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Original Articles

Dynamic stability during stair negotiation after total knee arthroplasty

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ABSTRACT

Background: The assessment of dynamic stability is crucial for the prevention of falls in the elderly and people with functional impairments. Evidence that total knee arthroplasty improves balance in patients with severe osteoarthritis is scarce and no information exists about how the surgery affects dynamic stability during stair negotiation.

Methods: This study aims to investigate if patients before and one year after surgery are less stable compared to asymptomatic controls. Seventeen control and twenty-seven patient participants with end-stage knee osteoarthritis that were scheduled to undergo unilateral total knee arthroplasty were recruited in this study. Participants' assessment was carried out by means of marker-based optical full-body motion capture with force platforms. The extrapolated Centre of mass and the margin of stability metrics were used to examine dynamic stability during stair ascent and descent.

Findings: Patient participants, during both pre-operative and post-operative assessments, were equally balanced to the asymptomatic controls during stair gait ($p > .188$). Additionally, the patients' overall stability did not improve significantly one year after arthroplasty surgery ($p > .252$).

Interpretation: Even if pain from arthritis and fear of falling is decreased following surgery, our results indicate that stability in stair walking in not affected by osteoarthritis and total knee arthroplasty.

Clinical trial registration number: NCT02422251.

1. Introduction

Falls are the most frequent cause of injury-related emergency hospital visits and the lifetime probability of death from a fall is 1 in 127 (National Safety Council, 2017). The likelihood of falling increases significantly with age and more than 40% of people over the age of 75 suffer one or more falls every year (Downton and Andrews, 1991). Compared to other locomotion activities, stair negotiation places increased musculoskeletal, somatosensory and visual demands, while structural and environmental factors may also increase the risk of stair falling. Most accidents involving stair falls occur during descent and can lead to severe injuries, such as head trauma and femoral neck fractures, which require prolonged hospitalization (Sjögren and Björnstig, 1989). Population ageing and the magnitude of the healthcare cost of fall-related injuries (Heinrich et al., 2010) underscores that efforts should be directed toward fall prevention research.

Attempts to determine the underlying causes of falls have indicated an association with a number of factors, such as hypnotics and antidepressants (Blake et al., 1988), urinary incontinence, arrhythmias and polypharmacy (Damián et al., 2013), and cognitive impairments (Kallin et al., 2005). The relationship between osteoarthritis (OA) and falls is still widely unexamined and the existing reports have been contradictory: Ng and Tan (Ng and Tan, 2013) concluded that patients with radiographic evidence of OA do not have an increased risk of falling, while a more recent study by Doré, et al. (Doré et al., 2015) contradicted that symptomatic knee or hip OA was associated with an increased fall likelihood. Additionally, people who underwent total knee arthroplasty surgery (TKA) appear to have a higher risk of falling up to 4 months after surgery and when compared to patients with severe knee OA (Levinger et al., 2011) and healthy elders alike (Matsumoto et al., 2012), as a result of their post-operative knee extension weakness and proprioception deficits. Moreover, TKA patients showed reduced knee flexion angles

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(Standifird et al., 2016) and quadricep strength in the TKA-side during stair negotiation (Bjerke et al., 2014), that may significantly increase unbalanced conditions and falls during stair walking.

In order to prevent falls, clinicians have frequently assessed the balance of patients with functional impairments, such as those with neurological, orthopaedic and vestibular deficits. Clinical assessment of balance may test different aspects of postural control and stability. In this context, postural control describes the compensatory and anticipatory actions that a person uses to maintain or restore balance, while stability refers to the inherent ability (motor, sensory and physical properties) of a person to remain balanced and not fall (Pollock et al., 2000). Maintaining balance is regarded as a complex motor skill integral to human posture (static) and movement (dynamic postural control and stability) that depends on cognitive, sensory and motor inputs. Since falls and loss of balance are more common during movement-related tasks rather than static activities, clinical assessment of dynamic postural control and stability aims to identify individuals who are at high risk of falling during locomotion.

Numerous methods exist for the assessment of human balance, including the maximum Lyapunov exponent (Mehdizadeh, 2018), maximum Floquet multiplier (Kang and Dingwell, 2008), margins of stability (MoS) (Hof et al., 2005), gait variability measures, maximum allowable perturbation and more (Bruijn et al., 2013). Each of these measures has its own merits and limitations, making their application more or less fitting depending on the studied activity. For example, the maximum Lyapunov exponent and Floquet multiplier may be calculated even from a single inertial measuring unit but they can only be applied to strictly periodic movements (e.g. treadmill walking) and they require more than 100 movement cycles to return precise and reliable stability estimates (Bruijn et al., 2013). In contrast, calculation of the MoS is straightforward and can be applied in a wide range of heterogeneous movements. However, as the MoS is defined as the difference between an extrapolated whole-body centre of mass (CoM) position, using CoM velocity, and the extremity of the base of support, its calculation does require capturing full-body kinematics.

Using MoS measures, it has been reported that elderly participants are at a greater risk of falling than younger subjects during stair negotiation (Bosse et al., 2012) and that step height and length affect balance during descent (Novak et al., 2016); a positive correlation between MoS and the times of Timed Up and Go tests was also observed for patients with knee OA (Koyama et al., 2015). Even though TKA improves balance and has a positive influence in fear of falling (Moutzouri et al., 2017), reports on stair ambulation biomechanics following TKA are not consistent between studies (Standifird et al., 2014), while the effect of TKA on MoS measures during stair negotiation is unexplored. In the present study, the metric of the MoS, along with gait variables, has been used to determine dynamic stability during stair negotiation pre and post TKA, together with an age-matched control group. Specifically, the aims of this study were to investigate the changes in dynamic stability of OA patients after TKA, and compare the stability of patients and asymptomatic controls.

2. Materials and methods

Patients with knee OA that were scheduled to undergo primary unilateral TKA and asymptomatic older control volunteers were invited to participate in this ongoing (Komaris et al., 2018; Komaris et al., 2020; Komaris et al., 2021) clinical study (ClinicalTrails.gov identifier: NCT02422251). Volunteers were sought from end-stage OA patients scheduled for unilateral TKA, between August 2015 and June 2017. Asymptomatic (self-reported), control volunteers over 50 years of age, were recruited from community groups and social clubs via email advertising. Control and patient participants were excluded if they had a lower limb joint replacement carried out in the previous twelve months, previous ankle surgery, or any musculoskeletal, neurological or sensory deficit. Patient participants had their operations performed by one of three consultant orthopaedic surgeons and received implant variations of the Columbus total knee system (B. Braun, Melsungen, Germany) that all surgeons have used in their routine clinical practice. Surgeries were performed using the OrthoPilot navigation system. Patients had their surgery and rehabilitation prior to discharge according to standard hospital practice, and returned to the hospital for standard follow up appointments at six weeks and one year after the surgery. Ethical approval was granted by an NHS authorised research ethics committee.

A prior one-sided sample size calculation for two independent groups, using the MoS values reported by Bosse, et al. (Bosse et al., 2012) revealed that 17 individuals per group were needed to detect an effect size of 0.88 with an alpha and beta of 0.05 and 0.2, respectively. Seventeen control and twenty-seven patient participants attended a single and two (pre-operatively and one-year post-operatively) motion capture sessions, respectively. Gender, age, affected knee side (patients only) and body mass index (BMI) were logged for all groups (Table 1). Patient participants were age-matched ($p = .38$) but had higher BMIs ($p < .01$) compared to the healthy recruits in this study. Participants wore tight-fitting shorts and t-shirts, and comfortable footwear. Thirty-five 14 mm retroreflective markers were fixed to anatomical body locations as per the full-body Plug-in Gait biomechanical model, while a knee alignment device (KAD) was used during the static calibration of the participants. Motion capture was carried out with twelve Vicon (Oxford Metrics, Oxford, UK) T-series cameras and four Kistler (Winterthur, CH) force platforms, sampling at 100 and 1000 Hz, respectively.

A four-step staircase was used, with two handrails, and a step's height and length equal to 185 mm and 280 mm, respectively (Fig. 1). The second step was modular and each part was singly mounted on force platforms 3 and 4. To ensure that no noise was captured by the force transducers during double support, 1 cm gaps were left between the second and its two neighbouring steps. Participants were asked to initiate gait at a two-step distance from the staircase, ascend with their own preferable manner, turn around at the end of the staircase and descend back to their starting position. Five ascent and five descent trials were recorded per participant.

Marker and force data were filtered with a 4th order Butterworth filter with cut-off frequencies of 15 Hz. Gaps of less than 0.05 s were filled with Woltring quintic spline fills, while gaps in the trajectories of the head, thorax and pelvis of 0.25 s or less were treated with rigid body fills; larger gaps were filled with pattern fills. Since a step-by-step strategy could significantly improve balance in stair negotiation, only the trials of participants following a step-over-step pattern were considered. The use of handrails was not restricted in order to aid patients with increased risk or fear of falling, while the percentage of participants that used the handrails for support during stair gait is also reported for all groups (no, single or double handrail contact, as documented after visual observation of the motion capture recordings). All remaining trials with sufficient marker visibility for the estimation of the CoM trajectory were used in this analysis, with an average of 6.3 trials per participant. The CoM trajectory was computed as the weighted sum of all the modelled segments' centers of mass, as defined by the full-body Plug-in Gait marker set. A threshold of 20 N was used for the detection of gait events from the force plate recordings.

Dynamic stability was measured according to the inverted pendulum model described by Hof, et al. (Hof et al., 2005), in which the body is

Table 1
Demographics.

Demographics	Controls	Patients
n	17	27
Male/Female	9/8	17/10
Age (years)	61 (11)	67 (5)
Affected side (L/R)	–	16/11
Pre-op BMI (kg/m2)	24.2 (3.2)	30.9 (4.0)
Post-op BMI (kg/m2)		30.7 (4.2)

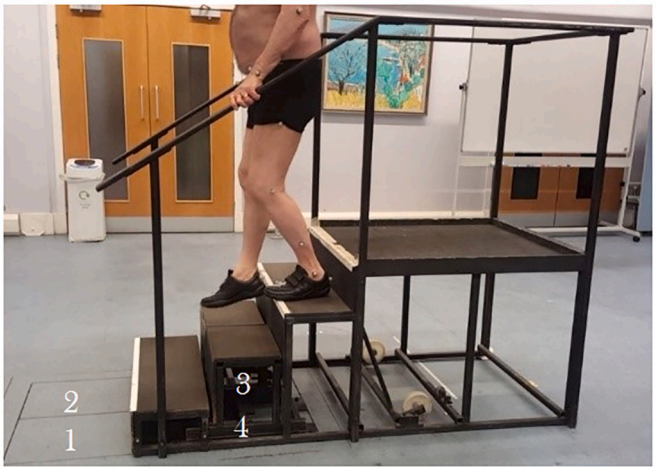


Fig. 1. Staircase with a step height and length of 185 mm and 280 mm, respectively.

modelled as a single mass suspended by a stick of a length l rotating around a pivot point. The ground projection of the CoM, denoted here as CoM′ (Fig. 2, top), and the CoM velocity (vCoM) were used for the computation of the extrapolated centre of mass position (xCoM):

$$xCoM_{(x,y)} = \mathrm{CoM'}_{(x,y)} + \frac{\mathrm{vCoM}_{(x,y)}}{\sqrt{g/l}} \quad (1)$$

here, g is equal to the gravitational acceleration and l is the pendulum's effective length and equal to the distance between the CoM and the ankle's joint centre. Stability in the model is conditioned on the quantity xCoM being within the subject's base of support (BoS), indicating that the shortest perpendicular distance between the xCoM and the BoS in the transverse plane, also referred to as margin of stability (MoS), can be used to measure dynamic balance (Fig. 2, bottom). As soon as the xCoM exceeds the boundaries of the BoS, stability cannot be maintained solely by the pendulum and a stabilising impulse proportional to the magnitude of the MoS is required to rebalance the system. Margins of stability were computed at the beginning (MoS_{α}) and the end (MoS_{ω}) of the single support phase and they are reported in positive or negative values whether the xCoM lies within or beyond the boundaries of the BoS, respectively. The more negative the MoS, the greater the ease which balance is disturbed, and therefore indicate a riskier or more dynamic locomotion strategy. This may be fully intended (e.g., faster walking speed), or it could suggest worse balance control. Gait events were detected from the recordings of the instrumented second step of the stair case, and the BoS boundaries were calculated from the position of the toe (mid-foot area over the second metatarsal head), heel (calcaneus area at the same height as the toe marker) and ankle (lateral malleolus) markers (Fig. 2, bottom).

Increased variability of the gait's spatiotemporal variables (such as stride time and width) may be indicative of a loss of coordination and balance, and hence, of an increased probability of falling (Bruijn et al., 2013). The magnitude of the same gait parameters can also be an index of gait stability, for example, a participant taking smaller or faster steps is more likely to tip over and fall due to the decreased BoS or fail to cope with an actual perturbation, respectively. Here, stride length and time were calculated from one foot contact to the next foot contact by the same foot during stair walking. Stair walking speed was calculated from stride time and length, and cadence is equal to the strides each subject took per minute during stair negotiation. Mediolateral CoM range of motion (RoM), and the mediolateral and anteroposterior peak of the CoM velocity were calculated during a single step, from foot contact to foot-off on the instrumented second step of the stair case.

Stability and spatiotemporal measures from multiple trials of the same participant were averaged, and the controls' and patients' pre-operative or post-operatively assessments were compared with one-way ANOVAs and Welch tests (when the assumption for homogeneity of variance was not met). Similarly, patients' pre- and post-operative stability and spatiotemporal indexes were compared with repeated measures ANOVAs. Margins of stability of the patient group were also computed and compared separately with reference to the OA (i.e., the affected joint pre-operatively), operated (i.e., the affected joint post-operatively) and contralateral knees (i.e., the asymptomatic joint). No categorization was made for the lower extremities of the control group, and the stability margins of both limbs are reported jointly. Significance was set at $p = .05$.

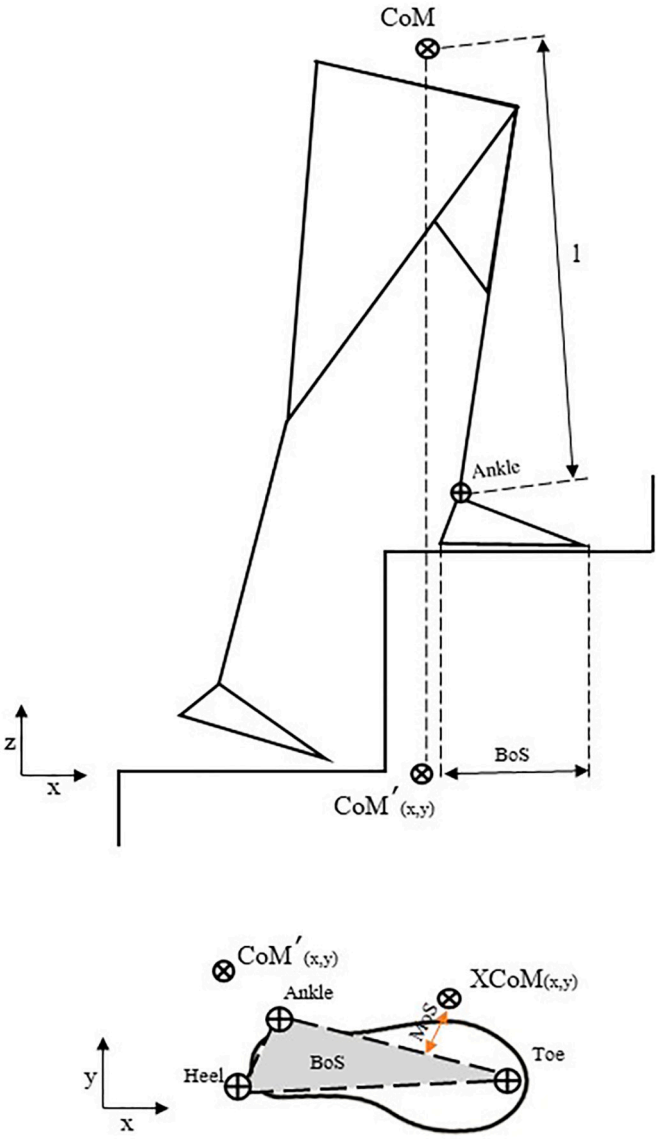


Fig. 2. The extrapolated centre of mass (xCoM) and margin of stability (MoS).

3. Results

Margins of stability (Table 2) between control and pre-operative patient visits (both limbs were considered jointly) had no statistically significant difference for the ascent (MoS_{α}: $p = .353$, MoS_{ω}: $p = .604$) and descent alike (MoS_{α}: $p = .810$, MoS_{ω}: $p = .245$). Post-operative stability was also statistically similar for all comparisons with the controls' performance during stair ascent (MoS_{α}: $p = .800$, MoS_{ω}: $p = .225$) and descent (MoS_{α}: $p = .393$, MoS_{ω}: $p = .188$). Additionally, no

Table 2
Margins of stability at the beginning (MoS_α) and the end (MoS_ω) of the single support phase.

	Pre-operative				Post-operative				Controls	
MoS_α (cm)	Ascent	−2.66 (2.0)	Contralateral	−2.94 (2.6)	Ascent	−2.01 (1.3)	Contralateral	−1.82 (1.8)	Ascent	−2.12 (1.4)
			OA	−2.91 (1.8)			Operated	−2.20 (1.5)		
	Descent	−4.19 (3.1)	Contralateral	**−2.80 (1.9)**‡	Descent	−3.58 (2.8)	Contralateral	−2.72 (3.0)	Descent	−4.46 (3.6)
			OA	**−6.41 (3.5)**‡			Operated	−3.80 (2.9)		
MoS_ω (cm)	Ascent	−3.99 (2.5)	Contralateral	−4.50 (3.0)	Ascent	−3.35 (2.5)	Contralateral	−2.85 (2.5)	Ascent	−4.48 (3.4)
			OA	−3.40 (2.1)			Operated	−3.75 (3.1)		
	Descent	−10.60 (7.2)	Contralateral	−8.30 (5.8)	Descent	−10.97 (4.8)	Contralateral	−9.71 (4.9)	Descent	−13.32 (6.2)
			OA	−13.37 (8.3)			Operated	−11.47 (5.6)		

‡ Statistically significant difference ($p < .05$) between contralateral and OA or operated knees.

differences were observed between the two patient assessments (pre- versus post-operative stability of both limbs, $p > .252$). Stability between the patients' contralateral and OA or operated knees was also statistically similar for all comparisons apart from the pre-operative MoS_α during descent ($p = .004$).

Compared to patients, control participants generally ascended and descended faster ($p < .12$, Table 3) and with higher cadence ($p < .005$). Controls also had statically significant shorter stride times ($p < .001$) and longer stride lengths ($p < .034$) compared to all patient visits, apart from the post-operative stair ascent assessment ($p > .05$). Regarding the mediolateral RoM, control participants showed significantly decreased frontal plane motion compared to patients in both ascent (pre-operatively, $p = .015$) and descent (post-operatively, $p = .013$). The patients' mediolateral peak CoM velocity during both of their assessments was comparable to the controls' measurements ($p > .156$). In agreement with their higher walking speed, control participants also showed significantly increased anteroposterior CoM velocity during both stair negotiation tasks ($p < .001$).

Table 3
Spatiotemporal parameters.

	Pre-operative		Post-operative		Controls	
Cadence (steps/min)	Ascent	**81.8 (17.0)***,†	Ascent	**96.9 (20.0)***,†	Ascent	**115.6 (13.9)***
	Descent	**78.4 (21.2)***,†	Descent	**87.8 (17.4)***,†	Descent	**107.5 (12.1)***
Walking Speed (m/s)	Ascent	**0.51 (0.15)***,†	Ascent	**0.71 (0.18)***,†	Ascent	**0.86 (0.14)***
	Descent	**0.46 (0.14)***,†	Descent	**0.58 (0.17)***,†	Descent	**0.77 (0.90)***
Stride Time (s)	Ascent	**1.55 (0.41)***,†	Ascent	**1.29 (0.25)**†	Ascent	**1.11 (0.25)***
	Descent	**1.67 (0.59)***,†	Descent	**1.43 (0.30)***,†	Descent	**1.13 (0.12)***
Stride Length (m)	Ascent	**0.76 (0.15)***,†	Ascent	**0.88 (0.06)**†	Ascent	**0.91 (0.10)***
	Descent	**0.70 (0.16)***	Descent	**0.78 (0.12)***	Descent	**0.86 (0.08)***
ML CoM RoM (cm)	Ascent	**5.43 (1.62)***	Ascent	5.01 (1.59)	Ascent	**4.25 (1.15)***
	Descent	5.70 (2.84)	Descent	**5.77 (1.93)***	Descent	**4.37 (1.21)***
ML Peak CoM Velocity (cm/s)	Ascent	16.5 (5.5)	Ascent	17.5 (4.6)	Ascent	17.2 (3.3)
	Descent	**17.2 (6.4)**†	Descent	**20.8 (4.9)**†	Descent	19.9 (4.7)
AP Peak CoM Velocity (cm/s)	Ascent	**52.2 (15.1)***	Ascent	**54.2 (9.0)***	Ascent	**64.5 (5.4)***
	Descent	**48.5 (8.4)***,†	Descent	**59.1 (11.3)***,†	Descent	**74.6 (7.8)***

* Statistically significant difference ($p < .05$) between control and (pre-operative and/or post-operative) patient participants.

† Statistically significant difference ($p < .05$) between pre-operative and post-operative patient visits.

Patient participants' cadence ($p < .041$, Table 3), walking speed ($p < .001$) and stride length (ascent, $p < .028$) were all significantly increased after TKA, while stride time ($p < .024$) was also significantly reduced post-operatively. All CoM spatiotemporal parameters during stair ascent were statistically similar between the pre- and post-operative patient assessments ($p > .289$); however, during stair descent, post-operative patients walked with significantly increased mediolateral ($p = .036$) and anteroposterior velocities ($p = .001$). Finally, patient participants frequently maintained contact with the staircase's handrails during both ascent (Table 4: 24% and 58% of the trials depicted patients reaching toward one or both banisters, respectively) and descent (19% single and 65% double handrail support) during their pre-operative visit. However, hand support during the post-operative assessment was less frequent with more than half of the trials depicting patients ambulating without any handrail contact (58% and 53% during ascent and descent, respectively). The patients' hand support behaviour after surgery appears to converge on that of the controls who predominantly ascended (87%, Table 4) and descended (72%) without interacting with the handrails.

4. Discussion

Patient participants during both their visits were equally balanced to the asymptomatic controls. No less importantly, patients' stability did not improve or deteriorate one year after TKA surgery. However, dynamic balance on the osteoarthritic lower limbs was significantly less stable compared to the contralateral limbs of the patient group during stair descent (Table 2). Spatiotemporal parameter analysis also demonstrated that control participants walked with higher speeds, briefer stride times and longer strides, while exhibiting lower frontal plane motion, indicating an ease to perform the task with limited mediolateral postural sway and without the fear of falling. Yet, patient participants exhibited an improvement (i.e., a statistically significant change that led to a parameter's average value being closer to the controls' corresponding measurement) in multiple spatiotemporal parameters after TKA surgery (Table 2: cadence, walking speed, stride time, stride length, ML and AP CoM velocities), reflecting confidence in the operated knee and reduced fear or falling.

The MoS measure signifies the ease of tipping over during gait and not the capacity of a participant to recover from perturbations or unbalanced conditions. In other words, the MoS indicates the extent of adaptive actions and when they are needed in order for the subject to

Table 4
Use of handrails.

	Handrail Contact	Pre-operative	Post-operative	Controls
Ascent	No	18%	58%	87%
	Single	24%	18%	13%
	Double	58%	24%	0%
Descent	No	16%	53%	72%
	Single	19%	23%	28%
	Double	65%	24%	0%

maintain gait stability (Bruijn et al., 2013). The magnitude of the MoS depends on multiple factors, such as the participant's height (Eq. (1), l), the degree of the frontal and sagittal motions (CoM˙), movement speed (vCoM) and the size of the BoS. Since maintaining stability during single support is harder than when both feet are in contact with the ground (due to the extent of the BoS), stability was assessed in this study during the single support phase. The two reported values at the beginning and the end of the single stance also represent the minimum and maximum values that MoS takes, respectively (Koyama et al., 2015). Negative MoS values were expected during locomotion due to the magnitude of the anteroposterior CoM velocity and the advancement of the CoM position when transitioning to the next step, bringing the xCoM quantity outside the BoS boundaries.

Our results contradict the findings of studies supporting that TKA positively influences balance up to 1-year following surgery, and that preoperative OA patients and age-matched controls have stability differences (Moutzouri et al., 2017). However, since we did not control for the stair ambulation strategy (i.e., the use of handrails, Table 4), it is possible that if patients were to use the same cautious movements one year post-operatively (i.e., strategies that potentially improve dynamic balance control, such as the double handrail support), we may have observed a significantly positive influence of TKA on balance. Additionally, postural control and stability in previous works was consistently assessed in dissimilar conditions than the ones tested in the present study, such as static single-limb stance (Cho and Hwang, 2013), obstacle avoidance (Mauer et al., 2005), balance in perturbation tasks (Gage et al., 2008), and in simulated stair descents with cadaveric knees (Borque et al., 2015). Additionally, given that the MoS measurement depends on multiple factors, our results indicating fair stability in the patient group are not entirely unexpected: a potentially high postural sway during the gait may be counteracted by a conservative movement strategy or a broader BoS. In that regard, the reduced walking speed and stride length of the patient groups (Table 3), which are also indicative of a cautionary behaviour to minimize risk of falling should a perturbation occur, may be the reason of their stability being similar to the corresponding indexes of the control group. It should also be noted that even though the MoS measure was previously used in studies on stair walkig (Bosse et al., 2012; Koyama et al., 2015; Novak et al., 2016), our findings cannot be directly compared with past published values; this is due to the BoS and the xCoM values being defined in the existing literature by the anterior edge of the step (Bosse et al., 2012; Koyama et al., 2015) and solely by the anteroposterior kinematics of the CoM (Novak et al., 2016), respectively. In contrast, in this study, the BoS was defined by the area under the foot, while both the anteroposterior and mediolateral components of the CoM movement were utilised.

Overall, the patients' affected limbs exhibited similar stability during single leg support compared to their contralateral joints. However, it should be also noted that the patients' contralateral limbs may occasionally have had, at the time of their assessments, radiographic or symptomatic evidence of osteoarthritis, however, the operated knees were in every case the predominantly affected joint. In fact, out of the 27 assessed patients, six self-reported that they are considering a potential feature TKA on their contralateral side, two have had their contralateral knee joints already replaced at least five years before their assessment, and the remaining nineteen reported no severe OA symptoms on their contralateral side.

A limitation of the present study emerges from the significantly lower BMI of the controls when compared to the patient population ($p < .01$). Given the well documented effect of obesity (Corbeil et al., 2001) in postural stability, our comparisons between control and patient populations may be biased, however, the patients' pro-operative and post-operative assessments remain valid irrespective of participant demographics. In agreement with previous studies reporting a reduction in fear of falling after TKA (Levinger et al., 2011; Moutzouri et al., 2017), the use of handrails was substantially decreased one-year after surgery (Table 4); however, since handrail support influences dynamic balance control during stair descent (but not in ascent, (Reeves et al., 2008)) the effect of handrail use on the MoS magnitudes remains undetermined and may be considerable. Additionally, another limitation originates from the use of a four-step staircase and the consideration of a single gait cycle per ascent and descent, which restricted the number of recordings available for analysis. Finally, we opted to define the BoS by the position of three retroreflective foot markers, whilst the toe marker was placed on the mid-foot area (Fig. 1) in order to prevent the BoS to extend from the step edge in cases of foot overhang. Future studies should consider restricting the BoS to the step edge if foot overhang is noted or when working with wider BoS areas.

5. Conclusion

Lack of balance can compromise daily living activities in patients with OA, resulting in a roughly three times higher risk of falling (Lawlor et al., 2003). Even if pain from arthritis is decreased following TKA, little is known about the effect of the operation on the dynamic stability of the patients. Contrary to other studies suggesting that severe OA affects balance control (Kim et al., 2011), the results of this work revealed that osteoarthritic knees exhibit similar dynamic stability indices compared to asymptomatic lower limbs. Operated knees in this study were also equally stable compared to both the patients' contralateral joints and asymptomatic controls. In contrast to evidence that TKA significantly improves dynamic balance (Moutzouri et al., 2017), the overall dynamic stability of OA patients in the present study was neither improved nor undermined from TKA surgery.

Declaration of Competing Interest

There are no conflicts of interest to declare.

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