REVIEW

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Postural changes versus balance control and falls in community-living older adults: a systematic review

Alterações posturais versus controle do equilíbrio e quedas em idosos da comunidade: Revisão sistemática

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Abstract

Introduction: Since falls are considered to be a public health problem, it is important to identify whether postural changes over time contribute to the risk of falls in older adults. **Objective:** To investigate whether postural changes increase fall risk and/or postural imbalance in healthy, community-dwelling older adults. **Methods:** In April 2016, two reviewers independently searched the PubMed, Web of Science, SPORTDiscus, and CINAHL databases for studies in English published in the previous 10 years, using the following combined keywords: "posture" or ("kyphosis","lumbar lordosis","flexed posture","spinal curvature","spinal sagittal contour") AND "elderly" AND "fall". Study quality was assessed according to the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines for observational studies. **Results:** The search retrieved 1,734 articles. Only observational studies that assessed posture, balance, and/or falls in older adults were considered eligible for review. The final sample included 17 articles: reliability and reproducibility of the instruments were not reported in five studies, while two studies offered a questionable description of the instruments used. Fourteen

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articles analyzed postural changes at the trunk level and three articles assessed them at the ankles and feet. Most studies found a positive association between postural changes and an increased risk for loss of balance and falls. **Conclusion:** Thoracic hyperkyphosis, loss of lumbar lordosis, and decreased plantar arch seem to contribute to greater postural instability, and thus to a higher risk of falls in community-living older adults.

Keywords: Older Adults. Posture. Postural Balance. Accidental Falls.

Resumo

Introdução: *As quedas são consideradas um problema de saúde pública, portanto torna-se relevante identificar se as alterações que a postura sofre no decorrer dos anos contribui para o risco de quedas em idosos.* ***Objetivo:*** *Analisar se as alterações posturais favorecem as quedas e/ou desequilíbrio postural, em idosos saudáveis da comunidade.* ***Métodos:*** *A busca ocorreu no mês de abril de 2016, de forma independente, por dois revisores, nas bases de dados PubMed, Web of Science, SPORTDiscus, e CINAHL, com delimitação de publicação dos últimos 10 anos, em língua inglesa, com as palavras chaves "posture" ou ("kyphosis","lumbar lordose","flexed posture","spinal curvature","spinal sagital contour") em combinação com "elderly" e "fall". A qualidade dos estudos foi avaliada pelas diretrizes do STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) para estudos observacionais.* ***Resultados:*** *Foram encontrados 1734 artigos, sendo considerados elegíveis, os estudos observacionais com avaliação postural, equilíbrio e/ou quedas em idosos, em um total de 17 artigos analisados. A confiabilidade e reprodutibilidade dos instrumentos não foram informados em cinco estudos, e em dois apresentaram descriçao questionável. Quatorze artigos analisaram alterações posturais a nível de tronco e 03 artigos avaliaram tornozelos e pés. A maioria dos estudos encontraram associaçao entre as alterações posturais com a perda do equilibrio e aumento das quedas em idosos.* ***Conclusão:*** *Hipercifose torácica, retificação da lordose lombar, diminuição do arco plantar de idosos que vivem na comunidade, parecem contribuir para maior instabilidade postural, e consequentemente aumentar o risco de quedas na população idosa que vive na comunidade.*

Palavras-chave: *Idoso. Postura. Equilíbrio Postural. Acidentes por Quedas.*

Introduction

Falls are considered to be an important public health problem due to the risks of morbidity and mortality [1]. In Brazil, about 30% of community-living older adults report falling at least once a year [2 - 4].

In addition to environmental risks [5], the literature points out several risk factors intrinsic to falls, such as age, female gender, functional disability, balance deficit, gait disorders, sedentary lifestyle, poor health self-perception, use of psychotropic drugs, muscle weakness, reduced visual acuity, cognitive deficits, and polypharmacy [1 - 7].

Although posture is not considered a risk factor for falls, several studies investigated the relationship between posture and body balance and/or falls in older adults [8 - 12]. *The Guide to Physical Therapist Practice of the American Physical Therapy Association* (APTA) defines posture as "the alignment and positioning of the body in relation to gravity, center of mass, or base of support" [13]. In ideal posture, there is a state of muscular and skeletal equilibrium and an adequate tension on support structures for a more efficient balance control [13].

Ideal postural alignment is indirectly associated with aging [8, 12, 14]. The body undergoes changes in the bones, muscles, and joints that lead to changes in the physiological spinal curvature [10, 13]. Thoracic hyperkyphosis is the most common, affecting 20 - 40% of older adults worldwide [15], along with osteoporosis as an associated clinical condition [16]. Patients with hyperkyphosis may have anterior displacement of the head, protrusion of the scapula, loss of lumbar lordosis [17], and, consequently, anteriorly project into the line of the center of gravity [8]. Changes in the projection of the center of gravity negatively affect body balance control [17].

The relationship between body balance and postural changes in the vertebral column due to the clinical condition of osteoporosis was also highlighted in the reviews by Hsu et al. [17] and Groot et al. [18]. These authors found poor balance control in patients with vertebral fractures, thoracic hyperkyphosis, and flexed posture.

A gap exists in the literature for systematic reviews to investigate how changes in postural alignment of different body segments affect postural stability and the risk of falls in healthy older adults. Thus, this study aimed to investigate whether postural changes increase fall risk and/or postural imbalance in healthy, community-dwelling older adults.

Methods

Search Strategy

In April 2016, two reviewers independently searched PubMed, Web of Science, SPORTDiscus, and CINAHL for studies in the last 10 years. After screening titles, abstracts and keywords, full-text versions of potential papers were selected. Discrepancies were resolved by a third reviewer. The following keywords (DESCs and MESH terms) and search strings were used: (*posture* OR *kyphosis* OR *lumbar lordosis* OR *flexed posture* OR *spinal curvature* OR *spinal sagittal contour* AND *elderly* AND *fall*).

Selection/Inclusion Criteria

The inclusion criteria were English written observational studies assessing posture, balance, and/or falls in adults 60 years and older. We excluded duplicates, reviews, case studies, theses and dissertations, studies with special populations such as those with a specific pathology (for instance, Parkinson's disease, stroke, osteoporosis, etc.), and articles not available in full text.

Quality assessment

Study quality was assessed according to the STROBE (*Strengthening the Reporting of Observational Studies in Epidemiology*) guidelines for observational studies (Table 1) [19].

Table 1 - The STROBE checklist for assessment of methodological quality of observational studies

ITEM	ASSESSMENT	
	Introduction and methods	
1. Study objective	+	Clearly stated the study objective;
	?	Questionable description;
	0	Gave no information on the study objectives.
2. Setting/location	+	Described the setting, locations, and relevant dates, including periods of recruitment and assessment, follow-up, and data collection;
	?	Questionable description;
	-	Only described the locations or the dates (e.g., periods of recruitment, assessment and follow-up);
	0	Gave no information on the locations or relevant dates, including periods of recruitment, exposure, follow-up, and data collection.
3. Sample	+	Described the eligibility criteria, the origin and the sources and methods of selection of participants;
	?	Description of the eligibility criteria, origin, and sources and methods of selection of participants;
	-	Only described the eligibility criteria or the origin and the sources and methods of selection of participants;
	+	Gave no information on the eligibility criteria, origin and sources and methods of selection of participants.
4. Sample size	+	Sample size calculation reported;
	?	Questionable description of sample size calculation;
	0	Gave no information on sample size calculation.

(To be continued)

Table 1 - The STROBE checklist for assessment of methodological quality of observational studies

ITEM	ASSESSMENT	
5. Control group (if applicable)	+	Properly explained how matching of cases and controls was addressed;
	?	Questionable explanation of how matching of cases ans controls was addressed;
	0	Gave no information on how matching of cases and controls was addressed.
6. Outcomes	+	All of the study outcomes were clearly described;
	?	Questionable description;
	0	Gave no information on the study outcomes assessed.
7. Assessment	+	The methods used in the assessment were described in the paper;
	?	Questionable description;
	0	Gave no information on the methods used in the assessment.
8. Reliability and reproducibility of the tool used for assessment	+	The tool used for assessment has intra- and inter-observer reliability and reproducibility or the intraclass correlation coefficient was calculated for the outcome;
	?	Questionable description;
	0	Gave no information on intra- and inter-observer reliability and reproducibility.
9. Bias	+	Described all efforts taken to address potential sources of bias;
	? +	Did not describe any efforts taken to address potential sources of bias;
	+	Gave no information on any efforts taken to address potential sources of bias.
10. Statistical methods	+	Described all statistical methods;
	?	Questionable description of statistical methods;
	0	Gave no information on statistical methods.

(To be continued)

(Conclusion)

Table 1 - The STROBE checklist for assessment of methodological quality of observational studies

ITEM	ASSESSMENT	
		Results and discussion / conclusion
11. Participants	+	Reported the numbers of individuals at each stage of the study (e.g., numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analyzed);
	?	Questionable description;
	-	Did not describe the number of individuals at each stage of the study;
	0	Gave no information on the number of participants.
12. Descriptive data	+	Described the characteristics of study participants (e.g., demographic, clinical, social);
	-	Did not describe all the characteristics of study participants;
	0	Gave no information on the characteristics of study participants.
13. Results	+	Clear description of study outcomes;
	?	Questionable description.
14. Clinical implications	+	Clinical descriptions were described according to study outcomes;
	?	Questionable description of clinical implications;
	0	Gave no information on the clinical implications of the study outcomes.
15. Limitations	+	Discussed the limitations of the study;
	?	Questionable description of the limitations of the study;
	0	Gave no information on the limitations of the study.

Note: + = positive rating; ? = questionable study design or methodology; - = negative rating; 0 = information unavailable; NA = not applicable.

Results

Characteristics of the studies retrieved

Figure 1 shows a flowchart describing the results of each step in the selection procedure. Of 1,734 articles retrieved, 17 were eligible for inclusion.

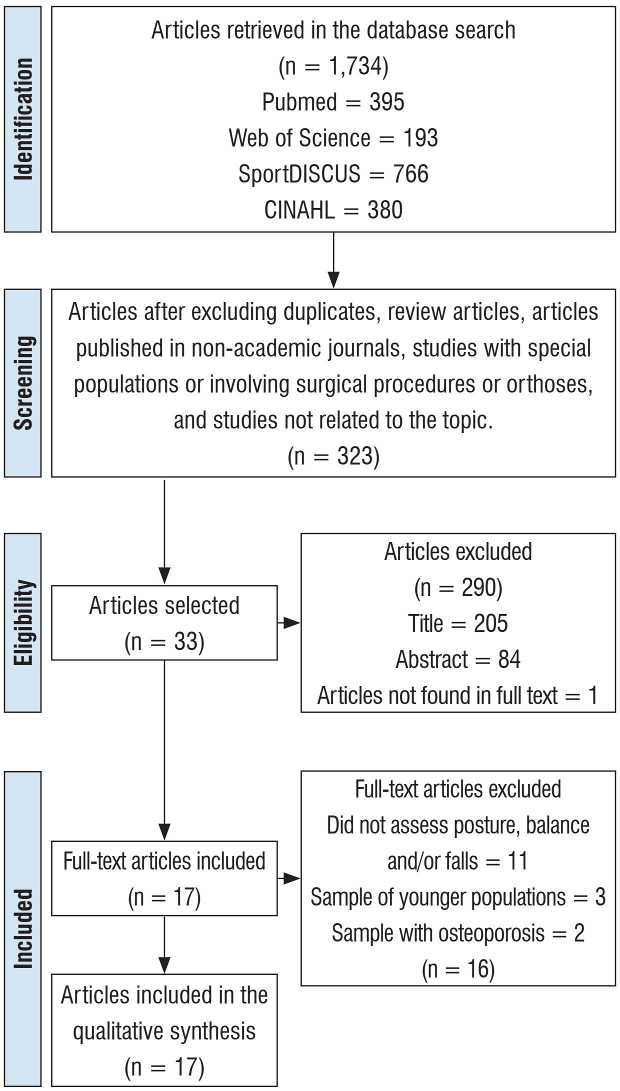

Figure 1 - Flowchart of the selection process using the PRISMA criteria [20].

Fifty per cent of the studies included in this review were conducted in Japan, while the remaining studies were representative of different geographical locations (Australia, USA, Netherlands, Italy, Japan, Malaysia, Poland).

The articles were analyzed with regard to design, sample characteristics, tools used to assess body posture, balance and/or falls risk, and outcomes (Table 2). Three studies have specifically assessed the feet and the ankles and their data are shown separately in Table 3.

Ten studies (58.8%) were cross-sectional studies, five (29.4%) were cohort studies (two of which were also prospective), one (5.9%) was longitudinal, and one (5.9%) was not defined (Tables 1 and 2). The following methods and tools were used to assess body posture: SpinalMouse [8, 21 - 24], occiput-to-wall distance (OWD) [25 - 27], method using 1.7 cm blocks [28], flexicurve ruler [29, 30], Cobb angle [24, 26, 27], photogrammetry/Moiré method [31], method with photographic recording [32] and digital inclinometer [33]. Foot posture was assessed using the *Foot Posture Index* (FPI) [34, 35], which tests foot characteristics across six domains: foot posture, foot deformity and lesions, plantar tactile sensation, toe muscle strength and foot pain, and a three-dimensional foot scanner (Footstep PRO, Dream GP Company, Japan) [36].

Falls were ascertained by the administration of a questionnaire, and assessed using the Falls Efficacy Scale (FES) [30]. Participants' falls risk was assessed using Pluijm's assessment [26] and the *Physiological Profile Assessment* (PPA) [34]. While most studies followed participants for 12 months [10, 21, 24, 28, 34], in one study participants were followed for only six months [27].

Body balance was assessed using more accurate methods of measurement, such as stabilometry, force plate [14, 21, 22, 24, 29, 36], and functional tests such as the *Timed Up and Go* (TUG) test [8, 23, 32 - 35], functional reach (FR) [8], *Berg Balance Scale* (BBS) [30], one-led stance [23, 32, 33], *Four-Square Step Test* (FSST) [34, 35] and feet-together stance, *semitandem* and *tandem standing* [25].

Table 2 - Characteristics of the studies with regard to methodologies, sample profile, outcomes and tools used for assessing body posture, balance and falls risk

References	Country of origin	Study design	Sample characteristics	n (mean age ± SD)	Body posture assessment	Assessment of balance and/or falls risk	Results
Antonelli-Incalzi et al. (2007)	Italy	Cross-sectional	Random sample. Subjects of both sexes from two different towns were randomly invited to participate in the InCHIANTI study. Subjects were divided into three groups according to the OWD distribution (1st quartile: short OWD; 2nd and 3rd quartiles: medium OWD; 4th quartile: long OWD).	783 participants, 55% women, (75 ± 6,85 years) and 45% men (73.8 ± 6.34 years).	Flexed posture: measured using the occiput-to-wall distance (OWD) Tool: rigid tape measure – subject standing with the head in the neutral position.	Balance: feet-together stance, semitandem standing and tandem standing for 10 seconds.	Balance: There were significant differences between groups. Subjects with short OWD performed better in the balance test, **p<0.009** for men and **p<0.001** for women. After adjustment for age and other variables, there was a correlation between balance and OWD, but only in women (**p=0.002**).
Kado et al. (2007)	USA	Cohort. Rancho Bernardo Study	Convenience sample. Subjects of both sexes who participated in the Rancho Bernardo Study (1988 -1992).	1883 participants, women (72.7 ± 9.0 years) and men (73.6 ± 8.9 years)	Thoracic hyperkyphosis: blocks method, 1.7 cm blocks. Occiput-to-table distance while in the supine position. Hyperkyphosis was de□ned as requiring the use of ≥ 1 blocks.	Self-reported falls in the previous 12 months.	Thoracic hyperkyphosis: n= 430 ± 30.2 (nonfallers) vs n=165 ± 36.2 (fallers) **p=0.015**; Participants were divided according to gender: Men (n= 342) OR 1.86 (1.22-2.85) 95% CI, **p=0.004**; Women (n=252) OR 1.50 (1.08-2.07) 95% CI, **p=0.01**; When adjusted for age: men OR 1.50 (0.96-2.36) 95% CI, **p=0.08**; women OR 1.30 (0.92-1.83) 95% CI, **p=0.24**.
Kasukawa et al.(2010)	Japan	Cross-sectional	Convenience sample. Subjects of both sexes, divided into three groups: 1- subjects without a history of falls or fear of falls (nonfallers); 2 - subjects with a history of fear of falls or requiring any support when walking; and 3 - subjects with a history of falls (fallers).	92 participants: Group 1, n=40 (72.9 ± 8.1 years), Group 2, n=36 (74.2 ± 9.4 years), and Group 3, n=16 (77.3 ± 6.5 years)	Spinal curvature: Angles of thoracic (T1-T-12) and lumbar kyphosis (L1-S1): Spinal inclination (T1-S1) Tool: SpinalMouse	History of falls in the previous 12 months: questionnaire. Balance: Stabilometry. Subject standing unaided in the upright position for 20 s with eyes open. Horizontal (X direction) and vertical (Y direction) movements of center of gravity (COG) during measurement were calculated as deviation of COG to origin. Tool: Force plate JK-101.	Thoracic kyphosis: 32.6 ± 15.6o (fallers) vs 3.2 ± 12.6 o (nonfallers) NS Lumbar kyphosis: 8.3 ± 16.8 o (fallers) vs -12.5 ± 13.7 o (nonfallers) **p<0.0001** Spinal inclination: 17.1 ± 13.8 o (fallers) vs 5.7 ± 6.6 o (nonfallers) **p=0.0007** Lumbar mobility: 18.8 ± 15.7° (fallers) vs 33.6 ± 15.2° (nonfallers) **p=0.004** Stabilometry: 435.1 ± 199.9 mm (fallers) vs 278.1 ± 104.7 mm (nonfallers), **p=0.0021**

(To be continued)

Table 2 - Characteristics of the studies with regard to methodologies, sample profile, outcomes and tools used for assessing body posture, balance and falls risk

References	Country of origin	Study design	Sample characteristics	n (mean age ± SD)	Body posture assessment	Assessment of balance and/or falls risk	Results
Regolin & Carvalho (2010)	Brazil	Cross-sectional	Convenience sample. Women divided into three groups: 1 - loss of bone mass and increase in thoracic kyphosis; 2 - loss of bone mass without increase in thoracic kyphosis; 3 - without loss of bone mass and without increase in thoracic kyphosis; 4 - without loss of bone mass and with increase in thoracic kyphosis	95 (67.20 ± 5.01 years).	Thoracic kyphosis angle Tool: flexicurve method	Balance: Stabilometry. Subject standing for 10 seconds, first with eyes open, then with eyes closed. One-minute rest between measurements. Tool: force plate, F-Scan system version 4.2 (Tekscan, Inc., South Boston, MA, USA) with 100 Hz sampling frequency.	Stabilometry, anteroposterior (AP) direction: Eyes open: 1.68 ± 0.56 cm (Group 1) vs 1.32 ± 0.58 cm (Group 3), **p=0.0124** Eyes closed: 1.77 ± 1.17 cm (Group 1) vs 1.27 ± 0.44 cm (Group 3), **p=0.0263**
Eum et al. (2013)	USA	MOBILIZE Boston Study cohort.	Convenience sample. Subjects of both sexes.	620 (79.2 ± 5.4 years)	Kyphosis index (KI) Tool: flexicurve ruler	Balance: *Berg Balance Scale* (BBS) Falls: FES (Falls Efficacy Scale), a cutoff of 90 was used to separate likely fallers from nonfallers.	There was no significant association between KI and BBS (p=0.23) or FES **p=0.527**
Ishikawa et al. (2013)	Japan	Cross-sectional	Convenience sample. Subjects of both sexes, divided into: Fallers (n=29) and nonfallers (n=184)	213 (70.1 ± 7.9 years)	Thoracic kyphosis (T1-T12) and lumbar lordosis angles (T12-S1), and spinal inclination (T1-S1) Tool: SpinalMouse	History of falls in the previous 12 months: questionnaire. Balance: Stabilometry. Tool: Force plate (JK-101)	Thoracic kyphosis: 33.3 ± 14.7° (fallers) vs 34.4 ± 14.4° (nonfallers) **p=0.396**; Lumbar lordosis: 3.8 ± 20.5° (fallers) vs 11.9 ± 14.3° (nonfallers) **p=0.035**; Spinal inclination: 10.9 ± 12.2° (fallers) vs 5.8 ± 7.9° (nonfallers), **p=0.017**; Stabilometry: AP direction 336.9 ± 243.9 mm (fallers) vs 214.5 ± 127.0 mm (nonfallers), **p=0.046**; ML direction 198.8 ± 116.2 mm (fallers) vs 150.1 ± 70,5 mm (nonfallers), **p=0.017**.

(To be continued)

Table 2 - Characteristics of the studies with regard to methodologies, sample profile, outcomes and tools used for assessing body posture, balance and falls risk

References	Country of origin	Study design	Sample characteristics	n (mean age ± SD)	Body posture assessment	Assessment of balance and/or falls risk	Results
Abe et al. (2013)	Japan	Cross-sectional	Convenience sample. Community-dwelling women from Nagasaki, Japan, who were invited to participate in periodic health examinations in 2006.	107 (66.2 ± 10.7 years)	Spinal inclination (T1-S1) Tool: SpinalMouse	Balance: *Timed Up and Go* (TUG) test and Functional reach (FR).	Spinal inclination = 4.6 ± 5.2°; TUG = 8.2 ± 1.6 s; FR= 27.5 ± 6.5 cm. There was a positive correlation between spinal inclination and TUG (r=0.37 **p<0.001**) and a negative correlation between spinal inclination and FR (r=- 0.37 **p<0.001**)
Miyazaki et al (2013)	Japan	Cross-sectional	Convenience sample. Community-dwelling males.	124 (73 ± 7.2 years)	Thoracic kyphosis angle (TKA) (T1-T12) and lumbar lordosis angle (LLA) (L1-L5). Tool: SpinalMouse	Balance: TUG and one-leg stance with eyes open for both lower limbs.	TKA (35.8 ± 9.7°) showed a negative correlation with LLA (-13.1 ± 9.3°, r=-0.36, **p<0.01**); LLA was correlated with TUG (r=0.36, **p<0.01**) and one-leg stance (r=-0.31, **p<0.05**); TKA was not correlated with TUG nor with one-leg stance (r=0.17 and r=-0.07, respectively, **p>0.05**)
Imagama et al. (2013)	Japan	prospective-longitudinal cohort	Convenience sample. Males who underwent a basic health checkup organized by the local government in 2007.	100 (70.2 ± 7.1 years)	Thoracic kyphosis angle (T1-T12) and lumbar lordosis angle (T12-L5). Tool: *SpinalMouse*.	History of falls: recorded in a journal Balance: Stabilometry. Tool: Force plate (G-620).	Correlation between thoracic kyphosis and balance: r=-0.08 (eyes open) vs r=0.054 (eyes closed), **p>0.05** Correlation between lumbar lordosis and balance: r=-0.465 (eyes open) vs r=-0.398 (eyes closed), **p<0.0001**. Correlation between lumbar lordosis and falls: 8.0 ± 10.6 (multiple falls) vs 17.7 ± 10.3 (one or no falls), **p=0.0280**.
Groot et al (2014)	Netherlands	Cross-sectional	Convenience sample. Subjects of both sexes, divided into two groups: flexed posture (FP, n=25) and normal posture (NP, n=31)	56 (80 ± 5.2 years)	Thoracic kyphosis: Cobb angle (hyperkyphosis > 50 degrees), assessment of lateral X-rays. Flexed posture: defined as an occiput-to-wall distance (OWD) of 0.5 cm or more.	Risk of falls: Pluijm score	Thoracic hyperkyphosis: 44.5 ± 12.1° (NP group) vs 58.6 ± 11.9° (FP group), **p<0.01**; Risk of falls: 4 (0–19 scores) for the NP group vs 4 (0–20 scores) for the FP group, **p= 0.73**

(To be continued)

(Conclusion)

Table 2 - Characteristics of the studies with regard to methodologies, sample profile, outcomes and tools used for assessing body posture, balance and falls risk

References	Country of origin	Study design	Sample characteristics	n (mean age ± SD)	Body posture assessment	Assessment of balance and/or falls risk	Results
Drzał-Grabiec et al (2014)	Poland	-	Female	90 (70 ± 8.01 years)	Thoracic kyphosis and lumbar lordosis: Photogrammetry based on the Moiré method	Balance: Stabilometry. Tool: CQstab platform.	All of the assessed balance parameters showed a significant (**$p<0.05$**), low to moderate correlation with spinal curvature $r=0.20–0.40$. Lumbar lordosis and thoracic kyphosis showed stronger positive correlations with balance, with $r=0.40$ and $r=0.44$, respectively, (**$p<0.001$**)
Ota et al. (2015)	Japan	Cross-sectional	Convenience sample. Women recruited from day care service users in Toyohashi.	53 (83.7 ± 6.3 years)	Body posture: spherical, colored-reflective markers attached to specific anatomic landmarks of participants' bodies in the standing position. Tool: Digital video camera (GR-D850), right lateral view.	TUG; one-leg stance with eyes open test (OLST)	There was a positive correlation between TUG and forward head position ($r=0.30$); and between TUG and lower lumbar spine angles ($r=0.34$), **$p<0.05$**. OLST was not correlated with any of the variables assessed (**$p>0.05$**).
Van der Jagt-Willems et al. (2015)	Netherlands	Prospective cohort	Convenience sample. Subjects of both sexes who visited an outpatient clinic in Amsterdam between October 2010 and April 2012.	51 (76 ± 4.8 years)	Thoracic hyperkyphosis: Cobb angle: hyperkyphosis was defined as Cobb angle ≥50°; Flexed posture: occiput-to-wall distance (OWD) > 5cm.	Falls: registered by monthly phone contact for the duration of 12 months.	Thoracic hyperkyphosis: 59 ± 16° (fallers) vs 49 ± 13° (nonfallers) **$p=0.04$**; Thoracic hyperkyphosis and future falls: OR 2.13 (1.10-4.51) 95% CI **$p=0.04$**; Flexed posture (OWD): 6.2 ± 4.1 cm (fallers) vs 4.2 ± 4.5 cm (nonfallers), **$p=0.18$**
Suzuki et al. (2015)	Japan	Cohort.	Convenience sample. Subjects of both sexes who participated in the Itabashi Cohort Study 2011.	834 participants: 484 women (72.7 ± 4.9 years) and 350 men (73.7 ± 5.5 years)	Inclination angle of the trunk: the digital inclinometer measured the inclination of the sternum. Tool: Digital inclinometer.	Static balance (one-leg stance with eyes open, dominant side); and dynamic balance (TUG)	In both sexes, the sternum inclination angle was not associated with static balance (**$p>0.05$**); the sternum inclination angle was associated with TUG in men, $r=0.26$ (**$p<0.01$**), but not in women, $r=0.02$ (**$p=0.61$**).

Table 3 - Characteristics of the studies with regard to methodologies, sample profile, outcomes and tools used for assessing the feet and the ankle, as well as balance and falls risk

References	Country of origin	Study design	Sample characteristics	n (mean age ± SD)	Assessment of the feet	Assessment of balance and/or falls risk	Results
Menz et al. (2006)	Australia	Longitudinal	Convenience sample. 176 subjects of both sexes, divided into 2 groups: Fallers (those who fell at least once during the follow-up period of 12 months) and nonfallers (those who did not fall)	176 (80.1 ± 6.4 years)	Assessment of the feet: FPI (*Foot Posture Index*)	Falls: 12 months follow-up. Tool: *Physiological Profile Assessment* (PPA) to assess participants' falls risk. Falls risk scores below 0 indicate a low risk of falling, scores between 0 and 1 indicate a mild risk of falling, scores between 1 and 2 indicate a moderate risk of falling, and scores above 2 indicate a high risk of falling.	There were significant differences between fallers and nonfallers: ankle flexibility (34.84 ± 10.14 degrees [nonfallers] vs 31.37 ± 11.46 degrees [fallers]; hallux valgus deformity (1.64 ± 1.84 [nonfallers] vs 2.32 ± 1.93 [fallers]; plantar tactile sensation (4.40 ± 0.55) [nonfallers] vs 4.62 ± 0.68 [fallers], **p<0.05**; failed paper grip test of the lesser toes (36.5% [nonfallers] vs fallers 59.2% [fallers], **p<0.01**. Physiological falls risk scores ranged from -1.47 to 5.17 (very low to very high). Fallers (1.23 ± 1.51) vs nonfallers (0.67 ± 1.20) **p=0.008**
Said et al (2015)	Malaysia	Cross-sectional	Convenience sample. Community-dwelling elderly women, divided into three groups, based on the foot posture index classification: neutral (n=16), pronated (n=14) and supinated (n=16).	44 (69.86 ± 5.62 years)	The feet of the participants were examined using the foot posture index (FPI), a clinical diagnostic tool that can classify foot postures.	Balance: TUG and *Four-Square Step Test* (FSST)	TUG: 10.73 ± 2.56 s (neutral); 10.38 ± 2.16 s (pronated); 9.85 ± 2.63 s (supinated) **p=0.484**; FSST: 14.33 ± 4,59 s (neutral); 16.75 ± 6.42 s (pronated); 13.40 ± 4.23 s (supinated) **p=0.291**.
Saghazadeh et al (2015)	Japan	Cross-sectional	Convenience sample. Community-dwelling elderly women divided into three groups based on standard scores of navicular height and drop: low arch and low foot mobility, medium arch and medium foot mobility, and high arch and high foot mobility	140 (73.9 ± 5.1 years).	Static foot posture, sitting and standing. Tool: Three-dimensional foot scanner ((Footstep PRO, Dream GP Company, Japan)	Balance: Stabilometry. Feet 10.6 cm apart, arms hanging naturally by their side as they looked at a spot on a wall 1.5 m in front of them. Postural balance was measured once for 30 seconds. Tool: Force plate (BM-101).	Balance (sitting position): 38.06 ± 16.02 cm (low arch), 30.32 ± 10.87 cm (medium arch), 29.88 ± 10.50 cm (high arch), **p=0.038**; Balance (foot posture): 36.23 ± 17.16 cm (low arch), 30.62 ± 10.82 cm (medium arch), 30.41 ± 10.20 cm (high arch) **p=0.273**; Foot mobility: 37.77 ± 14.41 cm (low mobility), 30.99 ± 12.44 cm (medium mobility), 29.77 ± 6.38 cm (high mobility), **p=0.018**

The methodological quality of the studies is shown in Table 4. All studies clearly described their objectives, assessment tools, statistics and outcomes. Only one study [31] failed to describe the eligibility and inclusion criteria of the participants (sample). Five studies [25, 26, 29, 33] did not describe the reliability of the tools used in the study, while two studies offered a questionable description of the tools' reliability [31, 36]. All studies but one [32] described their clinical implications. Finally, three studies did not mention limitations [22, 26, 33].

Table 4 - Methodological assessment results (STROBE)

Author	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Menz et al, 2006	+	+	+	0	NA	+	+	+	0	+	+	+	+	+	+
Antonelli-Incalzi, 2007	+	-	+	0	NA	?	+	0	0	+	+	0	+	+	+
Kado et al, 2007	+	+	+	0	+	+	+	+	0	+	?	+	+	+	+
Said et al, 2008	+	?	+	+	NA	+	+	+	?	+	+	+	+	+	+
Yusi Kasukawa et al., 2010	+	-	+	0	NA	+	+	+	0	+	+	+	+	+	+
Regolin & Carvalho, 2010	+	+	+	0	+	+	+	0	0	+	+	+	+	+	+
Abe et al, 2013	+	+	+	0	NA	+	+	+	0	+	?	+	+	+	+
Eum et al.,2013	+	-	+	0	NA	+	+	+	0	+	+	+	+	+	+
Ishikawa et al., 2013	+	+	+	0	NA	+	+	+	0	+	?	-	+	+	0
Imagama et al, 2013	+	?	+	0	NA	+	+	+	?	+	+	+	+	+	+
Miyazaki el al, 2013	+	?	+	0	NA	+	+	+	?	+	?	-	+	+	+
Groot et al, 2014	+	?	+	0	NA	+	+	0	0	+	?	-	+	+	0
Ota et al, 2015	+	+	+	0	NA	+	+	+	0	+	-	-	+	?	+
Van der Jagt-Willems et al., 2015	+	+	+	0	NA	+	+	0	0	+	+	+	+	+	+
Suzuki et al., 2015	+	+	+	0	NA	+	+	0	0	+	+	+	+	+	0
Saghazadeh, et al, 2015	+	?	+	0	NA	+	+	?	+	+	+	-	+	+	+
Drzał-Grabiec, et al, 2014	+	0	0	0	NA	+	+	?	?	+	?	-	+	+	+

Note: (+) = positive rating; (?) = questionable study design or methodology; (-) = negative rating; (0) = information unavailable; (NA) = not applicable

Discussion

Thus, this systematic review aimed to investigate whether postural changes increase fall risk and/or postural imbalance in healthy, community-dwelling older adults. In total, 17 articles were eligible and included for review. They used different tools to assess body posture, not only at the vertebral level, but also at the level of the ankles and the feet.

Postural deformities, such as thoracic hyperkyphosis, flexed posture, loss of lumbar lordosis, forward trunk inclination, and decreased plantar arch negatively affected postural balance and risk of falls in healthy older adults. Our findings are in line with those reported by Groot, Van der Jagt-Willems [18], in which postural control was affected in osteoporotic older adults with vertebral fractures, thoracic hyperkyphosis and flexed posture.

Most of the studies measured thoracic kyphosis [21 - 24, 26 - 31]. Thirty-six percent of older adults with thoracic hyperkyphosis had experienced falls and were 1.32 times more likely to report a fall in the past year than were those with normal kyphosis [28]. According to Kado [15], the relationship between thoracic hyperkyphosis and falls in women could be explained by age. In the study by Van der Jagt-Willems et al. [27], patients with hyperkyphosis were twice more likely to fall than their counterparts, regardless of sex. In contrast, Kasukawa et al. [21] and Ishikawa, Miyakoshi et al. [22] found no correlation between falls and increased thoracic hyperkyphosis.

Thoracic hyperkyphosis, flexed posture and forward trunk inclination are changes in the sagittal plane of the vertebral column that lead to a forward projection of the gravity line, negatively affecting postural balance [37, 38]. This is confirmed by the findings of this review, in which poorer stabilometry results were associated with postural malalignment and falls [21, 22, 24, 29, 31]. Previous studies have also associated thoracic hyperkyphosis with loss of mobility, reduced quality of life and increased falls risk in osteoporotic older adults [11, 16, 39, 40].

A relevant finding of this systematic review is that balance and risk of falls in older adults is not only affected by thoracic deformities such as thoracic hyperkyphosis. Special attention should be given to the lumbar spine, because several studies found an association between changes in lumbar curvature and poorer balance-test performance (as measured by stabilometry) and increased incidence of falls in healthy older adults [21 -24, 31, 32].

Loss of lumbar lordosis leads to pelvic retroversion and posterior shift of the gravity line [38]. In the study by Ishikawa et al. [10], loss of lumbar lordosis increased postural instability and propensity to fall in older adults with osteoporosis. Thus, both thoracic hyperkyphosis and loss of lumbar lordosis induce a displacement of the gravity line (GL) in the sagittal plane, reducing stability limits in all directions, as well as the magnitude of response and displacement speed, especially in the antero-posterior axis, fostering an increased postural balance in older adults [37].

Thus, the ankles and feet should also be taken into account when analyzing the influence of posture on balance and the risk of falls in healthy older adults. The feet play an important role in body stabilization, since it contributes to weight load distribution in the bipedal position and influences balance and balance control during gait [34, 41]. Studies have associated foot characteristics with the risk of falls in older adults. Loss of ankle mobility and plantar tactile sensation, deformities and toe weakness were found to negatively affect balance, gait speed and functional mobility test performance [7, 41, 42].

The maintenance of body balance depends on a complex, coordinate interaction of vestibular, somatosensory and visual systems, which hold the body's center of mass over the base of support [43]. This is why the use of multidimensional measures has been advocated for the assessment of balance and risk of falls in older adults. The *Clinical Guidance Statement on Management of Falls* [44] recommends the screening of different risk factors for falls and interventions, such as foot assessment and footwear correction, with level two evidence. It is important to highlight that other variables associated with postural changes may influence balance impairment and risk of falls in older adults, such as visual and proprioceptive muscle response [31], paravertebral muscle weakness [21 - 24], decreased spinal mobility [21] and low physical function [8].

Although postural alignment changes with ageing, stretching and strengthening exercise programs to paravertebral muscles may help to prevent or minimize these changes. In a twelve-month follow-up study, Pawlowsky et al. [45] found that older women receiving in-home physical therapy sessions twice a week for 12 months showed improved paravertebral strength and flexibility, and reduced thoracic kyphosis by 3°. Similar results were found in the study by Katzman et al. [46] with hyperkyphotic older women.

Despite the complexity of postural control and balance maintenance mechanisms in healthy older adults, this review shows that postural assessment in older adults should be part of the daily clinical routine of physical therapists, as a variable that still needs to be investigated as a risk factor for falls in healthy older adults. Moreover, exercise programs that contribute to increasing paravertebral muscle strength and flexibility should be included in the therapy prescribed by physical therapy professionals.

Some of the limitations of the studies included in this review were, first, the great variability of methods used to assess posture — ranging from more subjective (visual postural assessment) to more accurate technologies (*SpinalMouse*); second, the great variability of tools used to assess balance — from stabilometry to functional tests; third, some authors did not describe the reliability and reproducibility of the assessment tools; and, finally, the fact that some studies were cross-sectional and therefore did not assess the cause-effect relationship between postural changes, and/or impaired balance in community-living older adults.

Conclusion

This review shows that there is evidence that postural changes such as thoracic hyperkyphosis, loss of lumbar lordosis and decreased plantar arch seem to contribute to the increased postural instability and consequently an increased risk of falls in community-living older adults. However, since there is no consensus on the best method to assess balance in older adults, further studies should be conducted to elucidate this issue. Moreover, longitudinal studies need to be conducted to investigate the cause-effect relationship between age-related postural changes, and balance and falls in community-living older adults.

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