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Mechanical and neuromuscular changes with lateral trunk lean gait modifications

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ABSTRACT

Lateral trunk lean (LTL) is a proposed intervention for knee osteoarthritis but increased muscular demands have not been considered. The objective was to compare lower extremity and trunk muscle activation and joint mechanics between normal and increased LTL gait in healthy adults. Participants (n = 20, mean age 22 years) were examined under two gait conditions: normal and increased LTL. A motion capture system and force plates sampled at 100 and 2000 Hz respectively were used to determine joint angles and external moments including LTL angle and external knee adduction moment (KAM). Surface electromyography, sampled at 2000 Hz, measured activation of six trunk/hip muscles bilaterally. Peak LTL angle, peak KAM, gait speed, and mean values from electromyography waveforms were compared between normal and LTL conditions using paired *t*-tests or 2-way analysis of variance. There was a significant ($p < 0.05$) increase in peak LTL angle, decrease in first but not second peak KAM, and decrease in gait speed during LTL gait. There were significant ($p < 0.01$) increases in external oblique and iliocostalis muscle activation during LTL gait. There was no change in activation for internal oblique, rectus abdominis, longissimus, and gluteus medius. LTL gait decreased early/mid-stance KAM demonstrating its ability to decrease medial compartment knee loading. Increases in external oblique and iliocostalis activation were present but small to moderate in size and unlikely to lead to short term injury. Longitudinal studies should evaluate the effectiveness of increased LTL for knee osteoarthritis and if the increase in muscular demands leads to negative long term side effects.

1. Introduction

Approximately 16% of adults over 45 years of age have knee osteoarthritis (OA) [1]. Many interventions attempt to off-load the medial tibiofemoral compartment which is most commonly affected in knee OA [2,3]. For instance, increasing lateral trunk lean (LTL) during gait has been proposed as an intervention for patients with medial compartment knee OA [2,4–6]. For LTL gait, patients are instructed to increase trunk lean or sway in the frontal plane over the stance leg during gait. The rationale is that LTL shifts the center of mass laterally. This should move the ground reaction force laterally, thus reducing its lever arm to the knee center, and shifting knee loads from the medial to lateral compartment [4]. While direct measures of medial compartment loads are not readily available, the knee adduction moment (KAM) is used as a proxy [7].

Increasing LTL has resulted in decreased KAM in healthy participants and patients with knee OA [2,5,6]. LTL targets of 4, 8 and 12° reduced peak KAM by 7, 21, and 25% respectively, compared with normal gait in healthy adults [2]. Another study found a 55% reduction in early stance peak KAM when healthy participants ambulated with increased LTL [6]. Furthermore, the timing of LTL impacted KAM and the trunk should cross the vertical axis towards the stance leg 32 ms prior to heel strike [6]. When patients with knee OA ambulated with LTL angle targets of 6, 9, and 12°, they achieved early stance peak KAM reductions of 9, 12, and 15% respectively [5]. Therefore, increasing LTL during gait reduces the KAM, representing a shift in knee loads from the medial to lateral compartment.

There are potential barriers to using LTL gait as an intervention. Increased LTL in patients with knee OA resulted in greater energy

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expenditure, faster heart rate, and higher levels of perceived exertion compared to normal walking [8]. Some healthy individuals report pain or discomfort in the low back when ambulating with increased LTL [2]; although no such reports were found in patients with knee OA after one LTL walking session [5]. Potential adverse effects of increased LTL during gait should be investigated prior to recommending this as a knee OA intervention [5].

The biomechanical changes required for increasing LTL will increase demands on the neuromuscular system. However, the immediate demands on the trunk and hip musculature have only recently been studied [9]. Increasing muscle activation and force required for LTL gait could result in muscle soreness, fatigue, or injury since the muscles are not conditioned to these new, repetitive loads. Exploring the immediate muscular demands would provide insight into potential adverse effects associated with increasing LTL. The objective was to compare lower extremity and trunk muscle activation and joint mechanics (angles and moments) between normal and increased LTL gait in healthy adults.

2. Methods

2.1. Participants

Healthy adults (n = 20) were recruited using convenience sampling from the community with advertisements for this cross-sectional study. Exclusion criteria included lower extremity or trunk pain within three months, lower extremity trauma or surgery within 12 months, or any health condition affecting gait. Group descriptors are provided in Table 1. The study was approved by the local research ethics board and informed consent was obtained from participants.

A sample size calculation estimated the number of participants [10]. LTL was previously shown to have a large effect (d = 0.90) on KAM [5]. To be conservative, a lower effect size estimate (d = 0.80) was used. Twenty participants were required assuming β=0.20, p = 0.05, and one-tailed, paired *t*-test as the analysis for KAM.

The side to be assessed, termed ipsilateral side, was selected using simple randomization prior to data collection. Participants were required to draw labeled, masked papers. Right and left were allocated as the ipsilateral side for 13 and seven participants respectively.

2.2. Motion capture

Data were collected with an eight camera motion capture system (OQUS 300+, Qualisys) sampled at 100 Hz and two synchronized force plates (BP400600, AMTI) sampled at 2000 Hz. Thirty reflective markers were placed on participants according to established guidelines [11,12]. Bilateral markers included: acromion, anterior and posterior superior iliac spines, femoral greater trochanters and lateral epicondyles, fibular heads, tibial tubercles, lateral malleoli, 1st and 5th metatarsal heads, and calcanei. Markers were also placed on the manubrium, xiphoid process, and spinous processes of six vertebrae (C7, T2, T7, L1, L3, L5). In addition, six markers were placed bilaterally on participants during static standing trials only to determine joint center position: femoral medial epicondyles, medial malleoli, and 2nd metatarsal heads.

Table 1
Group descriptors of the study sample (n = 20, 14 men).

Variable	Mean (SD)	Minimum, Maximum
Age (y)	22 (4)	19, 35
Mass (kg)	76.08 (18.85)	47.90, 114.73
Height (m)	1.73 (0.09)	1.57, 1.88
Body Mass Index (kg/m^2)	25.16 (5.26)	17.38, 39.24

Note: SD, standard deviation.

2.3. Electromyography

Muscle activation was measured with a 16 channel surface electromyography (EMG) system sampled at 2000 Hz (Trigno, Delsys) (common mode rejection ration >80 db at 60 Hz, bandwidth 20–450 Hz, signal amplification 1000×). Electrodes were placed bilaterally over the following muscles using published guidelines (Table 2): external oblique, internal oblique, rectus abdominis, iliocostalis, longissimus, and gluteus medius [13,14]. Prior to placement, skin was debrided and shaved with a razor and cleaned with alcohol. Accurate electrode placement was confirmed with muscle palpation and submaximal contractions.

2.4. Data acquisition

Prior to data collection, participants were taught to ambulate with increased LTL using verbal instructions and demonstrations. They were instructed to increase medial-lateral trunk sway and lean over their stance leg. This was done for both sides such that they leaned to the right during right stance and leaned to the left during left stance. They were allowed practice time and feedback was provided.

Data collection began with participants standing on a force plate to determine joint centers and measure body mass. Two gait conditions were collected: normal and LTL. Participants ambulated barefoot at self-selected speeds along an 8 m, raised walkway. The normal condition preceded the LTL condition. During the LTL condition, real-time visual feedback of the LTL angle was provided on a large monitor using Visual3D (C-motion). Feedback was only provided for the ipsilateral side. An 8° target was set based on previous research demonstrating substantial reduction in peak KAM (21%) with 8° of LTL [2]. Participants were permitted at least two warm-up trials for each condition, including practice to become accustomed to the LTL visual feedback. Five trials were collected for each condition.

2.5. Maximum voluntary isometric contractions

Next, participants performed maximal voluntary isometric contractions (MVIC) that were used to amplitude normalize gait EMG waveforms. The following contractions (with targeted muscles) were performed [15]: (1) sit-up (rectus abdominis), (2) V-sit-up (rectus abdominis), (3) right and (4) left axial rotation in sitting (internal and external oblique), (5) back extension in prone (iliocostalis, longissimus), (6) right and (7) left axial rotation in prone combined with back extension (iliocostalis, longissimus), and (8) hip abduction in sidelying (gluteus medius). An investigator provided manual resistance for each contraction. The investigator placed his hands just medial to the anterior shoulders or over the scapula of the participant depending on the required force direction for exercises 1–7. For hip abduction, the investigator placed his hand slightly superior to the lateral knee. Participants were instructed to provide maximal force and the investigator met this force. Verbal encouragement was provided to ensure a maximal contraction. Participants performed at least one practice trial and two collection trials for each contraction. A 60 s rest was provided between trials.

2.6. Data processing

Positional reflective marker and force plate data were filtered with 4th order Butterworth filters, with cut-off frequencies of 6 Hz