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Balance impairments in individuals with symptomatic knee osteoarthritis: a comparison with matched controls using clinical tests

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Abstract

Objectives. To compare balance in individuals with symptomatic knee osteoarthritis (OA) and in age-, gender- and body-mass-matched controls using simple clinical measures.

Methods. Thirty-three people with OA and 33 controls participated. Static postural sway [antero-posterior (AP), lateral and total] was measured using a swaymeter on two different surfaces and under two visual conditions. Dynamic standing balance was assessed using the 'step test'.

Results. Both groups displayed similar postural sway on most variables measured. Significantly greater sway was noted in the OA group on a firm surface in both lateral (eyes open) and AP directions (eyes closed), as well as total sway (eyes closed) ($P < 0.05$). Poorer dynamic standing balance was observed in the OA group as evidenced by the step test ($P < 0.0001$).

Conclusions. Balance deficits can be identified in the osteoarthritic population using simple, inexpensive measures. However, the clinical relevance of the small deficits identified remains unknown and warrants further investigation.

KEY WORDS: Balance, Body sway, Clinical assessment, Knee, Osteoarthritis.

Knee osteoarthritis (OA) is one of the most prevalent musculoskeletal complaints worldwide, affecting 30–40% of the population by the age of 65 yr [1]. It is a major cause of impairment and disability among the elderly [2, 3], and poses a significant economic burden on the community [4]. Individuals with knee OA suffer progressive loss of function, displaying increasing dependency in walking, stair climbing and other lower extremity tasks [3]. Balance is an integral component of these and many other activities of daily living. Understanding the impact of knee OA on balance may allow possible mechanisms of disability in this patient population to be elucidated, and may permit more effective management of patients with the disease.

Balance is a complex function involving numerous neuromuscular processes [5–7]. Control of balance is dependent upon sensory input from the vestibular, visual and somatosensory systems. Central processing of this information results in coordinated neuromuscular responses that ensure the centre of mass remains within the base of support in situations when balance is disturbed. Effective control of balance thus relies not only on accurate sensory input but also on a timely response of strong muscles. Balance impairments are associated with an increased risk of falls and poorer mobility measures in the elderly population [8–10].

Age-related impairments in balance and postural stability are well documented [11–13]. Ageing is associated with a decline in the integrity of the physiological systems that contribute to the control of balance [6, 14, 15]. The presence of knee OA may result in changes that accelerate the deterioration of these systems or compound the effects of ageing. Individuals with knee OA display reductions in quadriceps strength and activation [16–19] as well as impairments in knee joint proprioception [17, 20, 21]. These deficits, in combination with the ageing process, may culminate in greater impairments in balance in this patient population, compared with their age-matched and healthy counterparts.

Control of balance is essential in all postures and situations, both static and dynamic. Postural sway is often used as an indicator of static standing balance [22–24] where bodily movement in both the antero-posterior (AP) and lateral direction is analysed, usually using force platforms. These expensive apparatus are not readily available to the majority of clinicians, and are thus not appropriate for use in the clinical setting. Furthermore, falls and loss of balance most commonly occur during movement-related tasks such as walking

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[25, 26], and less frequently during static activities. It is therefore important that the evaluation of balance incorporates testing procedures that reflect the dynamic nature of such locomotor tasks, as static tests of balance are less able to identify individuals at risk of falls than dynamic tests [10, 27]. Simple, inexpensive and easy-to-administer clinical tests are required to allow the clinician to assess balance readily and quickly in patients with knee OA.

Limited research has evaluated the impact of knee OA on balance. Few studies, all utilizing force platforms to measure postural sway, have been undertaken in this patient population and have revealed deficits in postural control compared with asymptomatic subjects [18, 28, 29]. No study to date has utilized simple, clinically practical measures to assess balance in individuals with knee OA. Additionally, the effect of knee OA on functional, dynamic tests of balance remains unknown.

The purpose of this study was to evaluate static and functional standing balance in individuals with symptomatic knee OA and in an age-, gender- and body-mass-matched control group.

Methods

Participants

Thirty-three participants (16 female, 17 male) with knee OA and 33 asymptomatic controls (16 female, 17 male) aged > 50 yr were recruited through advertisements in local clubs, libraries, and the print and radio media. Participant characteristics are presented in Table 1. Groups were similar in age, weight, height and body mass index (BMI). Diagnosis of OA was confirmed by a rheumatologist, based on the American College of Rheumatology classification criteria [30]. Participants with OA were included if they had knee pain on most days of the previous month [average pain >3 cm on a 10-cm visual analogue scale (VAS)], demonstrated osteophytes on X-ray, and experienced pain and/or difficulty when getting up from sitting or climbing stairs. All participants were independent in activities of daily living. Those taking non-steroidal anti-inflammatory drugs had been on a stable dosage over the previous fortnight. Exclusion criteria included formal consultation of a physiotherapist for treatment of the knee (previous 12 months), knee surgery (previous 12 months), past history of lower limb joint replacement, Synvisc® or intra-articular steroid injection (previous 6 months), systemic arthritic condition, or severe medical condition precluding safe testing.

Control participants were excluded if they reported any lower limb pathology or joint disorder, injury to or pain in either knee in the past year (for which treatment was sought, or which interfered with function) or displayed abnormality on physical examination of the knee [flexion range of motion (ROM) $\leqslant 125°$, effusion, palpable warmth, ligamentous laxity]. Due to ethical constraints, X-rays to exclude radiographic OA were not performed. The study was approved by the University of Melbourne Human Research Ethics Committee. All participants provided written informed consent.

TABLE 1. Presenting characteristics of OA and control participants

Characteristic	OA ($n=33$) mean (S.D.)	Control ($n=33$) mean (S.D.)
Age (yr)	68.1 (8.6)	68.1 (8.0)
Height (m)	1.67 (0.10)	1.67 (0.10)
Weight (kg)	80.0 (11.9)	76.7 (15.4)
BMI (kg/m^2)	28.6 (3.3)	27.5 (5.0)

S.D., standard deviation; BMI, body mass index.

Knee radiographs

Participants with OA had X-rays (skyline, weight-bearing AP and lateral) of the tested knee within the previous 12 months. Severity of OA was evaluated by a radiologist according to the Kellgren and Lawrence system [31], with 18% of participants graded as mild (grade I/II) and 82% graded as severe (grade III/IV).

Knee pain and disability

The Western Ontario and MacMaster Universities Osteoarthritis Index (WOMAC) evaluated knee pain and disability in the OA group [32]. Ten-centimetre horizontal VAS [33], marked in 1-cm increments, were used to record average pain (on movement and at rest) and activity restriction over the previous week, and severity of pain experienced during testing. Pain and disability characteristics of the OA group are presented in Table 2. Pain experienced by OA participants during the sway test ranged from 0 to 8 cm, with a mean of 2.5 cm, and during the step test ranged from 0 to 5 cm, with a mean of 1.5 cm.

Body sway

Body sway during bipedal static stance was measured using a swaymeter (Prince of Wales Medical Research Institute, High Street, Randwick, NSW, Australia), a

TABLE 2. Pain and disability characteristics of OA participants

Characteristic	Mean	S.D.	Range
Duration of symptoms (yr)	9.6	9.0	0.3–30
Average pain on movement over last week (VAS) (cm)	5.0	1.6	2–9
Average pain at rest over last week (VAS) (cm)	3.0	2.0	0–8
Average restriction of activity over last week (VAS) (cm)	4.8	2.1	1–8
Severity of pain in last 48 h (WOMAC; maximum score 20)	7.5	2.2	2–12
Severity of difficulty with physical functioning in last 48 h (WOMAC; maximum score 68)	26.3	7.9	7–42

S.D., standard deviation; VAS, visual analogue scale; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index (the higher the score, the worse the measured variable).

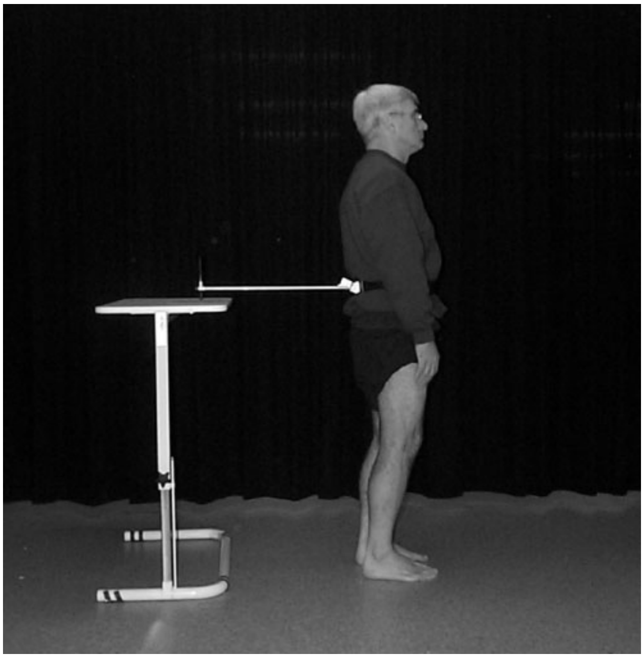

FIG. 1. The swaymeter used to assess postural sway in standing.

valid and reliable measure previously described by Lord *et al.* [34]. The swaymeter consists of a metal rod attached to the participant's waist by a firm belt. A pen, fixed to the rod, records movement of the participant's body on a sheet of graph paper fastened to the surface of an adjustable height table, positioned behind the participant (see Fig. 1).

Testing was performed with bare feet (10 cm apart) on the floor and a foam surface. The foam ($70 \times 62 \times 15$ cm) was used to reduce proprioceptive input from the lower limb, requiring participants to rely on visual and vestibular input to maintain a steady stance. Testing was performed twice on each surface, once with the eyes open and once with the eyes closed. Participants were instructed to stand as still as possible for a period of 30 s. Testing under each condition was performed once only, with no practice permitted. If loss of balance was imminent, testing was ceased for that particular condition.

Tracings of the pen on the graph paper yielded the following measures of postural sway: maximal sway in the (i) AP and (ii) lateral directions, and (iii) total body sway. A ruler was used to locate the outer borders of the sway path, and the linear measurement (in mm) in the AP and lateral directions used to determine the respective maximal sway measures (see Fig. 2). Total body sway was determined by counting the number of millimetre squares the pen traversed. These variables were recorded for each of the four test conditions. Participants unable to maintain balance for the duration of the testing period were allocated scores 2 standard deviations (S.D.) above the mean of the group for the relevant testing condition. Two control participants and four members of the OA group were unable to maintain their balance whilst standing on the foam with their eyes closed.

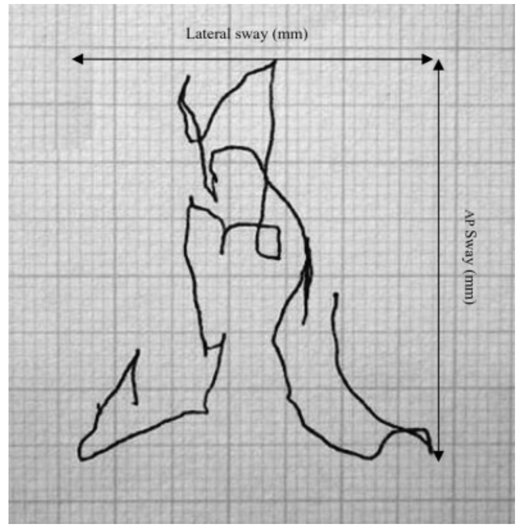

FIG. 2. Calculation of lateral and AP body sway from pen tracing.

Step test

The step test is a functional, dynamic test of standing balance [35], with known reliability and validity. Participants were instructed to maintain balance on one leg, whilst stepping the contralateral limb on and off a 15-cm step as quickly as possible. The number of times the participant could place the foot up onto the step and return it to the floor over a 15-s interval was recorded. Participants performed the test with bare feet, and no hand support was permitted. For OA participants, the test was performed whilst standing on the osteoarthritic limb. For those individuals with bilateral symptoms, the most symptomatic limb was deemed the osteoarthritic limb for purposes of this study. Control participants performed the test whilst standing on each leg. As no statistically significant differences were evident between limbs in the control group ($P > 0.05$), the mean of the result obtained for each limb was used in data analysis for comparison with the OA group. In all participants, the test was performed once only, with two to three practice steps permitted before the test. If loss of balance occurred, the test was ceased and the number of completed steps up until this point recorded. Only one OA participant was unable to maintain balance for the 15-s period.

Statistical analysis

Data were analysed using the Statistical Package for the Social Sciences (Norusis/SPSS, Inc, c/o Information Technology Services, The University of Melbourne, Australia). The data were assessed for normality by calculating values for kurtosis and skewness, as well as via the Kolmogorov–Smirnov test of normality.

Independent t-tests or Mann–Whitney U-tests were used to compare differences between groups. P values < 0.05 were regarded as statistically significant.

For those variables that were significantly different between groups, potential independent predictors were evaluated within the OA participants. Selected predictors included radiographic severity of disease and severity of pain and disability. Correlations between these predictors and the balance variables were determined using the Spearman ρ coefficient.

In order to determine the relationship between results obtained with the step test and the swaymeter, correlations between the postural sway variables and the step test were determined within the entire cohort using the Spearman ρ coefficient.

Results

Static postural sway

The means and standard deviations of body sway (AP, lateral and total sway) in the OA and control participants are presented for each of the four testing conditions in Figs 3–5. Of the 12 variables measured, only three were significantly different between the groups. Participants in the OA group displayed greater body sway in the lateral direction when standing on the floor with eyes open ($P = 0.017$) as well as increased total sway ($P = 0.008$) compared with controls, indicating poorer balance. OA participants also demonstrated greater body sway in the AP direction when standing on the floor with eyes closed ($P = 0.045$). Although the OA group displayed greater body sway than the controls when standing on the foam surface (with eyes open and closed), no statistically significant differences were seen between the groups.

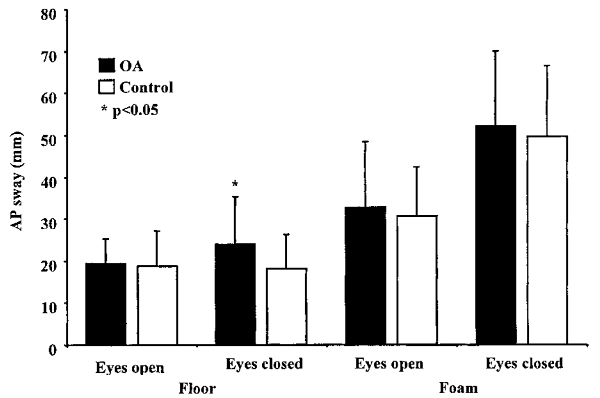

FIG. 3. Mean body sway in the AP direction in OA and control participants across the four testing conditions. Error bars indicate the standard deviations of the means.

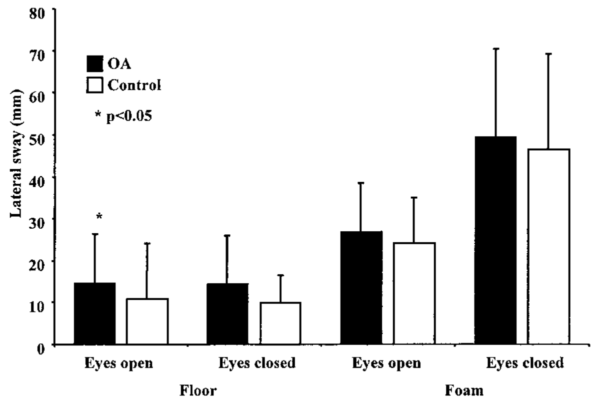

FIG. 4. Mean body sway in the lateral direction in OA and control participants across the four testing conditions. Error bar indicates the standard deviations of the means.

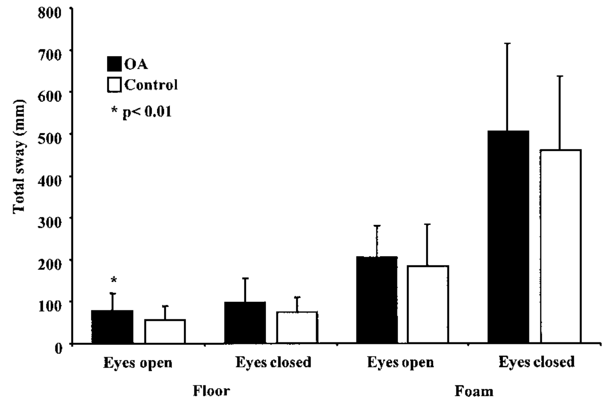

FIG. 5. Mean total body sway in OA and control participants across all four testing conditions. Error bars indicate the standard deviations of the means.

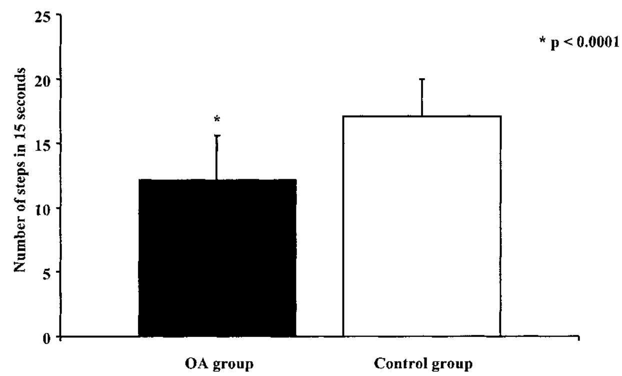

FIG. 6. Mean results of the step test for OA and control participants. Error bars indicate the standard deviations of the means. Note that the control data represent the mean result of both legs.

Dynamic standing balance

The mean results of the step test are presented in Fig. 6. Compared with controls, participants in the OA group took five fewer steps in the 15-s test period whilst standing on their osteoarthritic leg ($P < 0.001$), indicating poorer balance under this dynamic testing condition. As only nine members of the OA group reported unilateral symptoms, numbers were too small to permit statistical comparison of balance measures between unilateral and bilateral disease within the OA group.

Predictors of balance deficits in the OA group

Little was seen to predict the observed balance deficits within the OA group. Whilst increased severity of pain during sway measurement was associated with increased lateral sway ($r = 0.47$), no other relationship between pain and balance was evident. No significant relationship was observed between disability scores or radiographic severity and the selected balance variables.

Correlations between the balance measures

Correlations between the step test and postural sway data are provided in Table 3. Significant inverse relationships were observed between the step test and seven of the 12 postural sway variables. However, the strengths of the relationships were weak, indicating that the step test cannot accurately predict results obtained using the swaymeter.

Discussion

The control of balance is a complex process. Postural stability requires central integration of input from visual, vestibular and peripheral sensory systems, as well as precise motor control to maintain equilibrium [5–7]. Previous investigators have demonstrated that vision, peripheral proprioception and lower limb muscle strength appear to be important determinants of balance in the elderly [14, 24, 34, 36, 37].

Using simple clinical measures, the results of our study demonstrate that individuals with knee OA display some impairment in postural control, mostly under the dynamic testing condition. The step test, a dynamic test of balance, revealed that participants with OA took significantly fewer steps when standing on the osteoarthritic limb compared with controls. This reflects a reduced ability to maintain standing balance whilst performing a potentially destabilizing activity. Whether the balance deficit evident on the step test impacts functionally on individuals with knee OA remains unknown and should be the focus of future research.

Several potential mechanisms may be responsible for the balance deficit observed within the OA group, although the cross-sectional nature of our study does not allow these to be confirmed. Deficits in lower limb proprioception and muscle strength are associated with knee OA [17, 18, 20] and thus may be postulated as a cause of impaired balance. However, studies of balance in this population are yet to establish a relationship between these parameters [18, 29], rendering this hypothesis open to question. Pain associated with the osteoarthritic knee may play a role in balance impairments. The presence of pain may reflexively inhibit the muscles around the knee [38], which could compromise effective and timely motor responses in postural control. Furthermore, pain may result in reduced loading of the affected joint [39], potentially jeopardizing an individual's ability to maintain their centre of mass within the base of support. Whilst Hassan and colleagues [29] found pain to be a significant predictor of sway in their osteoarthritic sample, pain scores in our study were generally not correlated with observed balance deficits. This may be due to the milder levels of pain experienced by participants in our study in contrast to those of Hassan *et al.* [29]. Knee flexion contractures, often associated with OA, have been linked with increased postural sway [40, 41]. Joint contracture may cause a shift in an individual's centre of mass and thus must also be recognized as a possible cause of balance deficits. Further research is required to determine the impact of knee OA on the systems responsible for postural control before mechanisms behind balance deficits can be understood.

Compared with the step test, less significant differences in balance were evident between the groups when utilizing the swaymeter. Greater body sway was evident in the OA group when standing on the floor with respect to only three of the 12 measured variables. The nature of the difference between the groups was generally small, however, and the clinical relevance of such differences remains unknown. It is possible that the bilateral nature of the postural sway test allows an individual to compensate for the osteoarthritic knee with the contralateral, or less symptomatic, limb. This may explain why only small differences between groups were evident and with a limited number of the measured variables. It is also likely that reduced statistical power may account for the lack of difference between groups when standing on the foam. A much larger variation in postural sway was observed in participants on the foam when compared with those on the floor; thus, larger subject numbers would be required to demonstrate a difference between groups.

TABLE 3. Correlation coefficients (Spearman's ρ) between performance on the step test and postural sway within all participants

	Floor						Foam					
	Eyes open			Eyes closed			Eyes open			Eyes closed		
	AP	Lat	Tot	AP	Lat	Tot	AP	Lat	Tot	AP	Lat	Tot
Step test	−0.22	−0.34[a]	−0.37[a]	−0.28[b]	−0.19	−0.27[b]	−0.11	−0.18	−0.35[a]	−0.10	−0.26[b]	−0.25[b]

AP, antero-posterior sway; Lat, lateral sway; Tot, total sway.
[a]$P < 0.01$; [b]$P < 0.05$.

To our knowledge, only three other studies have evaluated balance in people with knee OA [18, 28, 29]. All have utilized force platforms and none have evaluated balance when standing on a compliant surface. Hassan *et al.* [29] and Wegener *et al.* [28] demonstrated increased postural sway in subjects with knee OA when standing on a firm surface, with eyes open and closed, in both AP and lateral directions. In contrast, Hurley and colleagues [18] were unable to detect a deficit in body sway in individuals with OA, despite the OA group being more unsteady as a whole when compared with controls. The close matching of control participants in our study, compared with published investigations, supports the hypothesis that observed balance deficits are due to the presence of OA, and not to inherent differences between groups with regard to age, gender or BMI.

Simple, inexpensive tests of balance are necessary for use in the clinical setting. The step test is very quick to perform, requires minimal apparatus and does not need analysis or manipulation of results. The swaymeter is an inexpensive, portable device that allows easy assessment of postural sway. The testing procedure is quickly performed (in $\sim$2 min), with no complicated set-up or calibration of equipment required. Analysis of sway in the AP and lateral directions is quickly established from the pen tracing with a ruler. Calculation of total sway is more laborious, as the number of millimetre squares traversed by the pen must be counted, which can be time consuming. As expected, both measures of balance appear to be correlated. However, the strength of the association between data from the swaymeter and the step test is weak at best, suggesting that performance on one test cannot accurately predict performance on the other. Due to the complex nature of balance control, it appears that application of both measures is necessary for a thorough evaluation.

Limitations to the interpretation of results of this study exist. The use of the swaymeter to assess postural sway generates multiple outcome variables. As such, the risk of finding a significant difference between groups, due to chance alone and not because of true deficits in balance, is increased and must be recognized. Furthermore, whilst results of the current study have shown some statistically significant balance impairments within the OA group, the functional impact of such deficits remains unknown. Further research is warranted to determine what magnitude of balance deficit (as assessed by the swaymeter and step test) is required before function is impaired.

The findings of this study have important clinical implications for the understanding and management of patients with knee OA. Balance deficits in this population can be identified quickly and easily in the clinical setting by the use of the step test and the swaymeter; however, the clinical and functional implications of such deficits are unknown. Multiple testing techniques appear necessary to evaluate balance in these individuals fully. Treatment strategies directed at improving balance in these people may be warranted and require future investigation.

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