Osteoarthritis and Cartilage 22 (2014) 203–209

Osteoarthritis and Cartilage

Lateral trunk lean gait modification increases the energy cost of treadmill walking in those with knee osteoarthritis

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A R T I C L E I N F O

Article history:
Received 1 August 2013
Accepted 4 December 2013

Keywords:
Energy expenditure
Gait modification
Knee osteoarthritis
Lateral trunk lean

S U M M A R Y

Objective: To compare the energy expenditure of increased lateral trunk lean walking – a suggested method of reducing medial compartment knee joint load – compared to normal walking in a population of older adults with medial knee osteoarthritis (OA).
Method: Participants completed two randomly-presented treadmill walking conditions: 15 min of normal walking or walking with ten degrees of peak lateral trunk lean. Lateral trunk lean angle was displayed in front of the participant in real-time during treadmill conditions. Energy expenditure (VO_2 and METs), heart rate (HR), peak lateral trunk lean angle, knee pain and perceived exertion were measured and differences between conditions were compared using paired *t*-tests.
Results: Twelve participants (five males, mean (standard deviation (SD)) age 64.1 (9.4) years, body mass index (BMI) 28.3 (4.9) kg/m^2) participated. All measures were significantly elevated in the lateral trunk lean condition ($P < 0.008$), except for knee pain ($P = 0.22$). Oxygen consumption (VO_2) was, on average 9.5% (95% CI 4.2–14.7%) higher, and HR was on average 5.3 beats per minute (95% CI 1.7–9.0 bpm) higher during increased lateral trunk lean walking.
Conclusion: Increased lateral trunk lean walking on a treadmill resulted in significantly higher levels of steady-state energy expenditure, HR, and perceived exertion, but no difference in knee pain. While increased lateral trunk lean has been shown to reduce biomechanical measures of joint loading relevant to OA progression, it should be prescribed with caution given the potential increase in energy expenditure experienced when it is employed.

Introduction

It is estimated that as many as 16% of adults have osteoarthritis (OA), with annual direct and indirect economic costs in the billions of dollars[1,2]. The knee is the most commonly affected weight-bearing joint by OA. With the economic burden of OA expected to rise with the ageing population, the development of inexpensive treatments to slow disease progression is necessary. The role of excessive knee load in knee OA progression is well-accepted[3–5]. As measuring load directly inside the joint is not feasible in humans, quantitative gait analysis has become a useful non-invasive tool to infer dynamic loading.

The most widely studied variable is the external knee adduction moment (KAM). The KAM has significant relationships to key clinical outcomes such as knee OA severity[6], pain[7], and risk of disease progression[8], and is a valid[9], reliable[10], and well-accepted outcome when assessing OA treatments aiming to reduce joint load. A number of gait characteristics are significantly correlated with the KAM, including the amount of lateral trunk lean over the stance limb during walking. Hunt *et al.*[11] showed that 13% of the variation in the first peak of the KAM was explained by peak lateral trunk lean in 120 patients with medial compartment knee OA. Further, trunk lean appears to have a dose–response relationship with the KAM, with greater lateral trunk lean angles resulting in greater reduction in KAM (first peak, second peak, and KAM impulse) in people with knee OA using a within-subjects design[12]. Accordingly, there has been interest in examining the effects of imposed increases in lateral trunk lean during walking. In fact, a

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1063-4584/$ – see front matter
http://dx.doi.org/10.1016/j.joca.2013.12.003

recent systematic review identified an increased lateral trunk lean gait modification as the most effective method of decreasing the KAM in people with or without knee OA[13]. Though the biomechanical effects of lateral trunk lean walking are known, and suggest a potentially important treatment option for knee OA, questions regarding the feasibility of gait modification treatments such as increased lateral trunk lean walking remain.

One potential issue that may limit the feasibility of increased lateral trunk lean walking in the community is the potential fatigue associated with this modified walking strategy. If lateral trunk lean walking requires significantly greater energy expenditure to perform than normal walking, then the ability to perform this gait modification over the longer term might be questioned. Indeed, all previous studies examining the biomechanical effects of increased lateral trunk lean walking have employed a single-session design, thus limiting the ability to assess long-term implications[12,14–17]. To our knowledge, there are no published papers on the effect of lateral trunk lean gait modification on energy expenditure, even in a single session, in individuals with knee OA. However, Caldwell *et al.*[15] assessed the energy expenditure of gait modification strategies including lateral trunk lean walking in a group of 12 healthy adults and reported a group mean 11.3% increase in energy expenditure as measured by indirect calorimetry with an average 18.7° peak lateral trunk lean. Though these results provide initial evidence of the physiological effects of lateral trunk lean gait modification, the amount of trunk lean was not controlled, and the effect of lateral trunk lean walking on energy expenditure has not been assessed in older adults with knee OA. It is unknown whether similar increases would be seen, as factors such as knee pain, not present in healthy individuals, may impact the metabolic cost of walking in individuals with knee OA[18]. The effect of other gait modifications have been assessed in people with knee OA, with Jones *et al.*[19] reporting a 50% increase in energy expenditure during cane walking in 64 people with knee OA. Other studies have found increases in energy expenditure in people without knee OA when performing other gait modifications such as stiff-knee gait, with energy expenditure increasing by 37% in a sample of 20 healthy individuals[20].

Assessing the energy expenditure of increased lateral trunk lean walking is important in order to better understand the physiological requirements of this particular gait modification strategy. Thus, the purpose of this study was to examine the energy expenditure of increased lateral trunk lean walking compared to regular walking in people with knee OA.

Methods

Participants

Participants 50 years of age and older with knee pain and radiographic evidence of medial compartment knee OA were invited to participate using print advertisements and a database of previous study participants. OA was determined using the Kellgren and Lawrence (KL) classification scale[21], with OA defined as the presence of osteophytes (KL $\geq$ 2). Relevant exclusion criteria included (1) articular cartilage degradation in the lateral tibiofemoral compartment greater than the medial; (2) inflammatory arthritic condition; (3) history of knee replacement surgery; (4) recent use of corticosteroids (oral or via injection); (5) inability to ambulate continuously on a treadmill for 30 min without a gait aid; and (6) recent (within 6 months) arthroscopic knee surgery. Informed consent was obtained from all participants and ethics approval obtained from the institutional Clinical Research Ethics Board.

Procedures

Participants attended a single testing session where demographic, biomechanical and metabolic data were collected. Demographic data included age, height, and body mass. KL grade of knee OA was determined by two independent raters (JT and MAH) from postero-anterior standing radiographs taken within the last 6 months. The arthritic knee was considered the study limb. In instances of bilateral disease, the more symptomatic limb was taken as the study limb. The only published paper investigating energy requirements with increased lateral trunk lean walking[15] found an effect size of approximately 0.7 across metabolic outcomes in a sample of young, healthy individuals. However, since previous studies of gait modification in people with knee OA (cane use) found much higher effect sizes for metabolic demand (effect size $>$ 2.5), we used a higher effect size estimate of 1.2 for the expected changes with increased lateral trunk lean walking in those with knee OA. With 80% statistical power and an alpha level of 0.05, we required 12 participants for this study[22].

Participants were then instructed by a trained assessor in lateral trunk lean gait modification, with a goal of 10° of ipsilateral lateral trunk lean towards the study limb. Participants were instructed to lean their trunk towards the study limb cyclically and to reach the target angle as soon as possible after foot contact. Ten degrees was chosen as the target lateral trunk lean angle as previous studies have shown significant changes in KAM at this target angle, while remaining a feasible and attainable amount of lateral trunk lean[12,23]. Participants were allowed to practice the gait modification on a 10 m walkway prior to the treadmill testing sessions. A mirror placed in front of the participant was used to provide visual feedback of performance during training. When they felt comfortable with the new gait pattern and were able to ambulate at their natural gait speed, participants were given a 5 min warm-up on the treadmill, where they were encouraged to walk with and without the new gait modification. Their self-selected treadmill walking speed for the lateral trunk lean was used for both conditions and was determined by incrementally increasing the treadmill speed until the participant felt the speed represented their comfortable walking pace while walking with the increased lateral trunk lean.

Resting heart rate (HR) was taken as the lowest HR recorded during quiet, seated rest over a period of 5 min using a wireless HR monitor (Polar, Lachine, QC), prior to the start of the training protocol. Participants then completed two, 15-min bouts of treadmill walking at their pre-determined self-selected treadmill walking speed. The order of the two conditions (normal walking or 10° of lateral trunk lean) was randomized prior to testing. Adequate rest was provided between conditions and the second condition was not started until the following two conditions were met: (1) a return to resting HR (within five beats per minute (bpm)), and (2) the participant deemed themselves ready to begin walking again.

Kinematic data were collected during treadmill walking using ten high-speed digital cameras (Raptor-E; Motion Analysis Corporation, Santa Rosa, CA) sampling at 120 Hz. Passive reflective markers were placed bilaterally on participants according to a modified Helen Hayes marker set[24]. Additional markers were placed over the medial femoral epicondyles and medial malleoli during an initial static standing trial to determine marker orientation and joint centre locations, and were removed before walking trials. Lateral trunk lean angle – defined as the angle between the vertical and a line through the midpoints of the anterior superior iliac spines and acromion processes, was calculated from kinematic data in real-time using commercial software (Biofeedtrak; Motion Analysis Corporation, Santa Rosa, CA). The amount of trunk lean was displayed as a continuous line on-screen in front of the