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Individual selection of gait retraining strategies is essential to optimally reduce medial knee load during gait

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ABSTRACT

Background: The progression of medial knee osteoarthritis seems closely related to a high external knee adduction moment, which could be reduced through gait retraining. We aimed to determine the retraining strategy that reduces this knee moment most effective during gait, and to determine if the same strategy is the most effective for everyone.
Methods: Thirty-seven healthy participants underwent 3D gait analysis. After normal walking was recorded, participants received verbal instructions on four gait strategies (Trunk Lean, Medial Thrust, Reduced Vertical Acceleration, Toe Out). Knee adduction moment and strategy-specific kinematics were calculated for all conditions.
Findings: The overall knee adduction moment peak was reduced by Medial Thrust (−0.08 Nm/Bw·Ht) and Trunk Lean (−0.07 Nm/Bw·Ht), while impulse was reduced by 0.03 Nms/Bw·Ht in both conditions. Toeing out reduced late stance peak and impulse significantly but overall peak was not affected. Reducing vertical acceleration at initial contact did not reduce the overall peak. Strategy-specific kinematics (trunk lean angle, knee adduction angle, first peak of the vertical ground reaction force, foot progression angle) showed that multiple parameters were affected by all conditions. Medial Thrust was the most effective strategy in 43% of the participants, while Trunk Lean reduced external knee adduction moment most in 49%. With similar kinematics, the reduction of the knee adduction moment peak and impulse was significantly different between these groups.
Interpretation: Although Trunk Lean and Medial Thrust reduced the external knee adduction moment overall, individual selection of gait retraining strategy seems vital to optimally reduce dynamic knee load during gait.
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1. Introduction

Symptomatic knee osteoarthritis (OA) is one of the most common types of OA, has a high prevalence of pain, and is one of the top ten causes of 'years of life lost due to disability'(Lopez and Murray, 1998). Additionally, OA entails high socio-economic costs (Bitton, 2009; Fautrel et al., 2005), mainly due to clinician visits, surgery and medication and indirect costs due to time lost from work. Pain and decreased range of motion are often followed by loss of mobility, though the structural quality of remaining healthy cartilage and bone is dependent on sufficient and frequent joint load (Beaupre et al., 2000; De Bruin et al., 2005; Robling et al., 2002; Suh et al., 1999).

Several studies have shown that a high external knee adduction moment (EKAM) during gait is closely related to the progression of medial knee OA as the EKAM reflects the medio-lateral load distribution on the tibio-femoral joint (Miyazaki et al., 2002; Pollo et al., 2002). Although the EKAM typically displays two peaks during the stance phase, only the overall EKAM peak is related to the progression of knee OA (Miyazaki et al., 2002; Sharma et al., 1998). In addition to peak EKAM, Bennell et al. (2011) showed that EKAM impulse is related to the progression of knee OA, while they could not reproduce a relation with EKAM peak. Impulse of EKAM is defined as the time integral of EKAM, and provides information on cumulative knee load throughout the entire stance phase. Similar to EKAM peak, EKAM impulse increases with severity of OA and can distinguish between grades 2 and 3 in the Kellgren and Lawrence scale where the EKAM peak cannot (Kean et al., 2012; Thorp et al., 2006).

Gait retraining has recently been proposed as a treatment strategy for knee OA: it is hypothesized that OA progression can be slowed down by reducing the EKAM through modification of gait kinematics. The effectiveness of several gait retraining strategies on reducing the EKAM has been evaluated in the past in both healthy participants (Erhart et al., 2008; Hunt et al., 2011; Mundermann et al., 2008; Van Den Noort et al., 2013) and in patients with knee OA (Jenkyn et al.,

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2008; Kuroyanagi et al., 2012; Shull et al., 2013). In both groups, strategies that vertically align the center of mass and the knee joint center in the frontal plane, such as leaning the trunk (Mundermann et al., 2008) in the direction of the stance leg ('Trunk Lean') and medialising the knee ('Medial Thrust') during the stance phase (Fregly et al., 2007; Schache et al., 2008), seem to reduce the EKAM more than others; over 50% for first peak EKAM. Inducing a lateral movement of the center of pressure by toeing out aligns the ground reaction vector closer to the knee center. An increase of the toe out angle by approximately 16–20° has been shown to decrease second EKAM peak by more than 55% (Lynn and Costigan, 2008; Van Den Noort et al., 2013) and in some studies also the first peak was decreased between 11.7 and 55.2% (Jenkyn et al., 2008; Lin et al., 2001). Although, some studies show an increase of EKAM in early stance (Simic et al., 2013; Van Den Noort et al., 2013), Chang et al. (2007) presented an observational study which showed that a greater toe-out angle at baseline reduces the risk of knee OA progression during an 18 month period. Other types of gait retraining such as toeing in and increased step width have also been investigated, but showed inconsistent results. Although toeing in can decrease the EKAM in early stance, it does not necessarily affect late stance (Van Den Noort et al., 2013). Simic et al. (2013) even found a significant increase of EKAM peak during late stance and an increase of EKAM impulse. Increasing step width can decrease EKAM by 9.3–15.4%, probably as a result of increased medio-lateral movement of the center of mass (Fregly et al., 2008; Reinbolt et al., 2008). However, evidence for the effectiveness of this strategy has not yet been presented for sufficiently large patient groups. Most gait retraining strategies aim to minimize the lever arm of the ground reaction force. However, as knee joint moments are also determined by the magnitude of the ground reaction force (Hunt et al., 2006), it is suggested that a decrease of the vertical ground reaction force could lower joint load as well (Creaby et al., 2013).

Although EKAM is used as an indirect measure of medial contact force, Walter et al. (2010) showed that the external knee flexor moment (EKFM) should also be taken into account. The medial contact forces in one patient with a force-measuring knee implant did not decrease during gait retraining when reduced EKAM was accompanied by an increased external knee flexion moment (EKFM). Therefore, both EKAM and EKFM should be considered in the assessment of gait retraining effects.

There is a wide range of peak EKAM in groups of asymptomatic people and patients with knee OA (1.9–4.0 %body weight·height) during gait at similar self-selected speed (Kemp et al., 2008; Lynn and Costigan, 2008; Lynn et al., 2008; Mundermann et al., 2004). Apparently, intersubject differences in joint geometry and alignment, muscle strength, and weight distribution could contribute to these differences. If these subject specific characteristics indeed play a prominent role in establishing the magnitude of the EKAM during gait, it seems reasonable that the magnitude of the effect of gait retraining strategies on the EKAM could also be subject specific. The selection of gait retraining strategies should then be tailored to the individual patient characteristics. However, there are currently no comparisons of multiple gait retraining strategies that provide adequate insight in the potentially individual specific nature of the effects of gait retraining on the EKAM. A first attempt to apply individualized gait retraining was made (Shull et al., 2011; Wheeler et al., 2011), though it is still unclear to which extent individualisation is preferred in practice when compared to conventional non-individualized application of gait retraining.

As described, Trunk lean, Medial Thrust, Toe out and Reduced Vertical Acceleration have the potential to reduce the EKAM during gait. However a direct comparison between the different strategies is still missing. Therefore, the purpose of this study is to determine which of these four conditions reduces the EKAM most effectively during gait. Secondly, we will determine if the same strategy is the most effective for each participant and if the efficiency of the strategy is related to how well the subjects can follow the instructions.

2. Methods

2.1. Subjects

All university staff was approached by email. Healthy volunteers aged between 18 and 65 were included as participants. Exclusion criteria consisted of current injuries at the lower extremities or a history of injuries that interfered with normal gait, such as ankle, knee or hip OA, medial tibial stress syndrome, cruciate ligament injuries, foot deformities and inflammation of the Achilles tendon.

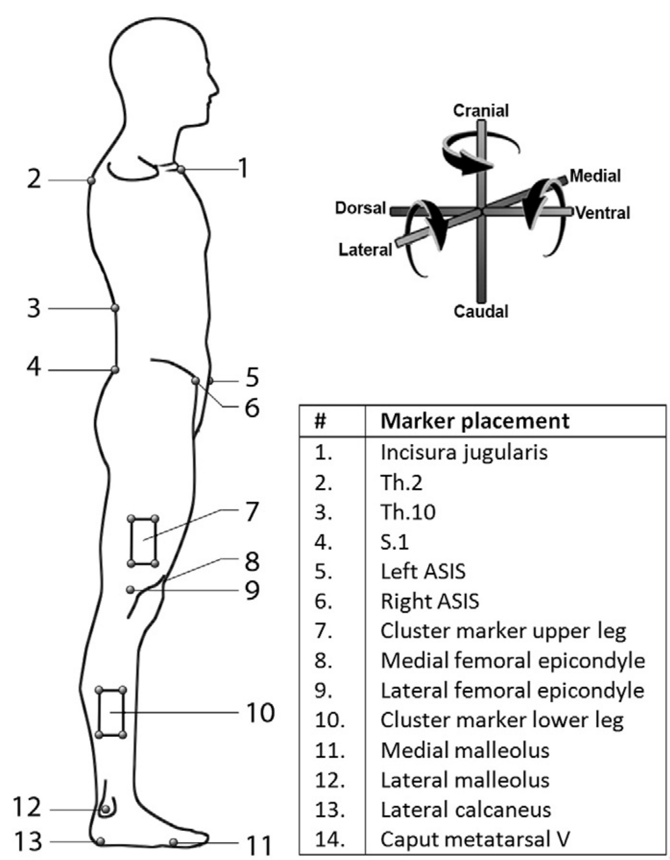
The study protocol was approved by the ethical committee of the University Medical Center Utrecht. After receiving the information about the study, all participants signed the informed consent form prior to the experiment.

2.2. Equipment

Twenty active markers placed on the segments and bony landmarks of the right leg and torso (Fig. 1) were captured at 200 Hz with a dual camera wireless active 3D-system (Charnwood Dynamics Ltd., Rothley Leicestershire, UK; Codamotion CX 1, standard deviation of static marker position is 0.05 mm). Ground reaction force was measured at a capture rate of 1000 Hz during one step per trial using a recessed forceplate (Advanced Mechanical Technology, Inc., Watertown, USA; OR 6–7). The walking distance to the forceplate was at least 7 m.

2.3. Segments and axes

All segments were modeled as rigid bodies. The hip joint center was defined using the model defined by Davis et al. (1991). The knee joint center was defined as half the distance between the lateral and medial



#	Marker placement
1.	Incisura jugularis
2.	Th.2
3.	Th.10
4.	S.1
5.	Left ASIS
6.	Right ASIS
7.	Cluster marker upper leg
8.	Medial femoral epicondyle
9.	Lateral femoral epicondyle
10.	Cluster marker lower leg
11.	Medial malleolus
12.	Lateral malleolus
13.	Lateral calcaneus
14.	Caput metatarsal V

Fig. 1. Segments as defined in the kinematic model. 1–3) Trunk, 4–6) pelvis, 7) upper leg cluster, 8–9) femoral epicondyles, 10) lower leg cluster, 11–14) foot. Positive joint rotations correspond to the direction of the arrows in the presented coordinate system.

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