ORIGINAL ARTICLE

Balance control, vitamin D and bone resorption marker in elderly women with osteopenia and osteoporosis

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Abstract

OBJECTIVES: Postmenopausal osteoporotic women are at high risk for fractures that cannot be completely explained only by skeletal, but also by nonskeletal factors such as increased body sway and postural instability. In this study we investigated balance control in healthy and osteopenic/osteoporotic women and the relationship between body sway during stance, 25 hydroxyvitamin D (25OHD) and bone resorption marker.

METHODS: Twenty-five elderly osteopenic/osteoporotic women and 19 healthy age-matched controls participated in the study. Subjects stood quietly under 4 static conditions: on firm and foam surface with eyes either open or closed. Body sway was recorded by two accelerometers fastened on upper and lower trunk and also by force platform, quantifying the centre of foot pressure (CoP) displacement. In serum samples of osteopenic/osteoporotic women, the levels of 25OHD and carboxyterminal telopeptide of type I collagen (CTx) were measured.

RESULTS: Significant differences in amplitude and root mean square of CoP displacement and also trunk tilts were observed between elderly healthy and osteopenic/osteoporotic women especially during the stance with eyes closed. Further higher sway velocity of CoP during the stance on foam support surface was showed in osteopenic/osteoporotic group. Significant correlations between amplitude of body sway and levels of 25OHD and either levels of CTx were found.

CONCLUSIONS: Elderly women with osteopenia/osteoporosis showed slight postural instability. Body sway was more increased in medial-lateral direction and particularly in stance with altered sensory input. Serum levels of 25OHD and bone resorption marker CTx were associated with increased body swaying.

Introduction

Postural control is the basis of our ability to stand and walk independently. Deterioration in postural stability in elderly people may contribute to falls and fall-related injuries incurred during activities in daily life (Melzer *et al* 2004). Balance is constantly controlled by visual, proprioceptive, and vestibular input, making automatic adjustments through the central nervous system. Sensory-motor impairments diminish the

functional state of body movement, furthermore elderly subjects have difficulties adapting to new sensory conditions. Several diseases, and ageing as well, degrade the ability to properly maintain the static balance and mobility can be impaired, too.

The presence of osteopenia and osteoporosis is of great concern for elderly persons presenting with postural instability (Miyakoshi *et al* 2003). It has already been established that bones become weaker, muscle status changes and it causes modifications to posture. The probability of falls and fractures increases, since the centre of gravity is modified, leading to a loss of body balance in osteoporotic individuals (Crepaldi *et al* 2007). The importance of vitamin D for skeletal health is also well known, but its possible association with impaired posture and balance is less clear. Low serum 25 hydroxyvitamin D (25OHD) levels in older adults have been associated with reduced muscle strength, reduced balance control and poor performances in functional tests (Deshi *et al* 2002; Houston *et al* 2007). Relatively, little work has been undertaken with regard to bone turnover markers and impairment of balance in elderly osteoporotic women. Bischoff *et al* (1999) found that poorer mobility was associated with higher bone resorption in elderly people. Worse stability and balance related to increased levels of markers of bone turnover were reported also by Chen *et al* (2006). In elderly women, increased risk of hip fracture has been shown to be associated with the increased levels of bone resorption markers (Garnero *et al* 1996). Thus the relationship between increased postural sway and risk of falling could be mediated through the increase of bone turnover. Evaluation of the risk of falls is of high priority for both research and clinical interventions. While this evaluation is often based on the questionnaires and falls history, more specific measurements of postural stability are needed in the risk groups of older people.

Du Pasquier *et al* (2003) suggest that the simply centre of foot pressure (CoP) on two-leg stance is a reliable way to assess postural stability and argue that postural stability impairment due to ageing can be precisely estimated. However, recent technological developments have led to the production of compact, accurate and easy to wear accelerometers that can reliably measure body tilts in ambulatory conditions (Moe-Nilssen & Helbostad 2002). No previous studies were found examining the postural sway in osteoporotic women by accelerometers, therefore we aimed at assessment of differences in balance behaviour not only using force plate, but also recording the body tilts by inertial accelerometric sensors attached to upper and lower trunk.

This study was designed to investigate the balance control in osteopenic and osteoporotic women and healthy age-matched controls using small lightweigth accelerometers placed on the trunk. The relationship between postural parameters and serum levels of 25OHD and bone resorption marker CTx was examined in the group of senior subjects with osteopenia and osteoporosis. We assumed that postural stability would be impaired in women with osteopenia/osteoporosis compared to healthy controls and it was hypothesized that low 25OHD level and high CTx level would correlate with poor balance.

Material & methods

A group of 15 elderly osteopenic (T-score of hip and/or spine between –1 and –2.5), 10 osteoporotic (T-score of hip and/or spine <–2.5) women and 19 healthy age-matched female controls participated in the study. The women were divided into two groups: group OSTEO was formed by women with osteopenia and osteoporosis (n=25, mean age 71.5±5.6 yrs, height 161±5.9 cm, weight 65.8±12.7 kg, BMI 25.2±4.1), group CONTROL consisted of healthy senior women (n=19, mean age 72.0±5.2 yrs, height 161±6.3 cm, weight 64.8±8.6 kg, BMI 25.0±2.5). None of the subjects reported previous bone fractures, peripheral neuropathies, vestibulopathies, osteoarthritis, diabetes mellitus and other metabolic or neurological diseases, none of them took supplementation with vitamin D at the time of testing. All subjects gave written informed consent prior to participation and the Local Science Ethical Committee approved the experimental protocol.

The balance control of all subjects was evaluated during the quiet stance in four upright postural conditions: standing on a firm surface with eyes open (EO); standing on a firm surface with eyes closed (EC); standing on a foam surface (thickness 10 cm) with eyes open (FEO); standing on a foam surface (thickness 10 cm) with eyes closed (FEC). The subjects stood relaxed on the force platform, barefoot, with the head in a straight-ahead position and arms along the body, with the heels together and feet displayed at angle of about 30°. During conditions with eyes open subjects were instructed to focus their eyes on a stationary eye-level visual target (a black spot with a diameter 2 cm) placed on a white scene in front of them at a distance of 1.5 m. Initial stance position and symmetrical weight loading were made consistent from trial to trial by tracing foot outlines and by monitoring anterior-posterior and medial-lateral position of the centre of foot pressure. The duration of each trial in each condition was 50 s followed by a short rest period (1–3 min).

Body sway was recorded by the custom-made force platform (45×45×5.5 cm) with automatic subject´s weight normalization. The CoP displacements in anterior-posterior (AP) and medial-lateral (ML) directions were recorded at a 100-Hz sampling frequency and after applying a 10-Hz cut-off, zero-phase, low-pass Butterworth filter. Trunk tilts were measured by two ADXL203 dual-axis accelerometers (Analog Devices, Inc., USA) with signal conditioned voltage outputs. Sensors measured in particular static acceleration with a full-scale range of ±1.7 g and the acceleration was converted to the body tilt in degrees. Accelerometric sensors were

calibrated for range ±10 degrees. Acceleration signals from the trunk AP and ML directions were collected also with a 100-Hz sampling frequency, transformed to a horizontal-vertical coordinate system (Moe-Nilssen & Helbostad 2002) and filtered with 10-Hz cut-off, zero-phase, low-pass Butterworth filter. One accelerometer was attached on the spinal column of the upper trunk at the level of the fourth thoracic vertebra (Th4), other one was placed on the spinal column of the lower trunk at the level of the fifth lumbar vertebra (L5) using adhesive tape and flexible belt. Experimental data were analyzed and evaluated in MATLAB®.

For each trial in each condition, five parameters were computed from the resultant planar (2D) displacement of the CoP to characterize posture: A_{ML}, A_{AP} – amplitude of body sway in ML and AP directions, respectively, RMS – root mean square, V_{ML}, V_{AP} – velocity of body sway in ML and AP directions, respectively (Hlavacka *et al* 1990; Prieto *et al* 1996). The same parameters were calculated also from the resultant 2D accelerations measured at Th4 and L5 levels.

In all subjects from the group OSTEO, serum concentration of CTx, a marker of bone resorption and serum level of 25OHD were measured. All biomechanical measurements were performed in duplicate and in identical assay batches. The 25OHD analysis was done with the LC-20AD analytical and measuring device (Shimadzu, Japan) with UV detection using the MassChrom® Kit (Chromsystems, Germany), bone resorption marker CTx was assessed by the immunochemical method using Modular E170 analyser (Roche Diagnostics, Switzerland) with the automated Elecsys immunoassay (Roche Diagnostics, Germany).

The normality of distribution of each analyzed sway parameter was examined using the Shapiro-Wilk test, homogeneity of variance was tested by the Levene´s test. The analyzed parameters were normally distributed and variances between groups were equal, therefore two-way repeated measures ANOVA were used having Vision (eyes open or closed) and Surface (firm or foam) as within-subject factors and Osteo (osteopenia/osteoporosis) as between-subject factor. The paired t-tests were used for detecting differences in all analyzed sway parameters between the group OSTEO and the group CONTROL. Spearman´s correlations (2-tailed) between the levels of 25OHD, CTx and analyzed sway parameters in the group OSTEO were calculated. All statistical analyses were conducted using the SPSS software (SPSS for Windows, V18.0-SPSS Inc., USA) at a significance level of 0.05.

Results

In the first part of our study, we focused on comparing balance control in postmenopausal osteopenic/osteoporotic women and healthy age-matched controls. We assessed balance in four experimental conditions during the quiet stance with presence or absence of vision and with or without alteration of somatosensory input. Postural parameters were evaluated from the CoP displacement, and from the body sway in upper (Th4) and lower (L5) trunk.

Analysis of variance revealed significant effect of factor Osteo on parameters A_{ML} ($F=7.830$, $p<0.01$), V_{ML} ($F=12.885$, $p<0.001$) and RMS ($F=4.068$, $p<0.05$) recorded by force platform (CoP). We observed significant effect of Osteo also on parameters A_{ML} ($F=5.864$, $p<0.05$) and RMS ($F=4.285$, $p<0.05$) of upper trunk tilts (Th4). No significant influence of factor Osteo was found on L5 parameters (Table 1). Analysis showed significant effects of both within-subject factors Vision and Surface on all measured sway parameters at CoP, Th4 and L5 at a significance level of 0.001, also significant interactions Vision x Surface on all parameters were found at the same level of significance. Significant influence of double interactions Osteo x Vision and Osteo x Surface and also significant effect of triple interaction Osteo x Vision x Surface was discovered on some postural parameters, F-coefficients of these interactions with levels of significance are presented in Table 1.

To assess differences in posture control between postmenopausal women from the group OSTEO and the group CONTROL, the paired t-test was conducted on each sway parameter in each experimental condition. All statistically significant differences were found during the stance with absence of vision. Osteopenic/osteoporotic women had a significantly greater medial-lateral amplitude of CoP displacement ($p<0.01$) and also greater amplitude of ML upper trunk tilts ($p<0.05$) compared to healthy controls during the stance on foam support surface with eyes closed. With regard to the anterior-posterior body sway, t-test showed significant increase of trunk tilts in both Th4 and L5 levels in the group OSTEO comparing to CONTROL group. The AP amplitude of upper trunk tilts was significantly increased in OSTEO group during the stance on firm surface with eyes closed ($p<0.05$) and also during the stance on foam surface with eyes closed ($p<0.05$). Similar result was found in parameter amplitude of lower trunk tilts (A_{AP} L5) in anterior-posterior direction. Parameter RMS CoP was significantly different in osteopenic/osteoporotic women compared to controls during the stance on foam surface with eyes closed ($p<0.01$). In female patients with osteopenia/osteoporosis, we observed significant increase of parameters RMS Th4 and RMS L5 in experimental situation with eyes closed standing on the firm surface ($p<0.05$) and RMS Th4 also in situation with eyes closed standing on the foam ($p<0.01$). Figure 1 shows comparison of sway parameters A_{ML}, A_{AP} and RMS of CoP as well as the same parameters of upper (Th4) and lower (L5) trunk tilts between the group CONTROL and the group OSTEO in all experimental conditions. The graphs illustrate mostly the same tendencies of higher values of represented postural parameters in osteopenic/osteo-

Tab. 1. F-coefficients from two-way repeated measures ANOVA of parameters A_{ML}, A_{AP} – amplitude of body sway in ML and AP directions, respectively, RMS – root mean square, V_{ML}, V_{AP} – velocity of body sway in ML and AP directions, respectively, from CoP, upper trunk (Th4) and lower trunk (L5) having Osteo as between-subject factor, Vision and Surface as within-subject factors and interactions between factors Osteo and Vision, Osteo and Surface, Osteo and Vision and Surface.

		Osteo	Osteo × Vision	Osteo × Surface	Osteo × Vision × Surface
CoP	A_{ML}	7.830**	11.313**	17.526***	14.118***
	A_{AP}	0.431	3.158	0.646	0.559
	V_{ML}	12.885***	22.172***	15.618***	19.989***
	V_{AP}	0.009	3.225	0.039	3.405
	RMS	4.068*	8.900**	7.175*	5.619*
L5	A_{ML}	1.412	2.880	1.887	4.749*
	A_{AP}	1.767	6.923*	0.364	0.132
	V_{ML}	0.007	4.913*	0.002	5.225*
	V_{AP}	0.813	1.029	4.211*	0.122
	RMS	2.136	6.386*	0.000	1.423
Th4	A_{ML}	5.864*	3.637	2.316	4.906*
	A_{AP}	3.258	6.154*	0.486	3.192
	V_{ML}	0.235	5.535*	3.106	7.064*
	V_{AP}	0.035	6.255*	0.553	4.016
	RMS	4.285*	6.398*	1.104	5.865*

df=1, *p<0.05, **p<0.01, ***p<0.001

Tab. 2. The grouped averages of values of sway parameters V_{ML}, V_{AP} – velocity of body sway in ML and AP directions, respectively, from CoP, upper trunk (Th4) and lower trunk (L5) in four tested conditions EO, EC, FEO, FEC.

		CONTROL		OSTEO	
		V_{ML}	V_{AP}	V_{ML}	V_{AP}
CoP (cm/s)	EO	0.58 ± 0.07	0.87 ± 0.10	0.63 ± 0.04	0.83 ± 0.06
	EC	0.74 ± 0.10	1.30 ± 0.17	0.91 ± 0.08	1.45 ± 0.19
	FEO	1.07 ± 0.10	1.91 ± 0.23	1.43 ± 0.12*	1.53 ± 0.17
	FEC	1.51 ± 0.14	3.06 ± 0.38	3.10 ± 0.29***	3.44 ± 0.40
L5 (°/s)	EO	2.06 ± 0.24	2.02 ± 0.28	2.06 ± 0.07	1.87 ± 0.05
	EC	2.22 ± 0.24	2.05 ± 0.24	2.26 ± 0.10	2.11 ± 0.11
	FEO	2.86 ± 0.39	2.58 ± 0.31	2.49 ± 0.12	2.05 ± 0.09
	FEC	3.40 ± 0.40	3.29 ± 0.43	3.84 ± 0.35	2.89 ±0.21
Th4 (°/s)	EO	2.19 ± 0.29	2.39 ± 0.39	2.00 ± 0.04	2.15 ± 0.07
	EC	2.32 ± 0.27	2.41 ± 0.35	2.18 ± 0.07	2.44 ± 0.13
	FEO	2.65 ± 0.32	2.97 ± 0.47	2.55 ± 0.15	2.76 ± 0.30
	FEC	3.12 ± 0.39	3.54 ± 0.58	4.16 ± 0.45	4.29 ± 0.51

The averaged data of the group CONTROL (n=19) and the group OSTEO (n=25) are presented as mean values ± SEM; *p<0.05, ***p<0.001

porotic women compared to healthy controls. Figure 2 shows the statokinesigrams (CoP trajectories in the horizontal plane) of a representative subject from the group CONTROL and subject from the group OSTEO in all tested conditions. In comparison with healthy senior controls, osteopenic/osteoporotic women showed slight impairment of balance with increased statokinesigrams in all situations. Their CoP responses in AP and ML directions increased mostly during the stance on unstable foam support surface with eyes closed.

We were also interested in velocity of CoP body sway and velocity of upper and lower trunk tilts. In the group OSTEO comparing to CONTROL group, we observed statistically significant increase of veloc-

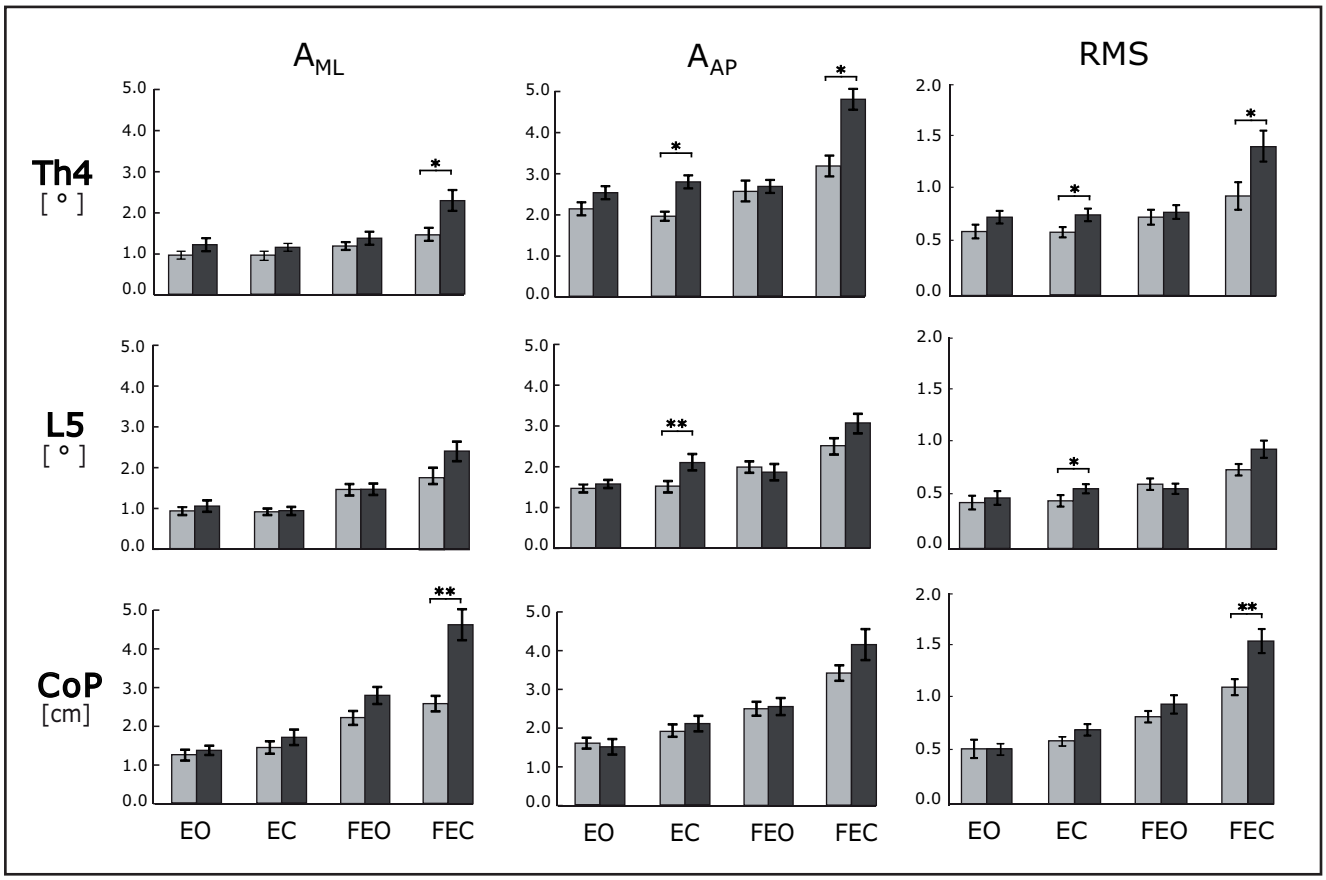

Fig. 1. The grouped averages of values of sway parameters A_{ML}, A_{AP} – amplitude of body sway in ML, AP directions, respectively, RMS – root mean square from CoP, lower trunk (L5) and upper trunk (Th4) in four tested situations: EO – standing on a firm surface with eyes open, EC – standing on a firm surface with eyes closed, FEO – standing on a foam surface with eyes open, FEC – standing on a foam surface with eyes closed. The averaged data of the group CONTROL (grey) and the group OSTEO (black) are presented as mean values ± SEM; *p<0.05, **p<0.01

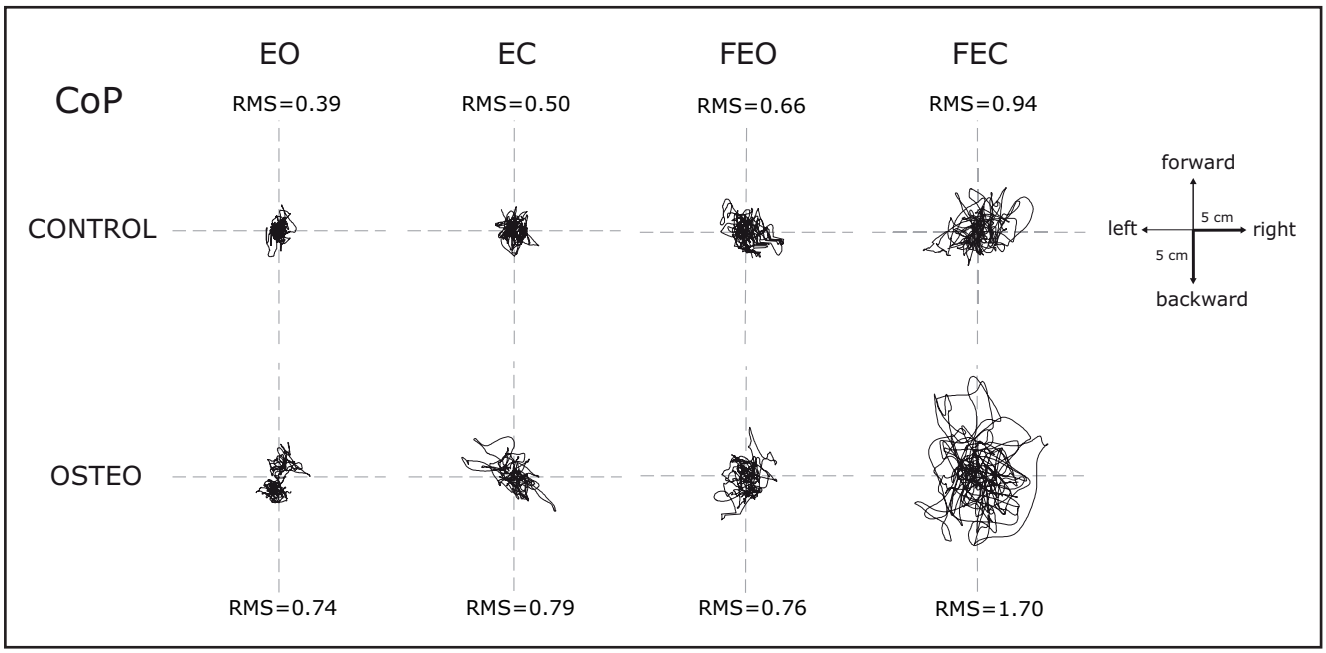

Fig. 2. Bidimensional displacement of CoP sway in the horizontal plane (statokinesigrams) of a representative subject from the groups CONTROL and OSTEO in four tested conditions EO, EC, FEO, FEC. The value of root mean square (RMS) is provided in each situation. The increase of CoP displacement in the group OSTEO was most evident during the stance with eyes closed.

ity only in parameter V_{ML} CoP (Table 2). Velocity of CoP displacement in medial-lateral direction was significantly increased in both situations with altered somatosensory input during the stance with eyes open ($p<0.05$) and eyes closed ($p<0.001$). We did not find any other significant differences in velocity of body sway between osteopenic/osteoporotic women and healthy controls, but the same tendency of increasing velocity of CoP body sway and trunk tilts from the first trial with presence of vision (EO) to the last trial with combined absence of vision and somatosensory information (FEC) was discovered in both groups.

In the second part of our study, we calculated Spearman´s correlations between the levels of bone resorption marker CTx, 25OHD and analyzed sway parameters in the group OSTEO. The mean 25OHD level for the study population (n=25) was 36.91±3.42 nmol/L. None of the subject had serum 25OHD >50 nmol/L, all osteopenic/osteoporotic women were vitamin D insufficient (Malabanan *et al* 1998; Faulkner *et al* 2006). The mean serum concentration of CTx was 0.47±0.06 ng/ml.

The analysis revealed significant negative correlation between the amplitude of body sway in medial-lateral direction in CoP (A_{ML} CoP) and the serum concentration of 25OHD (r=–0.405, $p<0.05$). Similarly the negative correlation between the amplitude of upper trunk tilts in ML direction (A_{ML} Th4) and the serum concentration of 25OHD was statistically significant (r=–0.462, $p<0.05$). Both correlations were approved in the experimental situation with altered somatosensory input, during the stance on foam support surface with eyes open. The highly significant positive correlation between the amplitude of lower trunk tilts in ML direction (A_{ML} L5) and the bone resorption marker CTx was found (r=0.507, $p<0.01$) during the standing on foam surface with eyes closed. None of the other postural parameters were significantly correlated with the levels of 25OHD or CTx. Furthermore we found statistically significant negative correlation between level of 25OHD and bone resorption marker CTx (r=–0.515, $p<0.01$). The correlation coefficients and corresponding levels of significance for sway parameter A_{ML} in CoP, Th4, L5 and serum concentrations of 25OHD and CTx calculated for all tested conditions are presented in Table 3.

Tab. 3. Spearman´s correlation coefficients for sway parameter A_{ML} – amplitude of body sway in medial-lateral direction in CoP, upper trunk (Th4), lower trunk (L5), serum concentrations of 25 hydroxyvitamin D (25OHD) and serum concentrations of bone resorption marker CTx in four tested conditions EO, EC, FEO, FEC.

		25OHD	CTx
A_{ML} CoP	EO	–0.168	0.127
	EC	–0.298	0.120
	FEO	–0.405*	0.027
	FEC	–0.322	0.321
A_{ML} L5	EO	0.077	0.201
	EC	–0.247	0.180
	FEO	–0.357	0.150
	FEC	–0.272	0.507**
A_{ML} Th4	EO	–0.034	0.224
	EC	–0.169	0.036
	FEO	–0.462*	0.260
	FEC	–0.315	0.241
25OHD		1	–0.515**
CTx		–0.515**	1

Correlations are calculated for subjects from the group OSTEO (n=25), the coefficient values *$p<0.05$, **$p<0.01$ were considered significant.

Discussion

For many elderly subjects, the aging process is inevitably accompanied with restriction of the ability to move independently, with the loss of balance and it is often associated with balance disorders or age-related pathologies as osteoporosis, osteoarthritis, Parkinson´s disease. The present study assessed the static balance in elderly women with osteopenia and osteoporosis and in age-matched controls with normal bone mineral density as well as relationship between the bone resorption marker CTx, 25 hydroxyvitamin D and postural parameters in the group of osteopenic and osteoporotic women. We focused on assessment of postural stability using small and accurate accelerometers attached to the trunk and we found that accelerometry can reliably detect changes in posture of osteopenic/osteoporotic women indicating even slight instability.

Our results showed mildly impaired balance control and postural instability in women with osteopenia and osteporosis compared to healthy senior controls. The findings are in agreement with previous studies examining the balance during quiet stance showing increased body sway in elderly women with osteoporosis (Abreu *et al* 2010; Burke *et al* 2010; Lynn *et al* 1997). It is known that postural sway increases with deficit of information from one sensory system: visual, vestibular or somatosensory (Hlavacka & Horak 2006). We approved that amplitude of CoP body sway in AP and ML directions increased in situations with absence of vision and/or somatosensory information in both examined groups of elderly women. Significantly increased amplitude of CoP body sway in ML direction and RMS occured in osteopenic/osteoporotic women during the stance with absence of visual information combined with altered proprioception (Figure 1). It is important to emphasize that more increased amplitude of CoP displacement occurred especially in medial-lateral rather than anterior-posterior direction in women with osteopenia/osteoporosis, which corresponds with results from other studies (Abreu *et al* 2010; Kuczynski & Ostrowska

2006). Melzer *et al* (2004) suggested that decreased postural control, mainly the CoP medial-lateral sway is a predictive factor of falls among elderly people, therefore it is likely that women with osteopenia and osteoporosis are at increased risk for falls. Our findings were also approved by the results from two-way repeated measures ANOVA, which revealed significant effect of factors Osteo, Vision, Surface and their interactions on amplitude of CoP body sway in ML direction and RMS (Table 1). This demonstrates that the ability of the elderly to maintain balance is impaired in conditions with reduced or conflicting sensory information (Melzer *et al* 2004) and may also be influenced by diseases like osteopenia and osteoporosis.

In this study, we also focused on velocity of body sway in both experimental groups. Our results agree with those by Liu-Ambrose *et al* (2003) and Burke *et al* (2010) that individuals with osteopenia/osteoporosis presented higher CoP sway velocities than control group. However, while Burke *et al* (2010) showed significant differences in CoP sway velocity only in the situation with stable surface and eyes open, we found significantly increased velocity of body sway in ML direction during the stance on unstable foam surface with eyes open and closed (Table 2). According to Woollacott (1993), the older adults begin to loose balance when the inputs from both sensory systems are reduced and the main source of sensory information available for keeping balance remains the vestibular input. That explains why elderly women with osteopenia and osteoporosis had significantly increased velocity of CoP body sway especially during the stance on compliant foam surface with eyes closed. In the situation with reduced sensory information they needed to maintain their balance more actively than healthy senior women and this was shown by faster body swaying. Despite this fact, osteopenic/osteoporotic women were not able to compensate for the altered sensory condition with faster swaying, because the amplitude of their body sway in ML direction increased significantly as well. Ostrowska *et al* (2008) found very similar values of CoP sway velocity in AP and ML directions in women with osteoporosis as we did. They also found out that subjects with osteoporosis swayed slightly less in AP than ML plane, which differentiates them from healthy subjects. This concurs with our findings. Due to an inability to adequately balance the body´s equilibrium represented by increased amplitude and velocity of body sway, it suggests higher risk for falling and related fractures in the group of osteopenic and osteoporotic senior women.

Postural sway is often described indirectly by the fluctuations of the CoP, however recent technological developments have led to the production of portable systems based on miniaturized inertial sensors that can reliably measure postural sway during quiet stance more directly (Moe-Nilssen & Helbostad 2002). Because no previous studies assessing the posture control in osteopenic and osteoporotic women using accelerometry were found, we decided to assess balance by using accelerometers placed on the upper and lower trunk. Our results showed that more pronounced body tilts occurred in upper trunk than in lower trunk in osteopenic/osteoporotic women compared to the healthy controls. Greater oscillations of upper trunk tilts were administered during the experimental conditions with eyes closed, particularly in anterior-posterior direction (Figure 1). Sundermier *et al* (1996) also showed that elderly subjects with history of falls are more visually dependent than matched non-fallers. Significantly increased amplitudes of trunk tilts and greater sway area in women from the group OSTEO represent mildly impaired balance control and reduced effectiveness to achieve stability by postural control system. Detection of changes in posture via accelerometers provides a new, promising application for clinical practice. Mancini *et al* (2011) proved that acceleration-based measurement of body sway offers efficient method for quantifying posture control and accelerometric parameters are able to describe the postural instability in elderly Parkinson´s patients.

Related to the serum level of 25OHD in the examined group OSTEO, all of the subjects were vitamin D insufficient. Our results showed a statistically significant negative correlation between the serum 25OHD level and ML amplitude of body sway in CoP and upper trunk during the stance on foam with eyes open (Table 3). Increased amplitude of body tilts is associated with impaired balance control and greater risk for falls. It can therefore be speculated that instability and increased fracture risk in osteopenic/osteoporotic women may be due to the association between low 25OHD and increased body sway and we could interpret that they are reciprocally related. Relationship between 25OHD levels and static balance in elderly people was the issue of Menant *et al* (2012). They found that subjects with vitamin D insufficiency had reduced balance control and stepping performance. Impaired stability and poorer coordinated balance in participants with low serum 25OHD have also been reported in other studies (Sambrook *et al* 2004; Gerdhem *et al* 2005).

Our study is one of the few that examined relationship between postural stability and bone resorption marker CTx. Accelerated bone turnover is an independent risk factor for vertebral and nonvertebral fractures (Garnero *et al* 1996). We hypothesized that increased bone resorption would be associated with postural instability in elderly osteopenic/osteoporotic women and thus increased serum concentration of CTx can be a significant predictor of risk for falling. We observed that the serum level of bone resorption marker CTx was highly significant correlated to the amplitude of upper trunk tilts in ML direction (Table 3). These results concerning the association between CTx level and worse static balance in the elderly should be interpreted with caution, but they are supported by a recent study by

Chen *et al* (2006). Results of Lips *et al* (1990) indicated the fact that lower mobility in the elderly leads to higher bone resorption.

The present study has several limitations. The relatively small size of study sample could limit the statistical power. Furthermore, the group OSTEO includes subjects with osteopenia and osteoporosis together. Therefore, follow-up research should focus on balance control in each of these groups separately. Also no attention was paid to daily physical activity and exercise performances in elderly subjects included in our study. There are studies which reported significant influence of exercise program and regular motor activities on body sway and bone resorption (Burke *et al* 2012; Park *et al* 2008). Further work is required, taking into account all of these limitations.

Conclusion

Our study suggests that postural control among postmenopausal women with osteopenia and osteoporosis is slightly impaired in comparison to healthy senior controls. This fact was approved by increased values of postural parameters particularly in stance with absence of vision and/or with altered somatosensory input. Increased amplitudes of body tilts and higher sway velocities may increase risk of falls and fall-related osteoporotic fractures. As little is known about the relationship between posture and levels of 25OHD and bone turnover markers in osteoporotic patients, this study investigated these issues as well. We found that vitamin D insufficiency was significantly associated with medial-lateral body sway. Furthermore, our results indicated that increased amplitude of lower trunk tilts is related to the higher serum level of bone resorption marker CTx. We also demonstrated that accelerometers positioned on upper and lower trunk can detect even mild impairments of posture in osteopenic/osteoporotic patients and they are suitable for the use in clinical settings because of their portability, lightweight and high measurement accuracy. Evaluating postural balance and its relation to the biomechanical markers may have important implications for developing better diagnosis in elderly subjects as well as improving the quality of life in osteopenic and osteoporotic women.

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Conflict of interest statement

All authors confirmed their agreement to submission and declared that they have no competing financial interests.

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