Gait & Posture 61 (2018) 483–487

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

Reduction of frontal plane knee load caused by lateral trunk lean depends on step width

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ARTICLE INFO

Keywords:
Gait retraining
Trunk sway
Knee abduction moment
Step width
Osteoarthritis

ABSTRACT

The internal knee abduction moment (KAM) in osteoarthritis is reduced by increased lateral trunk lean (TL). Mechanistically, this occurs as the Centre of Mass (COM) moves further over the stance leg. Since the size of the base of support constrains the COM, an associated increase in step width (SW) would be expected to maintain stability. This study tested the effects of TL on SW and KAM in healthy participants (n = 21) who performed normal and 6° TL walks. The latter was controlled via audio-visual biofeedback. We found two distinct gait strategies in TL walk: widening the step width substantially (> 50%) to permit an increase in the COM displacement (WSW, n = 13), or maintaining a baseline SW and minimally displacing the COM by moving the hip/pelvic complex in the opposite direction (NSW, n = 8). WSW doubled SW (11.3 ± 2.4 v. 24.7 ± 5.5 cm, p < .0001), NSW did not change SW (12.2 ± 2.8 v. 13.7 ± 4.7 cm, p > .05). These two distinct gait strategies resulted in unique patterns of KAM reduction across the stance phase. NSW reduced KAM impulse significantly in the initial half (0.08 ± 0.02 v. 0.06 ± 0.02, p = .04) but not in the later stance phase (0.07 ± 0.02 v. 0.07 ± 0.04, p > .05). WSW reduced KAM significantly in both initial (0.11 ± 0.03 v. 0.08 ± 0.04, p < .001) and later stance phase (0.09 ± 0.02 v. 0.06 ± 0.03, p < .001). KAM peak results followed the pattern of impulse. This study has revealed two distinct mechanisms for increasing lateral trunk lean which can be used to explain discrepancies in past research and in the future could be used to individualise gait re-training strategies.

1. Introduction

Knee osteoarthritis (OA) frequently leads to pain, disability and surgical intervention. The combination of an aging population and the increase in prevalence of OA with age [1] means the disease is a growing societal burden requiring cost effective management.

The medial compartment is affected ten times more often than the lateral compartment [2] as it withstands up to 80% of the frontal plane knee load during walking [3]. During dynamic movement, the internal knee abduction moment (KAM) is accepted as a valid and reliable measure of frontal plane knee load [3,4]. The KAM calculation uses inverse dynamics [5], which mainly consists of the product of the GRF and the distance between the knee joint centre and GRF vector but also includes segmental inertial properties. A KAM is produced when the force vector passes medially to the joint centre during the stance phase [6]. The KAM peaks and impulse are increased in patients with medial compartment knee OA [7]. Further, frontal plane moments, but not sagittal plane moments, have been associated with OA disease progression over 2 years [8]. Kumar and colleagues [9] confirmed that there is a greater KAM in OA patients in comparison to healthy controls and demonstrated that the frontal plane moment is related to medial knee loading.

The KAM is recognised as a modifiable risk factor for the progression of medial knee OA [10]. Accordingly, research focuses on methods of decreasing the KAM, including lateral wedge insoles [11] and high tibial osteotomies [12]. Unfortunately, clinical trials do not show benefits from lateral wedges over prolonged periods [13] and surgery is invasive with a long recovery. Gait modification strategies have the potential to delay the progression of the disease in a non-invasive manner.

Numerous gait modifications exist, including altering the foot progression angle, increasing medial knee thrust and increasing lateral

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https://doi.org/10.1016/j.gaitpost.2018.02.022
Received 20 March 2017; Received in revised form 15 September 2017; Accepted 20 February 2018

trunk lean. In a comparison of these strategies, lateral trunk lean was the most successful method of decreasing KAM in almost half the subjects [14]. Reductions of 30%, 38% and 28% for the KAM impulse, 1st peak and 2nd peak, respectively, were reported in comparison to normal walking. A review considering 14 gait modification strategies found lateral trunk lean and the use of a walking cane to most consistently decrease KAM [15]. However, some people have reservations about using a cane, based on its appearance [16]. Modifying trunk lean removes this obstacle. In the natural gait of patients with medial compartment knee OA, lateral trunk lean was shown to explain 13% of the variance in KAM when toe out angle and speed were controlled for [17]. This also suggests that gait modification strategies occur naturally in this population, adding an increased need to understand the impact these have on the affected and unaffected joints. Furthermore, increasing lateral trunk lean has been shown to reduce KAM more than that previously reported with high tibial osteotomies [18].

The mechanism behind the increasing TL causing a decrease in KAM hinges on the alteration in moment arm length. The increased TL moves the centre of mass (COM) further over the stance leg, causing the GRF vector to move laterally, shortening the moment arm of the knee joint [18], resulting in a decreased moment. However, the COM movement is constrained by the size of the base of support, and must remain within the borders of the step width (SW) [19,20]. As humans walk on a relatively narrow base of support with up to two thirds of an individual's mass carried superior to the waist [21], it is hypothesised that an increase in SW would occur alongside the increase in TL to prevent imbalance. Despite this, studies investigating TL do not generally report SW. Therefore, the aim of this study was to test the effects of increased trunk lean on consequential alterations in step width and the impact it has on the KAM. It is predicted that an increase in trunk lean will be accompanied by an increase in step width.

2. Method

2.1. Participants

Participants with no musculoskeletal or neurological injuries or impairments were recruited from a university population. Twenty-one subjects took part (male: 11, female: 10, 23 ± 2 years, 68 ± 8 kg, 1.74 ± 0.06 m). Ethical approval was granted by the University Ethics Committee (P14SEC020).

2.2. Set-up

A nine-camera (T10/T160, Vicon Motion Analysis Inc., Oxford, UK) motion analysis system (100 Hz) was centred around two adjacent force plates (Kistler 9281B; Kistler Instruments Ltd. Winterhur, Switzerland, 1000 Hz) and collected using Vicon Nexus (v1.85). Participants were barefoot to eliminate the impact of footwear on KAM [22]. Height, weight, knee width and ankle width were measured. A Helen-Hayes model [23] was adapted to include the trunk (markers on iliac crest, C8, Th7, xyphoid process, jugular notch, and acromion process). The Helen-Hayes thigh wand orientation was checked using the Vicon plug-in-gait model to ensure the frontal plane knee angle did not exceed ± 10° as these values are anatomically unrealistic and thus likely a result of cross talk from a misalignment of the knee flexion/extension axis.

2.3. Data collection

Participants were tested in two conditions: walking with normal trunk lean (NTL) and 6° of lateral trunk lean (LTL), similar to that previously used [24]. The NTL was tested first to gauge self-selected walking speed. Trials were accepted if walking speed lay within 10% of this value.

The TL movement was controlled using an inertial sensor (Xsens MTw, Xsens Technologies B.V.), attached on the xiphoid process. A custom biofeedback software application was created (D-Flow v3.18.1, Motekforce Link, Amsterdam). Visual feedback was presented on a screen at the end of the walkway. A blue line rotated about a fixed axis in the frontal plane as the participant walked, mirroring their trunk lean. Participants had a zone that spanned $4-8^\circ$ bilaterally of central that they were instructed to aim for. In this zone, the line changed to white and a beep was heard (Fig. 1). If they went past the 8° line, a second error noise was heard. Demonstrations and feedback were provided. The participants practiced the trunk lean walk until a consistently correct strategy was adopted. The sensor was reset to 0° when the participant was stood statically. This was reset after each trial to minimise drift. No instructions were given in regards to step width or the lower limbs. Trials were repeated if any of the steps exceeded or did not reach the required level of trunk lean and/or if the right foot did not cleanly contact the force plate. Three successful trials were collected for each condition.

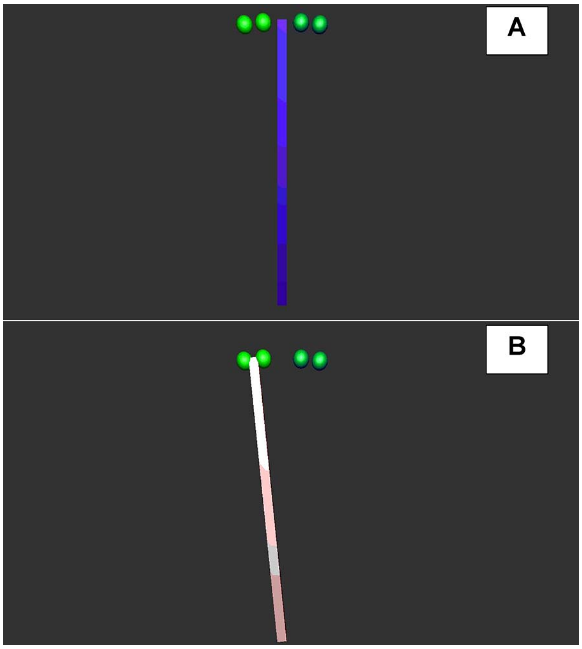

Fig. 1. Biofeedback system. Image A represents the screen image when the participant was stood straight. Image B shows the participant reaching the required zone to the left. The blue line has turned white and the end of the line is within the green circles zone. A noise would be heard at either green circle. Trials were only accepted if the line reached, but did not go over the correct zone. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.4. Data analysis

Each trial was cropped to a single stride exported into Visual3D (version 5; C-Motion, Inc., Germantown, MD, USA) and filtered (low pass, fourth-order Butterworth filter at 8 Hz). A Helen-Hayes lower limb model with an additional trunk segment was applied. Knee and ankle joint centres were defined as half of their measured width medial to the lateral marker. The trunk was defined using the acromion and iliac crest markers with the remaining used for tracking. Lateral trunk lean angle was calculated relative to the laboratory reference system, with all angles recorded from the optoelectronic system rather than the IMU. Right leg data was analysed. SW was defined as the medio-lateral distance between the heel markers during initial contact with the ground (double support) at each step. KAM impulse, calculated as the area under the curve, was exported directly from Visual3D. COM displacement was exported from Visual3D into Microsoft Excel (2013). Any small deviation from walking in a straight line caused a trend in the sideways position of the COM which was removed for each walk by subtracting the regression line that was fitted on the COM sideways