Accepted Manuscript

Title: A flexed posture in elderly patients is associated with impairments in postural control during walking

Author: Maartje H. de Groot Hanna C. van der Jagt-Willems Jos P.C.M. van Campen Willem F. Lems Jos H. Beijnen Claudine J.C. Lamoth

PII:	S0966-6362(13)00649-8
DOI:	http://dx.doi.org/doi:10.1016/j.gaitpost.2013.10.015
Reference:	GAIPOS 4069
To appear in:	*Gait & Posture*
Received date:	20-6-2013
Revised date:	11-10-2013
Accepted date:	13-10-2013

Please cite this article as: de Groot MH, van der Jagt-Willems HC, van Campen JPCM, Lems WF, Beijnen JH, Lamoth CJC, A flexed posture in elderly patients is associated with impairments in postural control during walking, *Gait and Posture* (2013), http://dx.doi.org/10.1016/j.gaitpost.2013.10.015

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

ACCEPTED MANUSCRIPT

A flexed posture in elderly patients is associated with impairments in postural control during walking

Maartje H. de Groot,[1] Hanna C. van der Jagt-Willems,[1,4] Jos P.C.M. van Campen,[1] Willem F. Lems,[3] Jos H. Beijnen,[2,5] and Claudine J.C. Lamoth[6]

Author affiliations:

[1] Department of Geriatric Medicine, and [2] Department of Pharmacy & Pharmacology, Slotervaart Hospital, Louwesweg 6, 1066 EC Amsterdam, the Netherlands;

[3] Department of Rheumatology, VU Medical Centre, De Boelelaan 1117, 1081 HV Amsterdam, the Netherlands;

[4] Department of Internal Medicine & Geriatric Medicine, Spaarne Hospital, Spaarneplein 1, 2134 TM Hoofddorp, the Netherlands;

[5] Department of Pharmaceutical Sciences, Faculty of Science, Utrecht University, Universiteitsweg 99, 3584 CG Utrecht, the Netherlands;

[6] University of Groningen, University Medical Centre Groningen, Centre for Human Movement Sciences, Ant. Deusinglaan 1, 9713 AV Groningen, the Netherlands;

E-mail addresses: Maartje.deGroot@slz.nl; HvanderJagt@spaarneziekenhuis.nl; Jos.vanCampen@slz.nl; WF.Lems@vumc.nl; Jos.Beijnen@slz.nl; C.J.C.Lamoth@umcg.nl

Accepted Manuscript

ACCEPTED MANUSCRIPT

Acknowledgments

The present study was not supported by any external funding.

Accepted Manuscript

ACCEPTED MANUSCRIPT

A flexed posture in elderly patients is associated with impairments in postural control during walking

Maartje H. de Groot, Hanna C. van der Jagt-Willems, Jos P.C.M. van Campen,

Willem F. Lems, Jos H. Beijnen, and Claudine J.C. Lamoth

Keywords

Elderly; postural control; walking; flexed posture; osteoporosis

Comments

Word count: 2958 words

Number of Tables: 3

Number of Figures: 2

Accepted Manuscript

ACCEPTED MANUSCRIPT

Abstract

A flexed posture (FP) is characterized by protrusion of the head, and an increased thoracic kyphosis (TK), which may be caused by osteoporotic vertebral fractures (VFs). These impairments may affect motor function, and increase the risk of falling, and consequently the risk of fractures. Therefore, it was aimed to examine postural control during walking in elderly patients with FP, and to investigate the relationship with geriatric phenomena often present in this population, such as increased TK, VFs, frailty, polypharmacy and cognitive impairments, being possible causes for FP. Fifty-six elderly patients (aged 80±5.2 years; 70% female) walked 160 meters at self-selected speed while trunk accelerations were recorded. In addition to walking speed, mean and coefficient of variation (CV) of stride times, postural control during walking was quantified by time-dependent variability measures derived from the theory of stochastic dynamics, indicating smoothness, degree of predictability, and local stability of trunk acceleration patterns. Twenty-five patients (45%) had FP and demonstrated a more variable and less structured gait pattern, and a more irregular trunk acceleration pattern than patients with a normal posture. FP was significantly associated with an increased TK, not with other geriatric phenomena. An increased TK may bring the body's center of mass forward requiring correcting responses, and reducing the ability to respond on perturbations, which was reflected by higher variation in the gait pattern. The results imply that patients with FP might be at increased risk of falling, since impairments in postural control during walking are a major risk factor for falling.

Accepted Manuscript

ACCEPTED MANUSCRIPT

1. Introduction

A flexed posture (FP) is characterized by an increased thoracic kyphosis (TK), protrusion of the head, and in severe cases knee flexion [1], which is a postural correction to the increased TK [2]. In the older population, TK is likely to increase and worsens over time [3], due to intervertebral disc deformities and/or spinal extensor muscle weakness [4,5]. Furthermore, vertebral fractures (VFs), recognized as a hallmark of osteoporosis, in the thoracic vertebral column may increase TK as well. In turn, these impairments can affect motor function, and increase fall risk [6], and therefore the risk of further fractures.

A recent review showed significant differences in postural control during standing and walking between patients with osteoporosis and healthy controls, particularly when variables indicating postural stability were calculated from objective measurements using instrumented devices like force plates and accelerometers [7]. However, in the majority of the reviewed studies, the presence and severity of VFs and/or TK and/or FP in the osteoporotic group was not specified, and the relation between these clinical entities is not fully clear yet.

In view of the fact that an impaired postural control during walking is a major risk factor for falls and new fractures among elderly [8], early recognition and quantification of balance disorders is of great importance to prevent osteoporotic patients from falling. To quantify postural control during walking, analyses of time-dependent variability, using measures derived from the theory of stochastic dynamics [9], have shown to be sensitive to detect differences between young and older persons, fallers and non-fallers, and patients with and without cognitive impairments [9–11]. Therefore, in the present study we applied measures that quantify time-dependent variations of postural control during walking, such as the Detrended Fluctuations Analyses [12], Sample Entropy [13] and maximal Lyapunov exponents [11], in addition to more conventional gait parameters (e.g. average gait speed, and stride times). In conventional measures each cycle is treated being an independent event

Accepted Manuscript

ACCEPTED MANUSCRIPT

unrelated to previous or subsequent strides, where the applied methods in the present study assess fluctuations throughout the gait cycle, and as such provide more insights into how movement behavior unfolds.

The aim of the present study was primarily to examine postural control during walking in elderly patients with FP, and secondly to examine the relationship with TK, VFs, and grip strength (as indicator for overall strength of the limb, i.e. muscle weakness), being possible causes for flexed posture [1,4,5]. Thirdly, since comorbid diseases, frailty, polypharmacy, and cognitive impairments, are often present in the older population visiting a geriatric outpatient clinic, the association of these geriatric phenomena with FP was examined as well. It is hypothesized that patients with FP will have increased variability of gait parameters compared to patients with normal posture. Further, we anticipated that the presence of increased TK, VFs, muscle weakness, and other geriatric phenomena might further worsen FP, and consequently worsen postural control during walking.

2. Methods

2.1. Participants

Patients were recruited from the population of elderly who visited the Diagnostic Geriatric Day Clinic of the Slotervaart Hospital in Amsterdam. They were included if they were ≥70 years, and could walk safely for 3 minutes without using any assistive device. Patients were excluded when they had any asymmetric mobility problems, and/or did not understand the instructions of the researcher.

The study was approved by the Medical Ethical Committee of the Slotervaart Hospital. All patients gave their informed consent.

ACCEPTED MANUSCRIPT

2.2. Gait analysis

Trunk accelerations were measured with a tri-axial accelerometer (DynaPort Minimod Hybrid, McRoberts BV, The Hague, the Netherlands; sample frequency 100 Hz) attached with a band at the level of the lumbar vertebral column, when patients walked about 160-meter in a well-lit, 80-meter long hallway at a self-selected speed. Walking time was recorded to determine gait speed.

Stride-related parameters

Medio-lateral (ML) and anterior-posterior (AP) trunk acceleration signals were analyzed using custom made software in MATLAB (The MathWorks Inc., Natick MA, USA). Signals were corrected for horizontal tilt, and high-pass filtered using a Butterworth filter (4^{th} order; cut-off frequency 0.25 Hz). From the peaks of the AP-acceleration time-series foot contact instances were determined. A median filter was used to exclude outliers in the data due to turning points in the gait assessment. From the foot contact instances, stride times were calculated, defined as the time interval between two ipsilateral foot contacts. Mean, and coefficient of variation (CV) of stride times, and stride frequency were computed for individual patients.

In addition, parameters were calculated estimating variations throughout the gait cycle. First, temporal variability was quantified by the variance of the relative timing between sequential ipsilateral foot contact instances using the point estimate of the relative phase: $\varphi_i=(FCR_{t(i)}-FCL_{t(i)})/(FCL_{t(i+1)}-FCL_{t(i)})*360°$ [14], where *FCL* and *FCR* are respectively the left and right foot contact instant at time $t(i)$. Because the relative phase is a circular measure, circular statistics were applied to calculate the mean and variance of the relative phase over strides [15]. A temporally symmetric gait pattern is denoted by φ_i=180°, and a higher variance indicates a more variable gait pattern.

Accepted Manuscript

ACCEPTED MANUSCRIPT

Second, long-range correlations in stride time intervals were quantified by calculating scaling exponent α using the Detrended Fluctuation Analysis (DFA) [12]. When $0.5 \geq \alpha \geq 1$, this indicates the presence of long-term correlations in the signal, which means future fluctuations are better predicted by past fluctuations. Therefore values of α closer to 1 represent a more structured pattern.

Trunk movement patterns

The magnitude of the ML and AP trunk acceleration patterns was quantified by calculating the Root Mean Square (RMS). Furthermore, the harmonic ratio (Hratio), sample entropy (SEn) [13], and maximal Lyapunov exponent (λ_{max}) [16] were calculated using open source software (UPMOVE version 0.2a; http://www.upmove.org), indexing respectively the smoothness, degree of predictability, and local stability of the trunk acceleration patterns.

The Hratio was computed using spectral dynamics to quantify the smoothness of the ML and AP trunk movements, with a higher Hratio representing a smoother trunk acceleration pattern. A discrete Fourier transform was used to estimate the power spectral density of the fundamental oscillatory frequency and of the six consecutive harmonics. The Hratio was defined by dividing the powers spectral density of the fundamental oscillatory frequency by that of the first seven harmonics. The first seven harmonics were chosen, because after low-pass filtering the data at 10 Hz, spectral analysis showed that at higher frequencies no additional information was obtained.

To index the degree of predictability in ML and AP acceleration time-series, the SEn was calculated [13], defined as the negative natural logarithm of an estimate of the conditional probability of epochs of length m (m=3 in this study) that match point-wise within a tolerance r and repeats itself for m+1 points. An optimization approach [17] was used to determine the tolerance parameter r and m, since the choice of r for given m is decisive. Smaller SEn values

Accepted Manuscript

ACCEPTED MANUSCRIPT

represent greater regularity, while larger SEn values are associated with a small chance of similar data being repeated. The ML and AP acceleration data was normalized to unit variance, making the outcome scale-independent.

Finally, local stability of the ML and AP trunk acceleration patterns was expressed by the λ_{max}, calculated by applying the Wolf algorithm [16], since this algorithm is most appropriate to evaluate local dynamic stability from relatively small data sets. The time-series were first low-pass filtered using a least squares finite impulse response filter (6^{th} order; cut-off frequency 10 Hz) [11]. Then, all stride cycles were resampled to 100 samples to be able to compare trials between patients with FP and normal posture on the same time scale. The estimated time interval was 10% of the stride cycle for all reconstructed state spaces. An embedded dimension of 5 was chosen, following previous studies [9]. Larger λ_{max} indicates greater sensitivity to local perturbations.

2.3. Additional measurements

Of the included patients, age, gender, Body Mass Index (BMI), and number of prescriptions was registered. FP was evaluated measuring the occiput-to-wall distance (OWD) [1]. While subjects stand with their head in a natural position with heels and back touching the wall and knees extended, the distance between occiput and wall was measured. FP was defined as OWD ≥5.0 cm [1].

To assess the degree of TK and the presence of VFs, lateral X-rays of the thoracic and lumbar spine were judged. TK was measured by the Cobb angle between the superior endplate of the second, and the inferior endplate of the twelfth thoracic vertebrae. Two observers measured the Cobb angle independently, and the mean value was used. An abnormal increased TK was defined as a Cobb angle of ≥50° [18], while a kyphosis of <50° was considered normal. VFs were independently scored by two observers using Genant’s

ACCEPTED MANUSCRIPT

semi-quantitative method [19]. When conclusions differed, final consensus was reached by discussion.

Grip strength (in kg) of the dominant hand (3 measures averaged; corrected for body height), as an indicator for overall strength of the limb (i.e. muscle weakness), was assessed with a Jamar hand-held dynamometer [20]. Furthermore, geriatric phenomena were registered, such as the presence of co-morbid diseases by the Charlson Comorbidity Index (CCI) [21], cognitive functioning with the Mini Mental State Examination (MMSE) [22], risk of falling using Pluijm's assessment [23] and the presence of frailty according to the presence of ≥3 criteria of Fried et al. [24].

2.4. Statistical analyses

For statistical analyses, PASW Statistics 18 (SPSS Inc., Chicago IL, USA) was used (level of significance was $p<0.05$). Non-parametric tests (Mann-Whitney U and χ^2) were used to test group differences between patients with normal posture and FP.

To test factors associated with FP, first simple linear regressions were computed with the OWD as dependent variable and as independent variables patient characteristics, e.g. amount of thoracic kyphosis, vertebral fractures and frailty. Then, three multiple linear regression models were computed: (A) a model based on the literature [1,4,5] (the included independent variables were the Cobb angle, presence of vertebral fractures, and grip strength corrected for body height); (B) a model with geriatric phenomena (CCI, number of prescriptions, Fried's frailty score, Pluijm's fall risk assessment score, and MMSE); and (C) a model based on the simple regression analyses (independent variables were included when $p<0.30$).

Accepted Manuscript

ACCEPTED MANUSCRIPT

3. Results

Fifty-six patients (aged 79.7±5.2 years; 70% female) were included in the present study. Twenty-five patients (45%) were classified as having FP (OWD ≥5.0 cm). The characteristics of patients with normal posture and FP are presented in Table 1. Patients with FP had a significantly higher Cobb angle than patients with normal posture. Consequently, significantly more patients in the FP-group were classified as having an increased TK (Cobb angle ≥50°) than in patients with normal posture (80% vs. 29%; $p<0.01$). The presence of VFs, an indicator for severe osteoporosis, as well as other characteristics, did not differ in both groups.

3.1. Effects of flexed posture on gait

Walking speed did not differ significantly between both patient groups ($p=0.26$). Variability (CV) of stride times was significantly higher ($p=0.03$) in patients with FP, and the scaling exponent α was significantly lower ($p<0.01$) implying less correlated stride time intervals (Table 2). In addition, in patients with FP a significant less symmetric gait pattern was observed, that is variability of discrete relative phase between foot contacts was higher ($p=0.02$). Other gait parameters did not differ significantly between both groups.

Variables quantifying trunk acceleration patterns for both groups are presented in Fig. 1. Patients with FP had significantly lower ML RMS ($z=-2.18$; $p=0.03$) and AP RMS ($z=-3.12$; $p<0.01$), and significantly higher AP SEn values ($z=1.99$; $p<0.05$). ML SEn values and ML and AP Hratio and λ_{max} did not differ significantly between groups.

3.2. Factors associated with flexed posture

In the first column of Table 3, the results of the simple linear regression analyses are shown examining the relation of each variable independently with OWD. Only the degree of TK was significantly associated with OWD ($p<0.01$). Fig. 2 illustrates the relationship between the

ACCEPTED MANUSCRIPT

Cobb angle and OWD. The other wellknown risk factors for FP, namely VFs and grip strength, were not associated with FP in this cohort. The other characteristics examined in this study, were not significantly associated with OWD in the simple linear regression analyses.

In addition, multiple linear regression analyses were performed (see second column of Table 3). In model A, which was based on the literature [1,4,5], the relation between osteoporosis-related parameters and the OWD was examined: the Cobb angle and grip strength (corrected for body height) were both associated with OWD (R^2=34%). In model B, including independent variables related to geriatric phenomena, frailty was the only variable significantly associated with the OWD (R^2=10%). Finally, in model C, based on the results of the simple linear regression analyses, Cobb angle was significantly associated with OWD, where the other included variables were not (R^2=35%).

4. Discussion

The objective of the present study was to examine postural control during walking in elderly patients with FP, and what factors may influence this. The results of the present study show that in elderly patients FP was associated with impairments in postural control during walking. Although walking speed did not differ, patients with FP showed a more variable and less structured gait pattern (higher CV of stride times), a less consistent gait pattern (higher variance of the relative phase), and less correlated stride times (lower α) than patients with normal posture. In addition, FP-patients exhibited a significantly decreased magnitude of trunk accelerations (smaller values for ML and AP RMS), and showed a significant more irregular (larger values for AP SEn), and borderline significant less smooth (lower Hratio values), and more unstable trunk acceleration patterns (higher AP λ_{max}).

Furthermore, it was found that FP, expressed by the OWD, was associated with an increased TK. This forward curvature of the trunk shifts the body's center of mass forward

Accepted Manuscript

ACCEPTED MANUSCRIPT

from the center of rotation (the spine), causing an increased forward bending moment [2,25]. Since postural control can be defined as the capacity to maintain the center of mass within the support base [26], it can be argued that patients with FP need adaptations to maintain balance. Therefore, an increased posterior counterbalancing force is required from dorsal musculature and ligaments. This can be obtained by flexing the knees and contracting the dorsal musculature to tilt hips [27], which brings the head and shoulders back up, but also tightens the hamstrings [2]. In addition, trunk movements and rotation, and arm sway may be reduced due to the changed trunk alignment and altered functioning of muscles and ligaments. Since dynamics of head, arms, and trunk are important mechanisms to maintain balance during walking [28], it is likely that the ability to react on (small) perturbations during walking is diminished in FP-patients. This was expressed in our results by a more robust effect on variability of the stride-related parameters than effect on the trunk acceleration patterns.

Beside the effects of FP on postural control during walking, it was investigated which factors present in the included elderly patient population were associated with FP. It was found that FP, expressed by the OWD, was associated with an increased TK and increased grip strength, according to the multiple linear regression analyses, where the presence of VFs was not. Other common phenomena in the geriatric population, such as frailty, cognitive impairments, increased fall risk, number of medications, and the presence of comorbid diseases, were weakly associated with the OWD (R^2=10%).

The hypothesis that the presence of VFs worsens the degree of TK and thus FP, was not confirmed in this study. Unfortunately, of the other known causes for an increased TK and consequently FP, namely degenerative disc diseases, or spinal extensor muscle weakness [1,4,5], we only included grip strength in the present study. Grip strength is not a direct measure of spinal extensor muscle strength, but was in model A of the multiple linear regression analyses associated with the OWD. Grip strength was higher in patients with FP,

Accepted Manuscript

ACCEPTED MANUSCRIPT

which may be explained by the increased posterior counterbalancing forces needed in FP-patients to maintain balance. However, this finding in the multiple regression might be a coincidence since grip strength was not associated with OWD in the single linear regressions or in model C of the multiple linear regression.

The results of several outcome measures in the present study were borderline significant and the goodness-of-fit of the regression analyses was low to moderate (10-35%), which was probably caused by the large variation in the patient data (see Fig. 1 and 2 presenting respectively boxplots of trunk movement pattern parameters, and the relation between FP and TK). However, the heterogeneity in the present cohort is illustrative for the older population visiting a geriatric outpatient clinic. These patients are typically characterized by a combination of physiological, psychological and social problems, and comorbidities are often present [29]. In the present cohort, geriatric phenomena like frailty, cognitive impairments and polypharmacy were present as well, and were equally distributed in patients with normal posture and FP. Therefore, it can be concluded that these factors were not directly associated with the presence of FP. Though, the patients of both groups were not healthy elderly, and the comorbidities present in the included population might have impaired postural control during walking in both groups.

In summary, FP is characterized by an increased TK, bringing the body's center of mass forward requiring correcting responses of the body, such as counterbalancing force from posterior musculature to tilt the hips and flex the knees. These correcting responses may reduce the ability to respond on perturbations, which is reflected by the found impairments in postural control during walking in this study. Patients with FP demonstrated a more variable and less structured gait pattern, and a more irregular trunk acceleration pattern than patients with a normal posture. This may imply that patients with FP are at increased risk of falling, since impairments in postural control during walking are a major risk factor for falling.

Accepted Manuscript

ACCEPTED MANUSCRIPT

Conflicts of Interest Statement

All authors declare that they do not have any conflict of interest.

References

[1] Balzini L, Vannucchi L, Benvenuti F, Benucci M, Monni M, Cappozzo A, et al. Clinical characteristics of flexed posture in elderly women. Journal of the American Geriatrics Society 2003;51:1419–26.

[2] Yuan HA, Brown CW, Phillips FM. Osteoporotic spinal deformity - a biomechanical rationale for the clinical consequences and treatment of vertebral body compression fractures. Journal of Spinal Disorders & Techniques 2004;17:236–42.

[3] Cortet B, Roches E, Logier R, Houvenagel E, Gaydier-Souquières G, Puisieux F, et al. Evaluation of spinal curvatures after a recent osteoporotic vertebral fracture. Joint Bone Spine 2002;69:201–8.

[4] Katzman WB, Wanek L, Shepherd JA, Sellmeyer DE. Age-related hyperkyphosis: its causes, consequences, and management. The Journal of Orthopaedic and Sports Physical Therapy 2010;40:352–60.

[5] Sinaki M, Itoi E, Rogers JW, Bergstralh EJ, Wahner HW. Correlation of back extensor strength with thoracic kyphosis and lumbar lordosis in estrogen-deficient women. American Journal of Physical Medicine & Rehabilitation 1996;75:370–4.

[6] Huang C, Ross PD, Wasnich RD. Vertebral fracture and other predictors of physical impairment and health care utilization. Archives of Internal Medicine 1996;156:2469–75.

[7] De Groot MH, van der Jagt-Willems HC, van Campen JPCM, Lems WF, Lamoth CJC. Testing postural control among various osteoporotic patient groups: a literature review. Geriatrics & Gerontology International 2012;12:573–85.

Accepted Manuscript

ACCEPTED MANUSCRIPT

[8] Ganz DA, Bao Y, Shekelle PG, Rubenstein LZ. Will my patient fall? JAMA 2007;297:77–86.

[9] Lamoth CJC, van Deudekom FJ, van Campen JPCM, Appels BA, de Vries OJ, Pijnappels M. Gait stability and variability measures show effects of impaired cognition and dual tasking in frail people. Journal of Neuroengineering and Rehabilitation 2011;8:2.

[10] Hamacher D, Singh NB, van Dieën JH, Heller MO, Taylor WR. Kinematic measures for assessing gait stability in elderly individuals: a systematic review. Journal of the Royal Society, Interface 2011;8:1682–98.

[11] Lockhart TE, Liu J. Differentiating fall-prone and healthy adults using local dynamic stability. Ergonomics 2008;51:1860–72.

[12] Hausdorff JM, Purdon PL, Peng C-K, Ladin Z, Wei JY, Goldberger AL. Fractal dynamics of human gait: stability of long-range correlations in stride interval fluctuations. Journal of Applied Physiology 1996;80:1446–57.

[13] Pincus SM. Approximate entropy as a measure of system complexity. Proceedings of the National Academy of Sciences of the United States of America 1991;88:2297–301.

[14] Roerdink M, Lamoth CJC, Kwakkel G, van Wieringen PCW, Beek PJ. Gait coordination after stroke: benefits of acoustically paced treadmill walking. Physical Therapy 2007;87:1009–22.

[15] Lamoth CJC, Beek PJ, Meijer OG. Pelvis-thorax coordination in the transverse plane during gait. Gait & Posture 2002;16:101–14.

[16] Stergiou N, Buzzi UH, Kurz MJ, Heidel J. Nonlinear tools in human movement. In: Stergiou N, editor. Innovative Analyses of Human Movement, Champaign, IL, USA: Human Kinetics Publishers; 2004, p. 63–90.

Accepted Manuscript

ACCEPTED MANUSCRIPT

[17] Lake DE, Richman JS, Griffin MP, Moorman JR. Sample entropy analysis of neonatal heart rate variability. American Journal of Physiology Regulatory, Integrative and Comparative Physiology 2002;283:R789–R797.

[18] Sinaki M, Brey RH, Hughes CA, Larson DR, Kaufman KR. Balance disorder and increased risk of falls in osteoporosis and kyphosis: significance of kyphotic posture and muscle strength. Osteoporosis International 2005;16:1004–10.

[19] Genant HK, Wu CY, van Kuijk C, Nevitt MC. Vertebral fracture assessment using a semiquantitative technique. Journal of Bone and Mineral Research 1993;8:1137–48.

[20] Desrosiers J, Bravo G, Hébert R, Dutil E. Normative data for grip strength of elderly men and women. The American Journal of Occupational Therapy 1995;49:637–44.

[21] Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. Journal of Chronic Diseases 1987;40:373–83.

[22] Folstein MF, Folstein SE, McHugh PR. "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. Journal of Psychiatric Research 1975;12:189–98.

[23] Pluijm SMF, Smit JH, Tromp EAM, Stel VS, Deeg DJH, Bouter LM, et al. A risk profile for identifying community-dwelling elderly with a high risk of recurrent falling: results of a 3-year prospective study. Osteoporosis International 2006;17:417–25.

[24] Fried LP, Tangen CM, Walston J, Newman AB, Hirsch C, Gottdiener J, et al. Frailty in older adults: evidence for a phenotype. The Journals of Gerontology Series A, Biological Sciences and Medical Sciences 2001;56:M146–M156.

[25] Lyles KW, Gold DT, Shipp KM, Pieper CF, Martinez S, Mulhausen PL. Association of osteoporotic vertebral compression fractures with impaired functional status. The American Journal of Medicine 1993;94:595–601.

Accepted Manuscript

ACCEPTED MANUSCRIPT

[26] Alexander NB. Postural control in older adults. Journal of the American Geriatrics Society 1994;42:93–108.

[27] Saha D, Gard S, Fatone S. The effect of trunk flexion on able-bodied gait. Gait & Posture 2008;27:653–60.

[28] Winter DA. Human balance and posture control during standing and walking. Gait & Posture 1995;3:193–214.

[29] Ellis G, Langhorne P. Comprehensive geriatric assessment for older hospital patients. British Medical Bulletin 2004;71:45–59.

Accepted Manuscript

ACCEPTED MANUSCRIPT

Figure captions

Fig. 1. Effects of normal (NP; n=31) and flexed posture (FP; n=25) on medio-lateral (ML) and anterior-posterior (AP) trunk movement pattern parameters, namely Root Mean Square (RMS), Harmonic Ratio (Hratio), Sample Entropy (SEn), and maximal Lyapunov exponent (λ_{max}), presented as boxplots. A significant difference between the patient groups is marked as ★ (p<0.05, based on Mann-Whitney *U* tests).

Fig. 2. Relation between the Cobb angle T2-T12, the presence of vertebral fractures and the Occiput-to-Wall Distance. The black squares (■) represent patients without VFs and the white triangles (△) patients with prevalent VFs. The dotted line is the fit-line of the model based on the linear regression analysis.

Accepted Manuscript

ACCEPTED MANUSCRIPT

Table 1. Characteristics of patients with normal (NP; OWD <5.0 cm) and flexed posture (FP; OWD ≥5.0 cm).

Patient characteristics	**NP (n=31)**	**FP (n=25)**	***p*-value**
Age (years), mean (SD)	79.7 (5.50)	79.6 (4.92)	0.85
Female, n (%)	22 (71%)	17 (68%)	0.81
BMI (kg/m2), mean (SD)	26.8 (4.40)	27.1 (3.47)	0.70
Vertebral fractures			
- Presence of VFs, n (%)	11 (36%)	11 (44%)	0.52
- Thoracic VFs (T2-T8), n (%)	9 (29%)	8 (32%)	0.81
- Thoracolumbar VFs (T9-L1), n (%)	4 (13%)	5 (20%)	0.47
- Lumbar VFs, n (%)	2 (7%)	1 (4%)	0.69
Thoracic kyphosis			
- Cobb angle T2-T12 (°), mean (SD)	44.5 (12.1)	58.6 (11.9)	<0.01
- Increased thoracic kyphosis (Cobb angle ≥50°), n (%)	9 (29%)	20 (80%)	<0.01
Grip strength			
- Grip strength (kg), mean (SD)	24.2 (8.76)	26.0 (8.45)	0.50
Comorbidities			
- CCI score, median (range)	1 (0-4)	1 (0-5)	0.74
- ≥2 co-morbid diseases, n (%)	12 (39%)	11 (44%)	0.70
- Dementia, n (%)	8 (26%)	7 (28%)	0.85
- Myocardial infarct, n (%)	7 (23%)	7 (28%)	0.64
- Chronic pulmonary disease, n (%)	2 (6%)	6 (24%)	0.06
- Peripheral vascular disease, n (%)	5 (16%)	1 (4%)	0.15
- Diabetes type II, n (%)	5 (16%)	2 (8%)	0.36
- Cerebrovascular disease, n (%)	2 (6%)	3 (12%)	0.47
Prescriptions			
- Number of prescriptions, median (range)	5 (0-15)	5 (0-15)	0.82
- Polypharmacy (≥4 prescriptions), n (%)	21 (68%)	16 (64%)	0.77
Frailty			
- Fried's frailty score, median (range)	1 (0-4)	1 (0-5)	0.30
- Frail, n (%)	5 (16%)	3 (12%)	0.66
Cognitive functioning			
- MMSE score, median (range)	24 (13-30)	25 (15-30)	0.24
Fall risk			
- Pluijm score, median (range)	4 (0-19)	4 (0-20)	0.73
- Increased fall risk (Pluijm score ≥7), n (%)	7 (23%)	4 (16%)	0.54

BMI = Body Mass Index; **CCI** = Charlson Comorbidity Index; **MMSE** = Mini-Mental State Examination; **OWD** = Occiput-to-Wall Distance; **VF** = vertebral fracture; **SD** = standard deviation

Accepted Manuscript

ACCEPTED MANUSCRIPT

Research Highlights

- A flexed posture (FP) is characterized by an increased thoracic kyphosis (TK)
- Effects of FP on postural control during walking were examined in elderly patients
- Patients with FP demonstrated more variability in stride-related parameters
- In addition, a more irregular trunk acceleration pattern was found in FP-patients
- These results imply that patients with FP might be at increased risk for falling

Accepted Manuscript

ACCEPTED MANUSCRIPT

Table 2. Group differences of patients with normal (NP) and flexed posture (FP) for gait variables. Values are presented as mean (SD). Statistical differences between patient groups are indicated by *z*- and *p*-values (based on Mann-Whitney *U* tests).

Gait parameters	**NP (n=31)**	**FP (n=25)**	**z-value (p-value)**
Walking speed (m/s)	0.90 (0.22)	0.81 (0.29)	-1.13 (0.26)
Mean stride time (s)	1.16 (0.15)	1.17 (0.12)	0.95 (0.34)
CV of stride time (%)	3.56 (1.68)	4.27 (1.53)	2.22 (0.03)
Stride frequency (strides/s)	0.88 (0.10)	0.85 (0.09)	-1.39 (0.16)
SD of relative phase (°)	4.11 (1.22)	4.98 (1.38)	2.37 (0.02)
α stride times	0.81 (0.16)	0.67 (0.19)	-2.65 (0.01)

CV = Coefficient of Variation; **SD** = Standard Deviation

Accepted Manuscript

ACCEPTED MANUSCRIPT

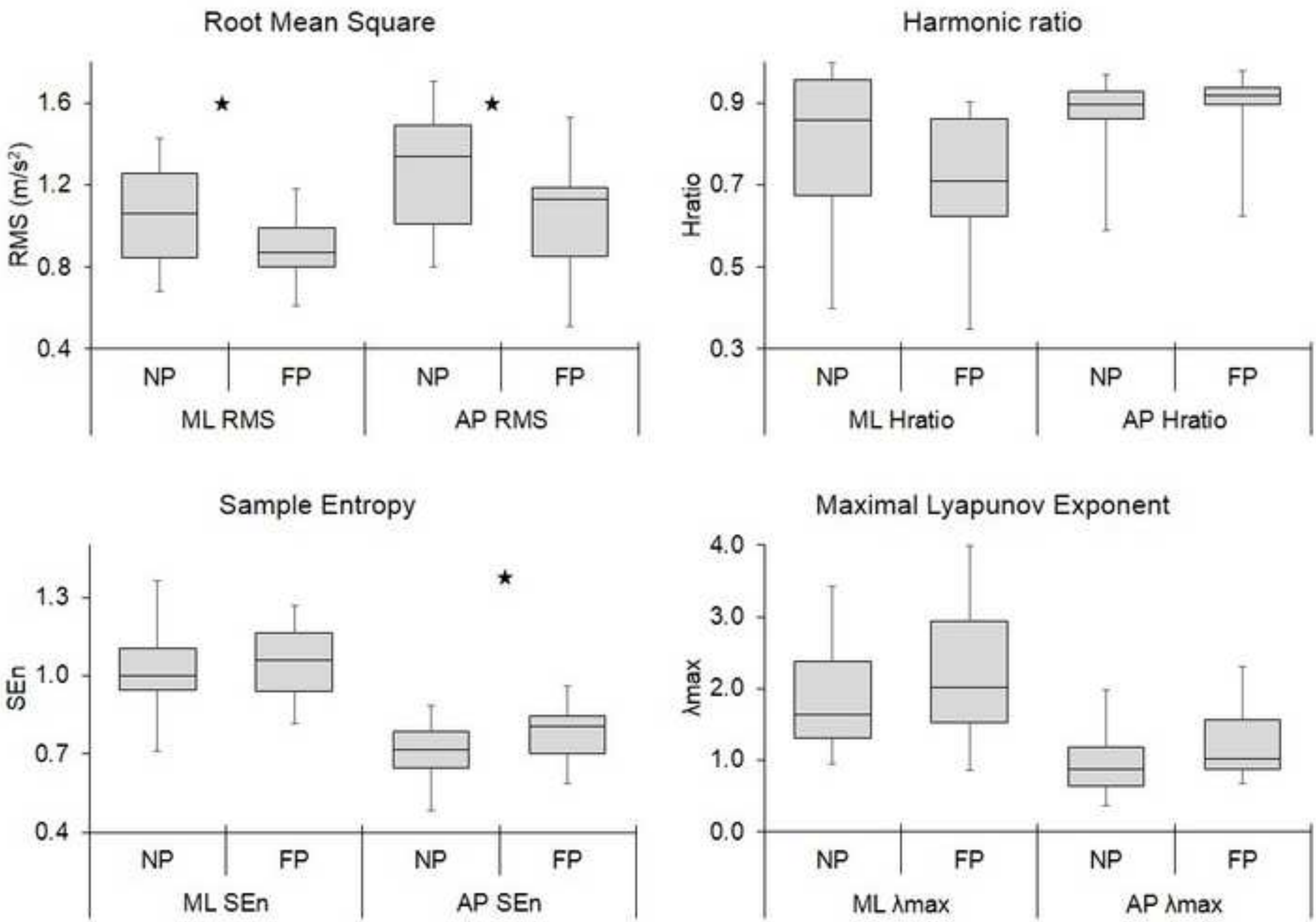
Table 3. Results of simple and multiple linear regression analyses, examining the relationship between the Occiput-to-Wall Distance and (A) osteoporosis-related parameters, (B) comorbidities present in the population, and (C) a model based on the results of the simple linear regression analyses.

				Multiple linear regression analyses					
	Simple linear regression analyses			**Model A**		**Model B**		**Model C**	
Patient characteristics	**B (SE)**	***p*-value**	**R^2**	**B (SE)**	***p*-value**	**B (SE)**	***p*-value**	**B (SE)**	***p*-value**
Age (years)	0.03 (0.12)	0.82	<0.01						
Female	-1.76 (1.27)	0.17	0.04					-0.54 (1.74)	0.76
BMI (kg/m^2)	-0.03 (0.12)	0.83	<0.01						
Osteoporosis-related parameters									
Presence of VFs	0.55 (1.21)	0.65	<0.01	-0.83 (1.09)	0.45				
Cobb angle T2-T12 (°)	0.17 (0.04)	<0.01	0.27	0.18 (0.04)	<0.01			0.17 (0.04)	<0.01
Grip strength (kg)*	0.04 (0.04)	0.28	0.02	0.07 (0.03)	0.04			0.07 (0.05)	0.20
Comorbidities									
CCI score	0.04 (0.46)	0.93	<0.01			0.23 (0.45)	0.64		
Number of prescriptions	-0.02 (0.15)	0.90	<0.01			-0.19 (0.18)	0.30		
Fried's frailty score	0.69 (0.50)	0.17	0.04			1.26 (0.59)	0.04	0.50 (0.47)	0.30
MMSE score	0.11 (0.14)	0.42	0.01			0.15 (0.15)	0.30		
Pluijm score	-0.08 (0.12)	0.47	0.01			-0.16 (0.13)	0.30		
			R^2:	**0.34**		**0.10**		**0.35**	

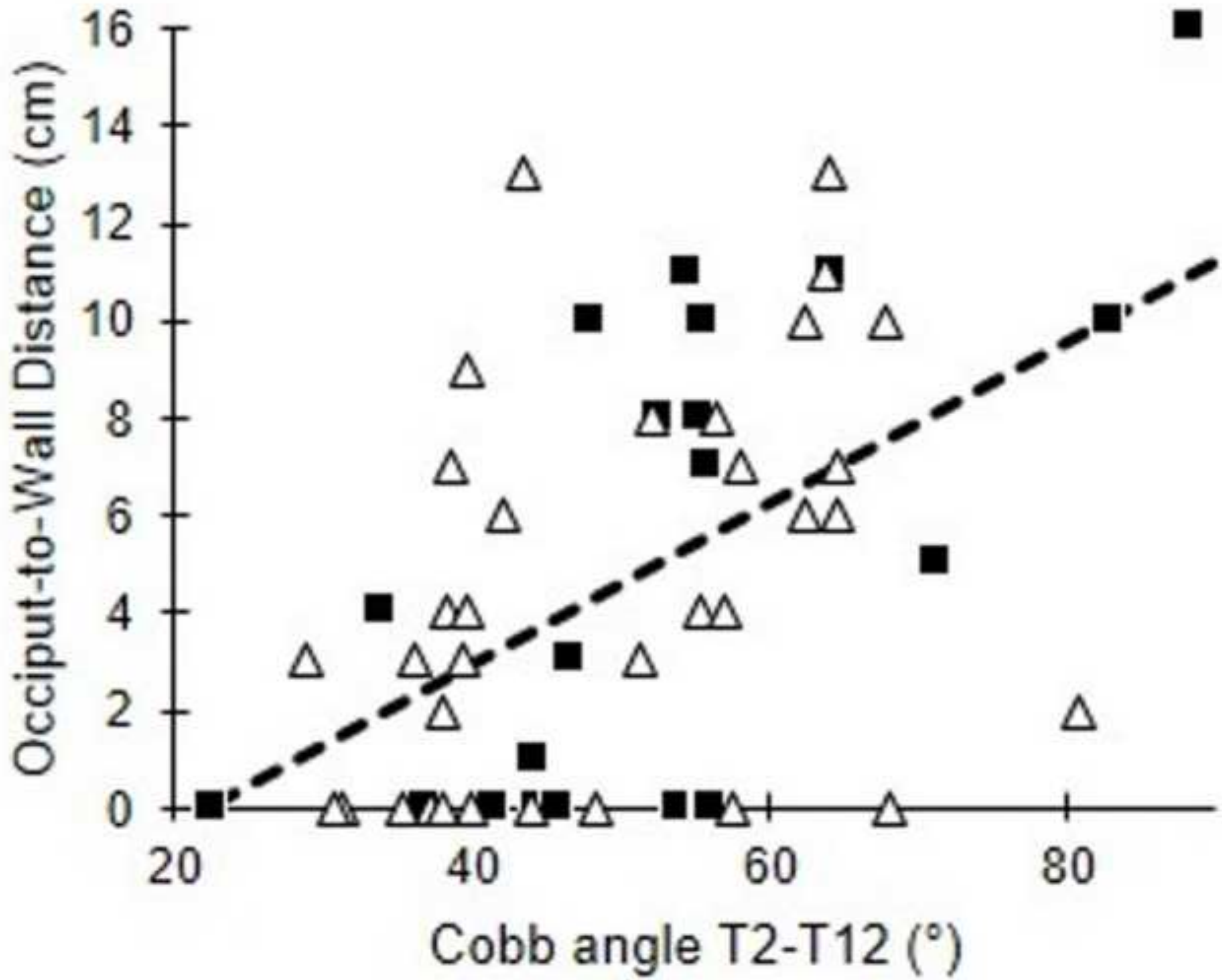
***** Grip strength was corrected for body height; **B** = regression coefficient; **BMI** = Body Mass Index; **CCI** = Charlson Comorbidity Index; **MMSE** = Mini-Mental State Examination; **R^2** = Coefficient of Determination; **SD** = Standard deviation; **SE** = Standard Error; **VF** = Vertebral Fracture.

Accepted Manuscript

7. Figure 1 (with measurement unit of RMS)



7. Figure 2



Occiput-to-Wall Distance (cm)
16
14
12
10
8
6
4
2
0
20
40
60
80
Cobb angle T2-T12 (°)