters (skinfolds, girths, lengths, breadths/lengths) and somatotype on BMC and BMD values in young healthy women. Slemeda et al. (1990) found a significant relationship between BMD and skinfold thicknesses in adult females.

Different body composition parameters influence BMC and BMD values at least by three possible mechanisms: mechanical stress due to body mass, muscular forces and different hormonal factors (Reid et al. 1992, Lanyon 1992, Jürimäe et al. 2005; Jürimäe and Jürimäe 2007). FFM appears to be one of the main predictors of different bone mineral values in healthy premenopausal women (Rico et al. 1994; Jürimäe and Jürimäe 2007). In young females, Ellis et al. (1997) found a very high relationship between BMC and FFM ($r = 0.963$). In another study, Bedogni et al. (2002) concluded that FFM is a stronger predictor of BMC than FM in healthy females, while Nichols et al. (1995) demonstrated that lean tissue mass values, both arms and legs, were significantly and positively correlated to the corresponding regional bone density levels. On the contrary, Reid et al. (1992) emphasised that body FM is an important determinant of whole body BMD in premenopausal women. Body fat had also a negative impact on BMC and BMD in 10–19-year-old healthy females in Weiler et al. (2000) study. Lazcano-Ponce et al. (2003) concluded that body fat

% is associated in an inversely proportionate manner as an independent predictor for BMD in the lumbar spine in 9–24-year-old Mexican females.

Significant positive relationships between BMD and FFM indicate the importance of physically active lifestyle, which increases FFM (Heinonen et al. 1995) and also leads to increments in bone mass. In addition, several studies have shown that athletes involved in weight-bearing activities with such loading characteristics exhibit greater BMD compared with non-athletic controls (Heinonen et al. 1995). Sport participation in some events has been connected with very low body mass and increased FFM values. Exercise and mechanical loading stimulate both muscle and bone development.

Not all body composition and especially anthropometrical factors associated with the attainments of optimal BMC and BMD have been clearly identified. We hypothesised that there are from the anthropometrical parameters site-specific relationships with the BMC and BMD in differently trained young females.

2.2. Blood hormonal characteristics and bone mineral values

Although the precise mechanism has not been specifically clarified, different hormonal factors have been postulated to be involved with the mechanisms between FM and BMD (Abou Samra et al. 2005, Jürimäe and Jürimäe 2007). The positive association between body mass and bone mass might be attributable for several possible mechanisms, including the association of FM with the secretion of bone-active hormones from the pancreatic β-cell (i.e. insulin, IGF-1), and secretion of bone-active factors from adipocytes (i.e. leptin etc) (Reid 2002).

One of the factors that may play a role in BMD and BMC is leptin, the product of LEP gene. Leptin is secreted mainly by white adipose tissue (Cinti et al. 1997) and has a crucial role in regulation of appetite, glucose homeostasis and body fat, while defects in leptin production or function are associated with obesity in animal models and humans (Lonnqvist et al. 1995). However, as there are large variations in leptin concentrations among individuals with similar body composition, it is likely that plasma leptin concentrations are also influenced by factors other than the adipose tissue (Considine et al. 1996).

The relationships between plasma leptin levels and BMD are controversial. For example, Ducy et al. (2000) have described that leptin-deficient ob/ob mice have a “high bone mass” phenotype, whereas Steppan et al. (2000) found that ob/ob mice have lower total body BMC and BMD as well as lower femoral BMC and BMD values than normal mice. Moreover, some authors have found positive associations between plasma leptin levels and BMD (Thomas et al. 2001, Zhong et al. 2005). Weiss et al. (2006) found similarly that leptin plays a

fundamental role in both short-term (antiresorption) and long-term (bone mass) female bone health. This is in accordance with the findings of other studies (Blain et al. 2002, Pasco et al. 2001, Whipple et al. 2002, Yamauchi et al. 2001). Also Tamura et al. (2007), who studied associations between leptin and BMD in patients with type 2 diabetes mellitus found that leptin may have protective effect on bone metabolism at the distal radius site. In contrast, other authors have failed to find such a relationship in pre- and postmenopausal women (Abou Samra et al. 2005, Rauch et al. 1998). Different studies have also suggested that not in men but in women, relationships between leptin and BMD have been observed at different skeletal sites and there could be a gender effect (Thomas et al. 2001). Although both BMD and plasma leptin levels increase with obesity, nonhuman models suggest that leptin may be inversely related to BMD (Ducy et al. 2000). Therefore, systemic administration of leptin in leptin-deficient mice (Steppan et al. 2000), wild mice (Cornish et al. 2001), and humans (Farooqi et al. 1999) results in increased bone growth, increased skeletal mass and increased skeletal strength.

There is little information about the influence of different long-term physical activity patterns on leptin values. Repeated daily exercise bouts have been described either to decrease (Perusse et al. 1997; Mäestu et al. 2003) or not to alter (Dirlewanger et al. 1999) plasma leptin concentration. It has been suggested that plasma leptin concentrations do not change during exercise and that endurance training is associated with a reduction in circulating leptin levels in men but not in women (Perusse et al. 1997). Ryan et al. (2000) found that neither aerobic nor resistance training affected plasma leptin concentration independent of the changes in body fat in postmenopausal women. Based on previous information it was hypothesized in our study that leptin has the highest impact on the measured parameters in normal weight and especially overweight sedentary females because of their higher BMI and also presumably higher bone mineral values, compared to different groups of athletes.

IGF-1 belongs as polypeptide ligand into insulin-like growth factor family together with IGF-2 and is involved in many functions, including the regulation of energy metabolism (Gomez et al. 2003) and playing a role in the reproductive axis (Kaaks et al. 2003). It is known that higher circulating IGF-1 concentrations are associated with greater BMD values in women, as insulin and IGF-I through the insulin receptor have a positive effect on BMD (Langlois et al. 1998). This is supported partially with the finding of Vestergaard et al. (1999), where significant relationship of IGF-1 with distal forearm and spine BMD values, but not with femoral neck BMD value was observed in peri-menopausal women. However, Seck et al. (1999) did not find any relationship between IGF-1 and BMD values.

The combined effects of chronic hyperglycaemia, insulin deficiency and low IGF-1 concentration may reduce osteoblast activity, leading in turn to a decrease in bone formation (Lu et al. 2003, Terada et al. 1998, Thrailkill et al. 2005). Also high doses of insulin and low IGF-1 levels have been found to have

independent deleterious effect on bone (Léger et al. 2006). Recent data on animal models demonstrate that a certain threshold of circulating IGF-1 is necessary for normal bone growth, suggesting that serum IGF-1 concentration plays a prominent role in the pathophysiology of osteoporosis (Yakar et al. 2002). There is little and controversial information available about the influence of IGF-1 on the BMD in young females with different physical activity patterns.

Estrogen release from ovarian follicles and progesterone release from corpus luteum are regulated by follicle-stimulating hormone and luteinising hormone, and therefore both are elevated in luteal phase (Jones 1997, Marsh and Jenkins 2002, Stachenfeld et al. 1999), while increase in estrogen concentration is evident already during ovulation (Jones 1997). Estradiol has strongest intracellular effect among estrogens and has a role in the prevention of bone loss, reduction of induced gain of body mass and elevation of locomotor activity after ovariectomy (Hertrampf et al. 2007). Clegg et al. (2006) pointed out that estrogen acts within the brain to increase leptin sensitivity, decrease insulin sensitivity, and favour subcutaneous fat over visceral fat. It has also been found that leptin secretion can be stimulated in women by the administration of estradiol together with progesterone (Messinis et al. 2001). Low estrogen levels together with low calcium and protein intake combined with late menarche could lead to an increased incidence of spontaneous bone stress fractures and the development of premature osteoporosis (Nichols et al. 2000). Because estrogen suppresses bone turnover, decreased estrogen levels result in an increase in bone turnover with a greater increase in bone resorption than bone formation (Eastell et al. 1993). On the other hand, the primary goal of different exercise programmes to decrease bone loss should be the elevation of circulating estrogen levels (Burrows and Bird 2000). Zaman et al. (2000) demonstrated that the adaptive response of bone cells to mechanical stress involves the estrogen receptor; blocking the estrogen receptor impairs the bone formation response to mechanical stress. In our study we hypothesised that there are moderate effects of different types of physical activity to the BMD in young females with normal menstruation, sex hormones estradiol and progesterone and IGF-1 concentrations.

2.3. Physical activity and bone mineral values

The influence of physical activity and mechanical loading on skeleton peak bone mass has extensively been studied in humans (Bourrin et al. 1995, Heinonen et al. 1995). Peak bone mass at skeletal maturity has been identified as a risk factor for osteoporosis in later life (Johnston et al. 1981). Osteoporosis is a bone disease associated with low BMD that increases the risk of debilitating bone fractures (Nevill et al. 2003). Osteoporosis might be prevented or delayed by maximalizing peak bone mass through the modification of lifestyle

influences such as diet and physical activity during childhood and adolescence (Kannus et al. 1996). Recent study of Schneider et al. (2007) shows that school based intervention on fitness, activity and bone among the adolescent females increased physical activity, maximal oxygen consumption and BMC in the thoracic spine, while bone turnover markers were not affected. Moreover, in longitudinal analyses they found that cardiovascular fitness predicts increased bone formation and bone resorption (Schneider et al. 2007). Physical activity causes mechanical strains on bones with different magnitude, rate and pattern (Einhorn 1992, Turner 1991). It has been shown that skeletal adaptations to loading appear to be site-specific (Bourrin et al 1995, Judex et al. 1997, Ginty et al. 2005, Egan et al. 2006). This means that another important factor influencing both regional and total peak bone mass might be the anatomical distribution of loads (Duncan et al. 2002).

Cross-sectional studies have demonstrated that female weight-lifters (resistance training that consists of using heavy loads with few repetitions) have higher areal BMD than athletes in other sports and nonathletes (Conroy et al. 1993, Heinonen et al. 1993). Of different exercise modalities, high-impact physical activity, e.g., jumping, seems to be especially osteogenic (Heinonen et al. 1995). Shibata et al. (2003) found that walking about 10,000 steps per day if done continuously appears to maintain BMD, they also suggested that jumping exercise together with walking could serve to promote bone formation further. A longitudinal study of Nordström et al. (2006) showed that former male athletes (ice hockey and badminton players) retained significantly higher BMD at the clinically important proximal femur and humerus five years after reduction in activity level suggesting that high peak BMD resulting from previous training may reduce the risk of osteoporotic fractures in males. Gustavsson et al. (2003) investigated the effect of reduced training on BMD values in males and found contrarily that subjects who ended active hockey player career lost more BMD at the femoral neck compared to still active athletes. Moreover, they found that former ice hockey players even lost significantly more bone mineral density at the femoral neck than the untrained control subjects (Gustavsson et al. 2003). This is similar with the findings of Valdimarsson et al. (2005) investigation. They studied female soccer players and concluded that physical activity during the postpubertal period in children is associated with an increased accrual of BMD and that retirement from physical activity is associated with faster loss in BMD compared with the physically inactive control subjects. Vico et al. (2000) studied cosmonauts before and after microgravity during spaceflights and found that BMD was lost at the weight-bearing tibia, but no changes were seen at the non-weight-bearing distal radius. Same finding was at the Nordström et al. (2005) study, where no BMD of the arms was lost with the reduced physical activity among the young former athletes. It might be explained by the statement of Leblanc et al. (1990), that after reducing physical activity, unloaded skeletal regions increase in BMD

possible because of a redistribution of BMD with reduced activity level from weight-loaded to unloaded skeletal regions.

In addition to isoinertial measurements, strength can also be assessed in isometric and isokinetic context. Isometric strength is the maximal voluntary contraction that can be developed against an immovable object without a change in joint angle. Results from isometric protocols have been used as indicators of athletic strength (Häkkinen et al. 1984). Isokinetic assessments involve the measurement of torque and power through a range of motion in which the limb is moving at a constant angular velocity (Abernethy et al. 1995). It appears that both isometric and isokinetic strength could be used to assess the possible relationship between BMD and strength determined at laboratory conditions in young healthy females. To date, there has been relatively few published work about the possible relationships between BMD, BMC and maximal isometric and isokinetic strength in young healthy females with different physical activity and body composition patterns. It was hypothesized in our study that leg strength parameters influence LBMD and LBMC more in physically inactive groups than in active groups because of their lower lean body mass (directly connected with strength).

3. AIMS OF THE STUDY

The general aim of the present study was to determine possible relationships between anthropometric, body composition, leg strength, blood hormonal characteristics with BMD and BMC values in young females with different body composition parameters and physical activity level.

Accordingly, the specific aims of the present investigation were to:

1. test possible relationships between specific anthropometrical, somatotype and body composition parameters with BMD and BMC values in strength- and endurance-trained, and untrained normal- and overweight young females;
2. find possible relationships between plasma leptin concentrations and BMD values in strength- and endurance-trained, and untrained normal- and overweight young females;
3. investigate possible relationships between plasma IGF-1, estradiol and progesterone concentrations with BMD values in strength- and endurance-trained, and untrained normal- and overweight young females;
4. determine possible relationships between maximal isometric and isokinetic knee extensor muscle strength and CMJ with BMD values in strength- and endurance-trained, and untrained normal- and overweight young females.

4. MATERIAL AND METHODS

4.1. Subjects

In total, 129 females participated in this study. Before entering the study, volunteers were interviewed about their medical conditions and physical activity. All subjects were healthy and none of them was at that moment taking any medications and they were free from present or past diseases known to affect skeletal metabolism. They were instructed not to change their normal practice schedule, normal physical activities or their dietary intake during the study and not to exercise for 24 hours prior to the measurement day. Before signing written information consent forms, all participants were informed of the procedures and possible risks involved in the experiments. This study was approved by the Medical Ethics Committee of the University of Tartu.

Subjects were found to the study from health clubs and via advertisements. For inclusion the subjects must have fulfilled the following criteria:

- Provision of written informed consent;
- Females in age 17–40 years;
- Healthy;
- Participation in strength training at least 6 hours per week during the last five years; or
- Participation in endurance training at least 6 hours per week during the last five years; or
- Is untrained at least during last 2 years with BMI 17–25 kg/m^2; or
- Is untrained at least during last 2 years with BMI over 25 kg/m^2.

Any of the following was regarded as criterion for exclusion:

- Use of oral contraceptives;
- Use of medications known to affect skeletal metabolism;
- Present or past diseases known to affect skeletal metabolism;
- Severely irregular or absent of menstrual cycle.

Females were divided into four groups according to their physical activity patterns: (1) strength-trained (weight lifters and aerobics trainers; n = 33), (2) endurance-trained (cross-country skiers, swimmers and long distance runners; n = *32*), (3) normal-weight untrained (n = 41), and (4) overweight untrained (n = 23, Table 1) females. The overweight untrained group consisted of females whose BMI value was more than 25 kg/m^2 and they were physically inactive. All studied females were eumenorrheic (10–12 cycles/year). There were no significant differences within the separate groups in the ages of starting menstruating (12.8 ± 1.1, 13.1 ± 1.5, 13.2 ± 1.3 and 12.7 ± 1.5 years in the strength-, endurance-trained, and normal and overweight untrained groups, respectively).

Table 1. Physical characteristics of the subjects (mean ± SD).

	Strength-trained (n = 33)	Endurance-trained (n = 32)	Normal-weight untrained (n = 41)	Overweight untrained (n = 23)
Age (yrs)	26.9 ± 6.1	22.6 ± 4.3*	24.6 ± 4.5	25.5 ± 4.5
Height (cm)	167.0 ± 5.9	169.5 ± 5.7	166.5 ± 5.6	167.1 ± 7.2
Body mass (kg)	60.6 ± 6.4	59.3 ± 6.3	57.9 ± 6.7	77.2 ± 8.7*#¤

Superscripts indicate a significant mean difference between groups as follows:
* $p < 0.05$ compared to strength-trained females
# $p < 0.05$ compared to endurance-trained females
¤ $p < 0.05$ compared to normal-weight untrained females

4.2. Anthropometry, somatotype and body composition

Body height was measured using Martin's metal anthropometer to the nearest 0.1 cm and body mass to the nearest 0.05 kg using medical electronic balance scale (A & D Instruments Ltd., UK) with the subjects wearing no shoes and only light clothing. The BMI (kg/m^2) was calculated. All anthropometrical parameters were measured according to the protocol recommended by the International Society for the Advancement of Kinanthropometry (Norton & Olds 1996). Nine skinfolds (*triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh, medial calf, mid-axilla*), 13 girths (*head, neck, arm relaxed, arm flexed and tensed, forearm, wrist, chest, waist, gluteal, thigh, thigh mid trochanter-tibiale laterale, calf, ankle*), eight lengths (*acromiale-radiale, radiale-stylion, midstylion-dactylion, iliospinale-box height, trochanterion-box height, trochanterion-tibiale laterale, tibiale laterale to floor, tibiale radiale-sphy tibiale*) and eight breadths/lengths (*biacromial, biiliocristal, foot length, sitting height, transverse chest, A-P chest depth, humerus, femur*) were measured on the right side of the body. Three series of anthropometric measurements were taken and the means were used. Skinfold thicknesses were measured using Holtain (Crymmych, UK) skinfold caliper. Other anthropometrical parameters were measured using the Centurion Kit instrumentation (Rosscraft, Surrey, BC, Canada). Calibration of all equipment was conducted prior to and at regular intervals during the data collection period. The tester had a Level 1 certificate from the International Society for the Advancement of Kinanthropometry (Norton & Olds, 1996). Three somatotype components – endomorphy, mesomorphy and ectomorphy were calculated according to the Carter and Heath (1990) anthropometric somatotyping method. Whole body fat percentage, FM and FFM were measured by dual-energy X-ray absorptiometry (DXA) using the DPX-IQ densitometer (Lunar Corp., Madison, USA). Subjects were scanned in light clothing while lying flat on their backs with arms on the sides.

4.3. Bone mineral measurements

BMD ($g \cdot cm^{-2}$) and BMC (g) were measured by DXA using the DPX-IQ densitometer (Lunar Corp., Madison, USA) at the total body, dominant arm distal radius (described as non-weight-bearing sites), antero-posterior lumbar spine (L2–L4), femoral neck (described as weight-bearing sites); for both legs (LBMD, LBMC), and dominant leg (DLBMC) sites. Participants were scanned in light clothing while lying flat on their backs with arms on the sides. DXA measurements were carried out in Bone Densitometry Laboratory of the Tartu University Clinics and were evaluated by the same examiner.

4.4. Blood samples

Arterialized blood samples (10 ml) were drawn from a dorsal hand vein for the determination of plasma leptin, IGF-1, and sex hormones estradiol and progesterone at the morning ~ 8 a.m. after an overnight fast in upright position in the early follicular phase of the menstrual cycle (days 5–7). Leptin samples were analyzed in duplicate by a radioimmunoassay (Mediagnost GmbH, Germany). This assay has a detection limit of 0.01 ng/ml and intra-assay and inter-assay coefficients of variation (CV) were < 5% and < 7.5%, respectively. IGF-1, estradiol and progesterone were determined in duplicate on Immulite 2000 (DPC, Los Angeles, USA). The intra- and interassay CVs for estradiol were 5.3% and 6.5%, respectively, for progesterone 5.4% and 3.4%, respectively, and for IGF-1 5.0% and 4.3%, respectively. The samples from one individual were run on the same assay.

4.5. Muscle performance assessment

During the measurement of ISOM of the dominant leg during unilateral contractions, the subjects were seated in a custom-made dynamometer with the knee and hip angles equal to 90° and 110°, respectively (Pääsuke et al. 1999). The body position of the subjects was secured by three belts placed over the chest, hip and thigh. The ISOM of the dominant leg was recorded by standard strain-gauge transducer placed inside a metal frame that was placed around the distal part of the ankle above the malleoli using a Velcro belt. The electrical signals from the strain-gauge transducer were digitalized online (sampling frequency 1 kHz) using a personal computer. During the testing, subjects were asked to exert maximum voluntary isometric knee extension against the belt of the strain-gauge transducer as forcefully as possible for the duration of two to three seconds. The subjects were motivated, both verbally and through visual feedback, to achieve the best results. Three trials were recorded with a break of

two minutes between each effort, while the best result was set as a measure of ISOM.

Cybex II dynamometer was used (Division of Lumex Inc., New York, USA) for the assessment of ISOK. Subjects were familiarized with the testing apparatus and protocol prior to test administration and performed one practice trial. In order to ensure consistency, the testing was carried out by the same technician for all subjects and each test. The extension of the dominant leg was recorded during concentric activity at an angular velocity of 60 deg·s^{-1}. During the testing, the subjects were seated in a chair and restrained with belts to prevent any extraneous movements of the body. The axis of the dynamometer resistance arm was aligned with the lateral epicondyle of the femur. Concentric leg strength was measured through a 90º arc, ranging from the start position of 90º of knee flexion to the full extension at 180º. The subjects performed one set of three repetitions, from which the peak torque was noted as the parameter for ISOK.

CMJ test was performed using a contact mat (Newtest OY, Oulu, Finland) connected to a digital timer (±0.01 s). The timer was triggered by the lift of feet from the mat and stopped at the touch-down, while the flight time was recorded. During the test, the subjects were told to jump as high as possible with their hands on the hips to eliminate the influence of the arms swing impulse. The flight time was used to calculate the jumping height by the height of the rise of the centre of gravity of the body above the ground. Three maximal CMJs were recorded and the trial with the best jumping height was used for further analysis, while a resting interval of 1 minute was allowed between the trials.

4.6. Statistical analysis

Data analysis was performed by using SPSS 10.0 for Windows (Chicago, IL, USA). Standard statistical methods were used to calculate mean ($\overline{X}$) and standard deviation (± SD). Statistical comparisons between groups were made by using analysis of variance (ANOVA) and Tukey post-hoc test. Spearman's rank correlation coefficients were used to determine the relationships between dependent variables. Partial correlations were used where the influence of body fat mass was controlled. Stepwise multiple regression analysis was used to analyse the effect of the leptin, IGF-1, progesterone and estradiol on different BMD values; the effect of different strength, anthropometrical and body composition parameters on the DLBMC, LBMD and LBMC; and the effect of different anthropometrical and body composition variables to the BMC and BMD values at each of the regions studied. The level of significance was set at $p<0.05$.

5. RESULTS

Strength-trained females were significantly older than endurance-trained females (Table 1). Overweight untrained females had higher values for body mass, BMI, body fat % and also body FM compared to the physical activity groups of females and normal-weight untrained females, while normal-weight untrained females had higher body fat % compared to strength- and endurance-trained females. In normal-weight untrained females, FFM was significantly lower than among the strength- or endurance-trained and overweight untrained females (Table 2).

Skinfold thicknesses were significantly higher in the overweight untrained group compared with both physical activity groups (data not presented). There were no significant differences in girths (except abdominal), lengths and breadths/lengths. In the normal-weight untrained group, most of the skinfold thicknesses were higher than in the physical activity groups. There were significant differences in the somatotype components between different groups (Table 2). Overweight untrained females had more endomorphy than the strength- and endurance-trained ones. They also had more mesomorphy and ectomorphy compared with strength-trained females (Table 2).

According to the results of the stepwise multiple regression analysis in strength-trained and overweight untrained females, none of the measured bone variables was a predictor of body composition parameters (body mass, BMI, body fat % and FM). In endurance-trained females, only body mass was selected as a parameter of the bone density in femoral neck (46.9%; R^2x100) or lumbar spine BMD at site L2–L4 (58.3%; R^2x100).

Table 2. Body composition parameters and somatotypes of the subjects (mean ± SD).

	Strength-trained (n = 33)	Endurance-trained (n = 32)	Normal-weight untrained (n = 41)	Overweight untrained (n = 23)
BMI (kg/m^2)	22.0 ± 2.9	20.6 ± 1.6	20.9 ± 2.2	27.5 ± 2.2*#¤
Body fat (%)	19.9 ± 6.0	20.4 ± 5.2	24.8 ± 6.8	39.1 ± 5.1*#¤
FM (kg)	11.4 ± 4.4	11.5 ± 3.9	13.9 ± 5.0	28.4 ± 6.2*#¤
FFM (kg)	45.4 ± 3.9	44.2 ± 4.3	40.8 ± 3.2*#	43.7 ± 5.0¤
Endomorphy	3.15 ± 1.30	2.62 ± 0.82	3.38 ± 0.84	5.11 ± 1.08*#
Mesomorphy	2.73 ± 1.31	2.46 ± 1.11	2.96 ± 0.71	3.02 ± 0.98#
Ectomorphy	2.49 ± 1.01	3.24 ± 0.77	3.14 ± 0.87	3.11 ± 1.04#

Superscripts indicate a significant mean difference between groups as follows:
* $p < 0.05$ compared to strength-trained females
# $p < 0.05$ compared to endurance-trained females
¤ $p < 0.05$ compared to normal-weight untrained females

Endurance-trained females had lower BMD values in L2–L4 when compared to strength-trained and overweight untrained females. Normal-weight untrained females had lower values of BMD in sites L2–L4, femoral neck and total body BMD compared to the strength-trained females (Table 3). Overweight untrained females had higher BMD values in sites L2–L4 and total body BMD when compared to normal-weight untrained females (Table 3). Total BMC was significantly higher in overweight untrained females compared with endurance-trained and normal-weight untrained females, endurance-trained and normal weight untrained females had also lower BMC of dominant leg compared to overweight untrained females. BMD of legs was lower in normal-weight untrained compared to strength-trained females (Table 3). In all groups, BMC is highly dependent on the body mass (31.5–81.2%, R^2x100) (Table 4). In both physical activity groups, spine BMD (L2–L4) is dependent on body mass (31.5% and 53.7% in strength- and endurance-trained groups, respectively). In endurance-trained females, BMI highly characterised BMD in femoral neck, distal radius and in total body.

Table 3. BMC and BMD of the subjects (mean ± SD).

	Strength-trained (n = 33)	Endurance-trained (n = 32)	Normal-weight untrained (n = 41)	Overweight untrained (n = 23)
BMC (g)				
Total body	2973.6 ± 452.2	2778.4 ± 334.9	2681.2 ± 278.4	3142.4±360.3#¤
DLBMC	520.9 ± 83.5	499.1 ± 374.8	472.3 ± 58.8	570.4 ± 92.9#¤
LBMC	1038.0 ± 164.1	993.3 ± 145.9	940.2 ± 114.8	1135.8±183.6#
BMD (g/cm^2)				
L2–L4	1.4 ± 0.2	1.3 ± 0.1*	1.3 ± 0.1*	1.4 ± 0.1#¤
Femoral neck	1.3 ± 0.1	1.2 ± 0.2	1.2 ± 0.2*	1.3 ± 0.1
Distal radius	1.0 ± 0.2	0.9 ± 0.1	1.0 ± 0.1	1.0 ± 0.1
LBMD	1.3 ± 0.1	1.3 ± 0.1	1.2 ± 0.1*	1.3 ± 0.1
Total body	1.3 ± 0.1	1.2 ± 0.1	1.2 ± 0.1*	1.3 ± 0.1¤

Superscripts indicate a significant mean difference between groups as follows:
* $p < 0.05$ compared to strength-trained females
# $p < 0.05$ compared to endurance-trained females
¤ $p < 0.05$ compared to normal-weight untrained females

As a result of using stepwise multiple regression analysis, only one independent variable was selected in 71 cases out of the 77 stepwise regressions. Only 6 stepwise regressions had more than one step (see Tables 4–8). In all groups, BMC was highly dependent on the body mass (31.5–81.2%; R^2x100) (Table 4). In both physical activity groups, spine BMD (L2–L4) was dependent on body mass (13.7% and 53.7% in strength- and endurance-trained groups, respectively). In the endurance-trained females, BMI had a strong relationship with BMD in the femoral neck, distal radius and total body.

Table 4. Results of the stepwise multiple regression analysis where dependent variables were BMC and BMD and independent variables body height, mass and BMI (only significant models are presented).

	Independent variable	Multiple R	R^2	F	p
Strength-trained (n = 33)					
Bone mineral content	Body mass	0.562	0.315	13.82	0.001
BMD L2–L4	Body mass	0.370	0.137	4.61	0.040
Endurance-trained (n = 32)					
Bone mineral content	Body mass	0.901	0.812	94.80	0.000
BMD L2–L4	Body mass	0.731	0.537	25.20	0.000
BMD femoral neck	BMI	0.580	0.337	11.16	0.003
BMD distal radius	BMI	0.443	0.196	5.36	0.030
BMD total body	BMI	0.627	0.393	14.24	0.001
Normal-weight untrained (n = 41)					
Bone mineral content	Body mass	0.685	0.469	28.27	0.000
Overweight untrained (n = 23)					
Bone mineral content	Body mass	0.605	0.366	10.96	0.004
BMD L2–L4	Body mass	0.408	0.167	21.81	0.000
BMD femoral neck	Body mass	0.281	0.079	9.37	0.003
BMD distal radius	Body mass	0.193	0.037	4.22	0.042

From the body composition parameters, FFM was a very powerful predictor of BMC and BMD (Table 5). In endurance-trained females, BMD was highly related to FFM, especially in both weight-bearing sites (66.2% in L2–L4 and 35.3% in femoral neck). FFM explained 77.0% of the variance of BMC in this group.

Table 5. Results of the stepwise multiple regression analysis where dependent variables were BMC and BMD and independent variables body fat %, FM and FFM mass measured by DXA (only significant models are presented).

	Independent variable	Multiple R	R^2	F	p
Strength-trained (n = 33)					
Bone mineral content	FFM	0.578	0.334	7.52	0.015
Endurance-trained (n = 32)					
Bone mineral content	FFM	0.878	0.770	53.67	0.000
BMD L2–L4	FFM	0.813	0.662	31.29	0.000
BMD femoral neck	FFM	0.594	0.353	8.74	0.009
BMD total body	FFM	0.568	0.323	7.64	0.014
Normal-weight untrained (n = 41)					
BMD L2–L4	FFM	0.774	0.599	7.46	0.041

Somatotype components seldom characterised BMC or BMD. Only in the endurance-trained group did ectomorphy explain BMD in femoral neck (21.3%; R^2x100) and in lumbar spine (20.9%; R^2x100).

BMC in the strength-trained group was first of all dependent on the lower body anthropometrical parameters (Table 6). From the skinfolds thigh (18.2%; R^2x100), from girths calf (25.2%; R^2x100), from lengths trochanterion (24.1%; R^2x100) and from breadths/lengths sitting height together with femur (51.4%; R^2x100) were selected. There were some differences between BMD in different locations and anthropometry (see Table 6). From the skinfolds, thigh was the most important, explaining 17.2–26.1% (R^2x100) of the total variance (except in site L2–L4). From the lengths parameters, trochanterion was the most important, influencing the femoral neck BMD 16.7%. Interestingly, from the breadths/lengths, sitting height was the most important (Table 6).

Table 6. Results of the stepwise multiple regression analysis where dependent variables were BMC and BMD and independent variables measured skinfolds (9), girths (13), lengths (8) or breadths/lengths (8) in the strength-trained group (n = 33). Only significant models are presented.

	Anthropometry	Independent variable	Multiple R	R^2	F	p
BMC	Skinfolds	Front thigh	0.427	0.182	5.79	0.024
	Girths	Calf	0.502	0.252	8.75	0.007
	Lengths	Trochanterion	0.491	0.241	8.27	0.008
	Breadths/lengths	1.Sitting height	0.622	0.388	16.42	0.000
		2.Sitting height	0.717	0.514	13.20	0.000
		Femur				
BMD L2–L4	Skinfolds	Front thigh	0.511	0.261	8.84	0.006
	Breadths/lengths	1.Sitting height	0.420	0.176	5.35	0.029
		2.Sitting height	0.555	0.308	5.35	0.012
		Femur				
BMD femoral neck	Lengths	Trochanterion	0.409	0.167	5.01	0.034
	Breadths/lengths	Sitting height	0.428	0.183	5.60	0.026
BMD total body	Skinfolds	Front thigh	0.486	0.236	7.74	0.010
	Breadths/lengths	Sitting height	0.394	0.155	4.60	0.042

From the endurance-trained group, the skinfold thicknesses did not characterised either BMC or BMD (Table 7). First of all, BMC was dependent on the hip girth (75.2%; R^2x100) or in combination with ankle girth (81.2%; R^2x100). From the length parameters, trochanterion was the most important (55.8%; R^2x100) and from breadths/lengths, sitting height (57.1%; R^2x100). BMD in the weight-bearing sites was dependent on the anthropometrical parameters of legs (i.e., hip girth, trochanterion length and foot length), characterising 30.7–50.0% (R^2x100). BMD on distal radius was only dependent on the arm tensed girths (38.6%; R^2x100).

Table 7. Results of the stepwise multiple regression analysis where dependent variables were BMC and BMD and independent variables measured skinfolds (9), girths (13), lenghts (8) or breadths/lengths (8) in the endurance-trained group (n = 32). Only significant models are presented.

	Anthropometry	Independent variable	Multiple R	R^2	F	p
BMC	Girths	1. Hip	0.867	0.752	60.69	0.000
		2. Hip	0.901	0.812	41.08	0.000
		Ankle				
	Lengths	Trochanterion	0.747	0.558	25.26	0.000
	Breadths/lengths	Sitting height	0.755	0.571	25.58	0.000
BMD L2–L4	Girths	Hip	0.707	0.500	19.98	0.000
	Lengths	Trochanterion	0.598	0.357	11.13	0.003
	Breadths/lengths	Foot lengths	0.655	0.428	14.99	0.001
BMD femoral neck	Girths	Calf	0.554	0.307	8.86	0.007
	Breadths/lengths	Foot lengths	0.560	0.314	9.16	0.007
BMD distal radius	Girths	Arm tensed	0.621	0.386	12.57	0.002
BMD total body	Girths	Arm tensed	0.632	0.400	13.33	0.002
	Breadths/lengths	Foot lengths	0.547	0.299	8.54	0.008

In normal-weight females, BMC was dependent on the calf girth (31.1%; R^2x100), trochanterion length (28.2%; R^2x100) and sitting height (29.8%; R^2x100) (Table 8). In the overweight group, only chest girth (20.1%; R^2x100) and biacromial breadth/length (27.0%; R^2x100) characterised BMC. BMD in weight-bearing sites (L2–L4 and femoral neck) was dependent on normal BMI females on front thigh skinfolds, calf girths and sitting height. In the overweight group, there was no significant relationship between BMD and anthropometry.

Table 8. Results of the stepwise multiple regression analysis where dependent variables were BMC and BMD and independent variables measured skinfolds (9), girths (13), lengths (8) or breadths/lengths (8) in normal-weight untrained group (n = 41, A) and overweight untrained group (n = 23, B). Only significant models are presented.

	Anthropometry	Independent variable	Multiple R	R^2	F	p
A						
BMC	Girths	Calf	0.557	0.311	13.51	0.001
	Lengths	Trochanterion	0.531	0.282	11.76	0.002
	Breadths/lengths	Sitting height	0.546	0.298	12.72	0.001
BMD L2–L4	Skinfolds	Front thigh	0.354	0.126	4.46	0.043
	Girths	Calf	0.473	0.224	8.95	0.005
	Breadths/lengths	Sitting height	0.520	0.271	11.51	0.002
BMD femoral neck	Girths	Calf	0.349	0.155	5.69	0.023
BMD total body	Skinfolds	Front thigh	0.426	0.182	6.88	0.013
	Girths	Calf	0.489	0.239	9.75	0.004
B						
BMC	Girths	Chest	0.448	0.201	4.77	0.042
	Breadths/lengths	Biacromial	0.520	0.270	7.04	0.016

Plasma leptin concentration was significantly higher in overweight females when compared to strength- and endurance-trained ($p < 0.001$) and normal-weight untrained females ($p < 0.01$). Measured sex hormone values were within normal reference ranges in all subjects of the study. There were no significant differences between any of the measured groups in estradiol and progesterone values. IGF-1 concentration was lower in the overweight untrained group compared with the endurance-trained females (Table 9).

Table 9. Blood hormonal values of the subjects (mean ± SD)

	Strength-trained (n=33)	Endurance-trained (n=32)	Normal weight untrained (n=41)	Overweight untrained (n=23)
Leptin (ng/ml)	7.5 ± 6.9	4.7 ± 5.0	8.7 ± 7.1	16.0 ± 8.3 %£&
Estradiol (pmol/l)	162.2 ± 154.9	166.1 ± 215.5	165.7 ± 220.9	146.8 ± 141.3
Progesterone (nmol/l)	1.3 ± 0.6	1.7 ± 1.7	1.9 ± 1.5	1.6 ± 0.6
IGF-1 (µg/ml)	205.6 ± 66.2	240.1 ± 70.0	204.0 ± 81.9	186.0 ± 49.9#

Superscripts indicate a significant mean difference between groups as follows:
* $p < 0.05$ compared to strength-trained females
# $p < 0.05$ compared to endurance-trained females
¤ $p < 0.05$ compared to normal weight untrained females
& $p < 0.01$ compared to normal weight untrained females
% $p < 0.001$ compared to strength-trained females
£ $p < 0.001$ compared to endurance-trained females

No significant relationships were found between measured hormones and BMD parameters in strength-trained females, also between plasma leptin and any other BMD parameters in overweight untrained females (Table 10). In endurance-trained and normal-weight untrained females, leptin was correlated significantly with L2–L4 BMD (r = 0.461 and r = 0.456, respectively), while in endurance-trained females, progesterone was significantly related (r = 0.76) to femoral neck BMD. In normal-weight untrained distal radius BMD correlated significantly with leptin concentration (r = 0.388). However, by using a partial correlation analysis where body FM was controlled, the relationships were not any more significant. In normal-weight untrained females, IGF-1 was related to femoral neck (r = 0.40) and distal radius (r = 0.40) BMD. In overweight untrained females, IGF-1 was related to distal radius BMD (r = 0.57).

Table 10. Relationships between BMD and hormone parameters in different groups of subjects

	L2–L4	Femoral neck	Distal radius	Total
Strength-trained (n=33)				
Leptin	–0.09	0.14	–0.18	0.17
Insulin-like growth factor-1	0.03	–0.07	0.03	–0.01
Progesterone	–0.07	0.10	–0.05	–0.06
Estradiol	–0.02	–0.02	–0.01	0.01
Endurance-trained (n=32)				
Leptin	0.46*	0.38	0.18	0.38
Insulin-like growth factor-1	0.11	–0.10	–0.30	0.08
Progesterone	0.09	0.76***	0.25	–0.12
Estradiol	0.05	0.08	0.25	0.23
Normal-weight untrained (n=41)				
Leptin	0.46*	0.28	0.39*	0.28
Insulin-like growth factor-1	0.27	0.40*	0.40*	0.25
Progesterone	–0.14	0.05	–0.01	–0.18
Estradiol	0.18	0.04	–0.04	0.04
Overweight untrained (n=23)				
Leptin	0.20	0.23	0.18	0.24
Insulin-like growth factor-1	0.21	0.10	0.57**	0.38
Progesterone	–0.12	–0.34	–0.25	–0.27
Estradiol	–0.19	–0.28	–0.09	–0.16

* $p<0.05$
** $p<0.01$
*** $p<0.001$

According to the results of the stepwise multiple regression analysis in strength-trained and overweight untrained females, none of the measured bone variables was a predictor of combined plasma leptin level and body composition parameters (body mass, BMI, body fat % and FM). In endurance-trained females, only progesterone was related to the femoral neck BMD (57.3%; R^2x100), while in normal-weight untrained females, IGF-1 was related to the femoral neck BMD (16.9%; R^2x100). In overweight untrained females, IGF-1 was related to the distal radius BMD (33.2%; R^2x100).

Overweight untrained females had lower jumping height in CMJ compared to other measured groups (Table 11). Maximal ISOM strength was lower in normal-weight untrained females compared to other measured groups. Normal-weight untrained females had also lower maximal ISOK strength compared to strength-trained females (Table 11).

Table 11. CMJ height and knee extension strength characteristics in different groups of subjects (mean ± SD)

	Strength-trained (n=33)	Endurance-trained (n=32)	Normal-weight untrained (n = 41)	Overweight untrained (n = 23)
CMJ (cm)	28.7±4.4	26.1±4.9	23.8±3.7 *	19.9±3.1*#¤
ISOM (N)	522.5±81.4	507.3±83.9	444.7±76.4 *#	505.7±78.8¤
ISOK (N·m)	200.6±106.8	179.8±48.8	154.7±61.9 *	168.8±39.9

* $p < 0.05$ compared to strength-trained females
# $p < 0.05$ compared to endurance-trained females
¤ $p < 0.05$ compared to untrained females

Among the anthropometrical parameters, LBMD was dependent on BMI (33.7%; R^2x100) in endurance-trained females. In overweight untrained females, LBMD was dependent on the maximal ISOK strength (21.7%; R^2x100). Anthropometrical and leg strength parameters did not characterise LBMD in strength-trained and normal-weight untrained females (Table 12). In different groups of subjects, different anthropometrical parameters characterised LBMC (Table 12). In strength-trained females, body mass highly characterised LBMC (71.6%; R^2x100) and strength parameters did not characterise LBMC at all. In endurance-trained females, only body height (37.9%; R^2x100) characterised LBMC. In normal-weight and overweight untrained females, the most important anthropometrical parameter was FFM, characterised 52.1% and 61.4 % of LBMC, respectively. In these groups, the role of strength parameters was relatively low. Maximal ISOM strength characterized 15.3% and 25.9% of LBMC, respectively. However, the maximal ISOM and ISOK strength values together characterised LBMC highly (64.8%; R^2x100) in overweight untrained females. The differences between LBMC and DLBMC were small in all groups (DLBMC data not presented).

Table 12. Stepwise multiple regression analysis with LBMD or LBMC as a dependent variables and anthropometry or strength parameters as independent variables.

	Parameter	R^2	SEE	p
LBMD				
Anthropometry				
Endurance-trained	BMI	0.337	0.075	< 0.003
Leg strength parameters				
Overweight untrained	ISOK	0.217	0.067	< 0.033
LBMC				
Anthropometry				
Strength-trained	Body mass	0.716	79.6	< 0.001
Endurance-trained	Height	0.379	133.3	< 0.001
Normal-weight untrained	LBM	0.521	80.7	< 0.001
Overweight untrained	LBM	0.614	116.9	< 0.001
Leg strength parameters				
Normal-weight sedentarty	ISOM	0.153	107.3	< 0.022
Overweight untrained	1. ISOM 2. ISOM ISOK	0.259 0.648	162.1 111.9	< 0.018 < 0.001

6. DISCUSSION

6.1. Anthropometric and body composition characterisation of bone mineral density

Body mass, FFM and lower body anthropometrical parameters were the variables that first of all influenced BMD and BMC in healthy young females with different physical activity and body composition parameters. Surprisingly, the measured anthropometrical parameters did not influence bone BMD and BMC in overweight untrained females, who's BMC and BMD mean parameters were the highest recorded compared to other study groups.

There are conflicting results about the influence of body height, body mass and BMI on the BMC and BMD in different female populations studied. For example, Asomaning et al. (2006) found that females with lower BMI have a significantly higher risk for osteoporosis compared with normal weight women, while Rico et al. (1994) indicated that body mass is the main determinant of bone mass in post pubertal women. In another study, BMC is dependent on both body height and body mass in a heterogeneous group of 17–82-year-old women (Lindsay et al. 1992). In contrast, Hsu et al. (2006) found that risk of osteoporosis, osteopenia, and nonspine fractures are significantly higher for subjects with higher percentage body fat independent of body mass, physical activity, and age. Therefore FM has a negative effect on bone mass in contrast with the positive effect of weight-bearing itself. Interestingly, in our study, in both physical activity groups, spine BMD (L2–L4) is dependent on body mass while in both untrained groups, this relationship is absent. This means that during regular physical activity, total body mass (whether it is FFM or FM) is the most important predictor of spine BMD. On the other hand, it is quite difficult to explain why BMI highly characterised BMD in femoral neck and especially in distal radius in the endurance-trained group (see Table 4). The differences could be because of the methodology used and/or subjects chosen, or because of the training nature of the subjects. As majority of the endurance group females were skiers who during also the snow free period did the simulation training (very similar to skiing), so maybe the link between BMI and distal radius was the constant mechanical loading to this site. But on the contrary, Davis et al. (1996) indicated in untrained women a close relationship between BMI and BMC in spine and calcaneum.

There are some differences in the results of the stepwise multiple regression analyses between the strength- and endurance-trained groups, where the dependent variables were BMC and BMD in different skeletal sites and from the anthropometrical parameters separately skinfolds, girths, lengths and breadths/lengths were entered as independent variables (see Tables 6 and 7). However, as a rule, in the models, parameters were selected that were located

on the legs. From the skinfolds, only in the strength-trained group, the front thigh was selected; in the endurance-trained group, the skinfolds were not selected at all. In physical activity groups, a high proportion of FM situated in the subcutaneous compartment could explain why skinfolds are relatively good predictors of total body fat (Stewart and Hannan 2000). Interestingly, in the endurance-trained group, hip girth (75.2%; R^2x100) and especially in combination with ankle girth (81.2%; R^2x100) highly characterised BMC. In the strength-trained group, calf girth was the most important, characterising 25.2% (R^2x100) of the total variance in BMC. The leg length (trochanterion) was more important in the endurance-trained females (55.8%; R^2x100) compared with the strength-trained group (24.1%; R^2x100). BMD in weight-bearing sites in the strength-trained group was dependent on the sitting height or trochanterion length and in the endurance-trained, on the hip or calf girth and trochanterion length.

In normal-weight untrained females, BMC was dependent on calf girth, trochanterion length and sitting height from the anthropometrical parameters (see Table 8). However, the relationship appeared not to be high compared with physical activity groups (28.2–31.1%; R^2x100). Surprisingly, in overweight untrained group, only chest girth and biacromial breadth/length significantly characterised BMC. It is surprising that, for example, skinfolds were not important. It is interesting that the largest skinfold thicknesses in abdomen area (highly influencing total body mass) were not included in the model. In children, as a rule, adiposity measured by skinfold thickness does not appear to be an independent predictor of bone mineral measures once an adjustment has been made for the height or frame size (Miller et al. 1991). Normally, total body FM is not a limiting factor of BMC in women (Bedogni et al. 2002). To our knowledge, no studies have been made about the detailed anthropometrical parameters that could characterise BMC or BMD. Only Trivitayaratana et al. (2001) concluded that in women, arm span is not significantly correlated with BMD in young women.

From the somatotype components, only ectomorphy was important, significantly characterising BMC in the endurance-trained group (33.4%; R^2x100). In the endurance-trained group, ectomorphy moderately characterised BMD in spine (L2–L4) at 20.9% (R^2x100) and in femoral neck at 21.3% (R^2x100). The dominant role of ectomorphy, which describes the relative slenderness of the body (Carter and Heath 1990), on the endurance-trained group, is understandable because from the single anthropometrical parameter the trochanterion length and sitting height were dominant (see Table 7).

Several studies have indicated that from the body composition parameters, FFM is the main predictor of BMD in young women (Madsen et al. 1998, Witzke and Snow 1999, Valdimarsson et al. 1999, Vicente-Rodriguez et al. 2004, Blain et al. 2006). In our study, this relationship was strongest in the weight-bearing (endurance-trained) group and on the weight-bearing sites of the skeleton (see Table 5). Interestingly, in non-weight-bearing exercises, only

BMC was dependent on FFM and there was no relationship with BMD (see Table 5). In the strength-trained group, BMC was not significantly ($p>0.05$) higher than in the other groups, except the overweight untrained group. It is surprising that relatively high LBM and BMI values were not related to BMD in the strength-trained group. Probably, the reason is that weight exercises are using more whole body muscles (trunk, lower and upper limbs). For the endurance-trained women, it is more common to use lower limbs when exercising. Interestingly, in the untrained group, body composition parameters did not characterise either BMC or BMD (except BMD in L2–L4 site characterised by FFM). Body fat is normally not a significant predictor of BMC or BMD in young healthy women. However, FM would exert a mechanical effect as a component of body mass, evident in the lower limbs, while muscle contraction would induce a more significant dynamic effect in both lower and upper limbs. The results of present study are in agreement with Weiler et al. (2000) and Hsu et al. (2006) studies in that greater amounts of body FM relative to body mass could be a marker of lifestyles that do not support the attainment of optimal BMC in young women.

6.2. Relationships between leptin concentration and bone mineral density

Strength-trained and overweight untrained females were found not to have any significant relationships between plasma leptin and different BMD values, while in endurance-trained and normal-weight untrained females, this relationship was significant only in lumbar spine BMD. Distal radius BMD correlated with leptin only in normal-weight untrained group. However, when controlled for body FM, these relationships were not any more significant. This demonstrates that BMD is controlled by leptin only via body FM.

To our knowledge, the possible relationship between plasma leptin and BMD in premenopausal strength-trained females has not been studied before. Kontogianni et al. (2004) studied perimenopausal women and concluded that circulating leptin showed a negative correlation with bone mass, dependent on serum insulin level. While Ryan et al. (2000) investigated changes in plasma leptin and insulin action with resistive training in postmenopausal women and found that resistive exercise did not affect plasma leptin concentration independent of changes in body fat. This means that the changes in body fat (i.e., through body mass loss) are necessary for inducing reductions in leptin levels with resistive training. These findings might explain why no significant relationships were found between plasma leptin and different BMD values in our study. It is suggested that strength-training increases BMD in weight-bearing sites and decreases body mass (due to a decrease in body fat) and a negative relationship might appear between plasma leptin levels and BMD,

while also caloric deprivation is characterized by important decreases in the leptin, insulin, and IGF-1 levels (Haspolat et al. 2007). This was also the main finding in the study of Houmard et al. (2000) that exercise training that did not alter body mass, and did not change the fasting plasma leptin concentration in young and older individuals either. Courteix et al. (2007) found that hypoleptinemia induced by intensive and stressing physical training does not affect the bone health of adolescent elite rhythmic gymnasts. These results suggest that exercise training does not independently regulate fasting plasma leptin (Houmard et al. 2000). Our study was cross-sectional and therefore we cannot speculate whether there have been changes in body composition during their training history and why there were no significant relationships between plasma leptin and measured BMD values. A subsequent testing is needed for drawing any further conclusions.

Leptin was related to lumbar spine BMD at the site that is a load-bearing one in endurance-trained females, whose body fat % was also low. It has been suggested that physical activity may reduce leptin mRNA expression in rats (Friedman et al. 1997) and lower the abdominal tissue leptin production rate in humans (Racette et al. 1997). A training program that improves insulin sensitivity could alter plasma leptin concentrations independently of adipose tissue mass (Considine 1997). Similarly to other studies (Thomas et al. 2001), the results of our study of normal-weight untrained females show the existence of an association between plasma leptin levels and BMD at distal radius. Our normal-weight untrained females did not participate in any kind of physical activity. On the contrary, it has been described that muscles play a critical role in bone growth and modelling because the greatest loads on bone come from muscle contraction (Burr 1997).

We did not find a relationship between plasma leptin levels and measured BMD values in overweight untrained females. These results are similar to the study of Rauch et al. (1998), where no relation of plasma leptin levels to the total and distal radius BMD was found in obese women. This finding is contrary to the study of Liu et al. (1997), where the effect of leptin on cortical bone was studied. It is well known that obesity is associated with higher BMD (Heaney 1996), which can be explained by the muscle-mediated mechanical effects of increased body mass on bone (Frost 1997) and that leptin levels are higher in obese populations (Castracane et al. 1998). In obese humans, high plasma leptin levels can be associated with leptin resistance because of impaired transport of leptin to the hypothalamus (Ruhl and Everhart 2002). The lack of significant correlation of plasma leptin levels with measured BMD values in obese women might be caused by decreased leptin function despite high levels that occur with leptin resistance (Ruhl and Everhart 2002). Our study did not have the limitation that occurred in a study of Ruhl and Everhart (2002), where BMD was measured only at the proximal femur. In our study, BMD was also measured at L2–L4 and distal radius. It is possible that leptin influences the modelling of growing bones rather than the remodelling of the mature skeleton (Rauch et al.

1998), as mentioned by Ruhl and Everhart (2002), that in all cross-sectional studies leptin was measured at one point in time, while bone mass is accumulated and lost over a lifetime.

6.3. Relationships between IGF-1, estradiol and progesterone concentrations and bone mineral density

BMD at the femoral neck correlated significantly with progesterone (in endurance-trained females) and IGF-1 concentration (in normal-weight untrained females). In overweight untrained group, BMD was dependent on the IGF-1 concentration on the non-weight-bearing site (i.e. distal radius). These results are interesting because it was the first time that the female sports groups were made up of subjects that practise both non-impact and weight-bearing activities. The strength-trained group consisted of women who were practising both kinds of sports and some who belonged to the endurance group were used for non-weight-bearing exercises (swimmers).

It has been found that resistance training, which places heavy loads on the skeleton during a training session increased both strength and muscle mass (Snow-Harter et al. 1992), did not change (Gleeson et al. 1990) or even decreased (Rockwell et al. 1990) BMD in premenopausal women. In our study, strength-trained females had higher BMD than the endurance-trained ones. However, the difference was statistically significant in BMD value at the lumbar spine L2–L4. On the other hand, overweight untrained females had similar BMD values to the strength-trained females (see Table 3). Heinonen et al. (1996b) suggested that exercise intensity should be above the aerobic threshold, corresponding to 60% to 70% of the maximal oxygen consumption for increasing BMD. Finally, Afghani et al. (2004) noted that aerobic capacity is an important predictor of BMD.

The female sex hormone estradiol did not show a significant relationship with BMD in any investigated group, which is in agreement with other studies (Bemben et al. 2004). Recently, Kaga et al. (2004) concluded that in female adult long distance runners, intense training may be beneficial for the cortical bone status via increasing the muscle strength, but the abnormal sex steroid environment may have a lesser effect on bone metabolism.

There are some studies that have investigated the efficacy of combined estrogen and progesterone treatment for the protection of bone mass in young active women with a low body mass amenorrhea, where the majority has shown no beneficial effect (Munoz et al. 2002, Klibanski et al. 1995). Participants in both athletic groups (endurance- and strength-trained) were not very lean and they all have a regular menstrual cycle. On the other hand, their mean body fat % was slightly lower than the “critical point of body fat“ (22 %) proposed by Frish and McArthur (1974) after regular menstruation. However, in our study, estradiol concentration varied greatly with different subjects. 12 subjects in the

strength-trained group had very near to the lower physiological norm in the early follicular phase (<108 pmol/L), this was also the case for 14 subjects in the endurance group, 21 in untrained normal-weight group and 13 in untrained overweight group. The mean estradiol concentrations in different groups were not statistically different and on the lowest acceptable level which is suggested by other investigators as being optimal for preventing postmenopausal bone loss (Reginster et al. 1992). Interestingly, estradiol correlated significantly with progesterone only in the normal-weight untrained group ($r = 0.83$). On the other hand, it is well known that estrogen used alone or in combination with progesterone has been shown to have a protective effect against bone loss in postmenopausal women (Delmas 1999).

IGF-1 concentration, which is a well-known effective osteoporotic growth factor, correlated significantly with femoral neck BMD in untrained normal-weight group and with distal radius BMD in the untrained overweight group. Using stepwise multiple regression analysis, where the BMDs in different skeletal sites were predictor variables and three blood biochemical parameters as dependent variables, only IGF-1 was selected to characterise in normal-weight untrained group 16.9% (R^2x100) and in overweight group 33.2% of the total variance in BMD values. It is well known that IGF-1 usually influences bone growth and BMD (Ohlsson et al. 1998). Interestingly, the relationship is high in women younger than 35 years, i.e. during the peak period of bone mass (Ravn et al. 1995). There is a strong relationship between the magnitude of reduction of IGF-1 concentration and markers of bone formation under the conditions of energy reduction (Zanker and Swane 2000).

Relationship between IGF-1 and estradiol concentrations in each studied group was not significant. It is surprising because both parameters influenced BMD highly and on the other hand, estradiol is known to potentiate IGF-1 actions (Dupont et al. 2000). It is possible that the anabolic effect of IGF-1 may require estradiol. However, further studies are needed to establish whether the lack of IGF-1 anabolic effects on BMD in young physically active women is really dependent on the estradiol availability (amenorrhea, etc.).

6.4. Relationships between strength values and bone mineral density

Normal-weight untrained females had significantly lower results in ISOK values compared to other measured groups. Only in untrained normal- and overweight females, ISOK and anthropometrical parameters correlated significantly with LBMD, while FFM and ISOM correlated with LBMC. In the summarised untrained group, the characterisation of FFM on LBMC was higher than in the physically active group.

Information from human studies has documented a significant relationship between bone mass and maximal muscle strength (Pocock et al. 1989, Sinaki et

al. 1989). It has also been demonstrated that a weight training program increased muscular strength but did not increase the measured bone mass (Peterson et al. 1991). Hind et al. (2006) found significantly lower lumbar spine BMD both in male and female runners compared to reference values, while subjects had normal hip BMD values. In our study, strength-trained females had higher LBMD compared to normal-weight untrained females, while endurance-trained and normal-weight untrained females had significantly lower LBMC and DLBMC compared to overweight untrained females. Surprisingly, there were no significant differences between the strength-trained and any other measured groups of females in BMC values. Even in the physically active group, compared to the physically inactive group, there were no significant differences in LBMC, DLBMC and LBMD values (see Table 3). This may be explained by the findings of Reid et al. (1992), in which total FM was found to be the best predictor of total BMD in premenopausal women. In contrast, other researchers have found total FFM to be a more important contributor to BMD than total FM. For example, Nichols et al. (1995) found that regional FFM was a better predictor of BMD than regional FM, whereas regional leg FFM was found to be positively related to the corresponding regional BMD. Although leg FM was significantly related to LBMD, the relationship was weaker than that with leg FFM. This is in agreement with our study in the physically active group. However, the characterisation is quite weak – only about 15% of the total variance (see Table 12) in physically active women.

Normal-weight untrained females showed significantly lower ISOM values compared to all other measured groups. This might be explained by the fact that they also had significantly lower FFM compared to all other measured groups. This opinion is supported also by the recent study of Lorentzon et al. (2006) who concluded that lean mass has a greater impact on bone mass that adipose tissue. It was also found that only normal-weight untrained females had significantly lower BMD values compared to strength-trained females, while endurance-trained and normal-weight untrained females had significantly lower LBMC and DLBMC compared to overweight untrained females. Surprisingly, there were no differences in LBMC and DLBMC values between normal-weight untrained and strength-trained females.

In a study of premenopausal women (20–35 yrs), Friedlander et al. (1995) reported a significant regional increase in BMD (~2%) between the strength-trained athletes and the control group. Same trend occurred in Torstveit and Sundgot-Borgen (2005) study, where female athletes had 3–20% higher BMD than non-athletic controls and high-impact sports athletes had 3–22% higher BMD compared with medium and low-impact sports athletes. On the other hand, the studies of Heinonen et al. (1996a), Snow-Harter et al. (1992), and Vuori et al. (1994) showed that strength-training did not significantly increase the regional BMD when compared to a untrained group. It might be that human body prefers active muscle forces (muscles exhibit structural adaptation more easily and rapidly than bones), ensuring minimal bone mass (Munih et al.

1992). Bone strength must be adequate for the mechanical competence required, but bones must also allow effective locomotion with minimal bone weight (Heinonen et al. 1996a). It must also be drawn out that isometric strength tests bear little resemblance to the dynamic nature of most everyday physical activity tasks (Wilson and Murphy 1996).

Normal-weight untrained females had significantly lower ISOK values compared to strength-trained females. Normal-weight untrained females had lower LBMD compared to strength-trained females. It is similar to the findings of Nordström et al. (1995), where a site-specific relationship between BMD and muscle strength was found. The results suggest that FFM significantly characterised LBMC and DLBMC in normal- and overweight untrained females. It was interesting to find that in both training groups, FFM, on the contrary, did not characterise BMD or BMC. Putting physically active and passive women together in one group, FFM highly characterised LBMC. Thus we can conclude that LBMC is more influenced by LBM than LBMD (see Table 12).

Surprisingly, none of the measured parameters influenced LBMD in strength-trained and normal-weight untrained females. In strength-trained females, body mass was the only measured parameter that influenced DLBMC and LBMC. In endurance-trained females, BMI influenced LBMD. In normal- and overweight untrained females, FFM, ISOM (in normal-weight untrained females), and ISOK (in overweight untrained females) influenced DLBMC and LBMC. The only measured parameter that influenced LBMD in overweight untrained females was ISOK. BMD has been found to be associated with the strength of the anatomically related structures; positive associations have also been found between bone mass and FFM, and between BMD and muscular strength (Aloia et al. 1995, Ryan et al. 1998). Ryan et al. (2004) have found significant associations between lean tissue mass and total BMD and all regional measures of BMD in young women. Among the women, knee extension and flexion strength has been found to correlate with total BMD (Ribom et al. 2004). Moreover, lower limb muscle strength explained approximately 30% of total BMD in women (Ribom et al. 2004). Ribom et al. (1999) also found significant associations between maximal knee extension ISOM strength and total BMD in premenopausal women.

These findings are quite similar with our findings, but surprisingly, in our study, FFM characterised LBMC and DLBMC only in normal- and overweight untrained females. Moreover, none of the measured anthropometrical and muscle strength parameters characterised LBMD in strength- and endurance-trained females. It has been shown that athletes have higher muscle strength and BMD values compared to non-athletic groups mostly in site-specific regions. The association between muscle strength and BMD has been found to be the strongest in those with low to moderate levels of physical training (Sandström et al. 2000). It might explain our findings, where in athletic women, LBMD was not associated with measured strength values.

7. CONCLUSIONS

1. FFM was the most important parameter to predict total BMD and BMC values, while lower body anthropometric parameters were the most important parameters to predict areal BMD in healthy young females. Ectomorphy from the somatotype components was the predictor of measured BMD values in endurance-trained females only.
2. Plasma leptin concentrations, as a rule, were not related to measured BMD values in healthy young females. However, plasma leptin concentration characterised BMD values at skeletal site of spine in endurance-trained and normal-weight untrained females, and at distal radius in normal-weight untrained females when the influence of body fat mass was controlled.
3. Relationships between measured BMD values and IGF-1, estradiol and progesterone concentrations were significant but modest in healthy young females with different physical activity and body composition.
4. Isometric and isokinetic knee extensor muscle strength parameters were not related to measured BMD values in healthy young females. No relationships were observed in physically active groups, while isometric and isokinetic strength values were related to BMD values in untrained normal-weight and overweight females, respectively.

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SUMMARY IN ESTONIAN

Luu tihedus noortel erineva kehalise aktiivsusega naistel: seosed keha koostise, jalgade jõu ja vere hormonaalsete näitajatega

Sissejuhatus

Luu on ainevahetuslikult aktiivne kude, mis uueneb kogu elutsükli vältel. Erineva iseloomuga kehalisel koormusel on erinev mõju luu tihedusele, kusjuures enim on kehalisest treeningust mõjutatud koormust kandvad skeleti piirkonnad nagu reieluu kael ja selg.

Hoolimata mitmetest kõrvalnähtudest (südame-veresoonkonna haigused, diabeet jne.) seostatakse ülekaalu kõrgema luu tihedusega ja väiksema luumurdude arvuga. Liigne rasva mass, mis kaasneb rasvumisega, annab luudele suurema mehaanilise koormuse, mis omakorda aitab kaasa luu tiheduse suurenemisele. Tuleb aga meeles pidada, et rasvkoe ladestumise piirkonnad on heterogeensed. Rasva massi suurenemisega suureneb ka rasvavaba mass, mis omakorda mõjutab luu tihedust. Seega, lisaks skeletile rakenduvale mehaanilisele koormusele omavad luu tiheduse väärtuste juures olulist rolli ka keha koostise parameetrid.

Kuigi täpne mehhanism ei ole veel päris teada, avaldavad erinevad hormoonid mõju luu tiheduse ja rasva massi vahelisele seosele. On teada, et insuliin ja IGF-1 omavad positiivset mõju luu tihedusele läbi insuliini retseptori. Teine tähtis luu tihedust mõjutav faktor on leptiin, mida sünteesitakse peamiselt rasvkoes ning mis reguleerib söögiisu, glükoosi homöostaasi ja keha rasva sisaldust ning mille puudulikkust organismis seostatakse ülekaaluga. Arvatakse, et leptiini kontsentratsioon veres on seotud ka paljude muude teguritega, kuna sama keha koostisega inimestel võib esineda suur variatiivsus leptiini sisalduses. Naissuguhormoonid östrogeen ja progesteroon pärinevad ühest ja samast eellasest testosteroonist ning aitavad vältida luukadu ning nende koosmanustamisel on võimalik stimuleerida leptiini sekretsiooni. On leitud, et östrogeen mõjutab ajus leptiini tundlikkust, vähendab insuliini tundlikkust ning soosib nahaalust rasvkude vistseraalsele rasvkoele.

Regulaarne kehaline aktiivsus nii lapsepõlves kui ka täiskasvanueas aitab vältida osteoporoosi teket. Erinevatest kehalistest koormustest omab luu tihedusele positiivseimat mõju hüpped ning jõutreening, ehk siis suure löögiimpulsiga harjutused. Vähendades kehalist aktiivsust väheneb ka luu tihedus. Siinkohal esineb küllalt vastukäivaid uuringutulemusi: on leitud, et endistel sportlastel taandareneb luu tihedus mittesportlastest kiiremini, samas luu tiheduse väärtused jäävad mittetreenitute omast kõrgemaks.

Meile teadaolevalt ei ole senini uuritud kompleksselt luu tiheduse seost erinevate füsioloogiliste parameetritega uuritavate rühmadel, mis on grupeeritud

keha koostise ja kehalise aktiivsuse alusel. Seega oli käesoleva uurimistöö eesmärgiks välja selgitada võimalike antropomeetriliste, keha koostise, jalgade jõu ja vere hormonaalsete näitajate seos luu tihedusega erineva kehalise aktiivsuse ja keha koostisega noortel naistel.

Uurimistöö ülesanded:

1. Hinnata võimalikke seoseid luu tiheduse ning antropomeetriliste, somatotüübi ja keha koostise näitajate vahel jõu- ja vastupidavustreeningul osalevate ning kehaliselt treenimata normaal- ja ülekaaluliste noorte naiste rühmades.
2. Uurida võimalikke seoseid leptiini sisalduse ning luu tiheduse näitajate vahel jõu- ja vastupidavustreeningul osalevate ning kehaliselt treenimata normaal- ja ülekaaluliste noorte naiste rühmades.
3. Selgitada välja võimalikud seosed IGF-1, östrogeeni ja progesterooni sisalduse ja luu tiheduse näitajate vahel jõu- ja vastupidavustreeningul osalevate ning kehaliselt treenimata normaal- ja ülekaaluliste noorte naiste rühmades.
4. Leida võimalikke seoseid luu tiheduse, maksimaalse isomeetrilise ja isokineetilise reie nelipealihase jõu ning maksimaalse üleshüppe testi näitajate vahel jõu- ja vastupidavustreeningul osalevate ning kehaliselt treenimata normaal- ja ülekaaluliste noorte naiste rühmades.

Uuritavad ja metoodika

Uuritavateks oli 129 noort naist vanuses 17–40 aastat jaotatuna nelja rühma sõltuvalt nende kehalisest aktiivsusest ja keha koostisest:

1) jõutreeningul osalejad (n=33)
2) vastupidavustreeningul osalejad (n=32)
3) kehaliselt treenimata normaalkaalulised (n=41)
4) kehaliselt treenimata ülekaalulised (n=23)

Uuritavatel mõõdeti:

- keha pikkus (cm), keha kaal (kg), arvutati KMI (kg/m^2)
- antropomeetrilised näitajad vastavalt ISAKi (1996) soovitustele:
  - 9 nahavolti, 13 ümbermõõtu, 8 laiust, 8 pikkust/laiust
- arvutati Heath-Carteri (1990) metoodika alusel järgmised somatotüübi komponendid:
  - endomorf, mesomorf, ektomorf
- DXA meetodil luu tihedus (BMD, $g \cdot cm^{-2}$) järgmistes skeleti piirkondades:
  - kogu keha, dominantse käe ranne, L2–L4, reieluu kael, mõlemad jalad

- DXA meetodil luu mineraalne sisaldus (BMC, g) järgmistes skeleti piirkondades:
  - dominantne jalg, mõlemad jalad
- DXA meetodil keha koostis:
  - kogu keha rasva%, rasva mass (kg), rasvavaba mass (kg)
- vere näitajad (veeniveri 10 ml):
  - plasma leptiin, östradiool, progesteroon, IGF-1
- lihasjõud:
  - maksimaalne dominantse jala reie nelipealihase isomeetriline jõud (N) ja isokineetiline jõud (N·m), poolkükist üleshüpe (cm)

Järeldused

1. Rasvavaba mass määras enim kogu keha luu tihedust ja luu mineraalide sisaldust, kusjuures piirkondlikku luu tihedust määrasid enim alakeha antropomeetrilised näitajad. Somatotüübi komponentidest määras mõõdetud luu tiheduse väärtusi ainult ektomorfne komponent ning sedagi ainult vastupidavusaladega tegelevatel naistel.
2. Plasma leptiini sisaldus ei olnud seotud mõõdetud luu tiheduse väärtustega. Siiski vastupidavusaladega tegelevatel ja normaalkaalulistel inaktiivsetel naistel iseloomustas leptiin selja lumbaarpiirkonna ning normaalkaalulistel inaktiivsetel naistel ka randme luutihedust peale kehakaalu kontrollimist.
3. Määratud suguhormoonide ja IGF-1 sisaldus oli tagasihoidlikult seotud luu tiheduse näitajatega.
4. Lihasjõu näitajad ei olnud seotud luu tiheduse näitajatega kehaliselt aktiivsete naiste rühmas, samas isomeetriline ja isokineetiline lihasjõud oli seotud luu tiheduse näitajatega inaktiivsete normaalkaaluliste ja ülekaaluliste naiste rühmades.

ACKNOWLEDGEMENTS

I would especially like to thank:

- Professor Toivo Jürimäe, academic supervisor of this thesis, for the ideas to get started and full support during preparation of the thesis until completion;
- Professor Jaak Jürimäe, the second supervisor of this thesis, for his great help and best advice during my doctorate study;
- All the subjects who went through this study;
- Professor Mati Pääsuke, Dr Helena Gapeyeva and Dr Jaan Ereline for the help during the practical part of the thesis;
- Dr Aire Leppik for the support and help during the practical part of the thesis;
- Dr Ingrid Kull for medical procedures;
- Dr Karin Otter for her constant help and support in completing the thesis;
- My family for their positive attitude and moral support through my doctorate study;
- My friends who have helped me in any way to complete the thesis.

PUBLICATIONS

I

Jürimäe T., Sööt T., Jürimäe J. Effects of anthropometry and body composition on bone mineral content and density in young women with different levels of physical activity. *Journal of Physical Anthropology and Applied Human Science*, 2005, 24(6): 579–587.

II

Sööt T., Jürimäe T., Jürimäe J. Areal bone density in young females with different physical activity patterns: relationships with plasma leptin and body composition. *Journal of Sports Medicine and Physical Fitness*, 2007, 47(1): 65–69.

III

Sööt T., Jürimäe T., Jürimäe J. Relationships between bone mineral density, insulin-like growth factor-1 and sex hormones in young females with different physical activity. *Journal of Sports Medicine and Physical Fitness*, 2006, 46(2): 293–297.

IV

Sööt T., Jürimäe T., Jürimäe J., Gapeyeva H., Pääsuke M. Relationship between leg bone mineral values and muscle strength in women with different physical activity. *Journal of Bone and Mineral Metabolism*, 2005, 23(5): 401–406

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Peamised uurimisvaldkonnad

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- Kinantropomeetria
- Spordifüsioloogia

DISSERTATIONES KINESIOLOGIAE UNIVERSITATIS TARTUENSIS

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