Clinical Biomechanics 29 (2014) 997–1002

Contents lists available at ScienceDirect

Clinical Biomechanics

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

American Society of Biomechanics Clinical Biomechanics Award 2013: Tibiofemoral contact location changes associated with lateral heel wedging—A weight bearing MRI study

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ARTICLE INFO

Article history:
Received 24 January 2014
Accepted 13 August 2014

Keywords:
Knee
Cartilage
Osteoarthritis
Imaging
Contact
Lateral wedge

ABSTRACT

Background: Vertically open magnetic resonance imaging permits study of knee joint contact during weight bearing. Lateral wedging is a low cost intervention for knee osteoarthritis that may influence load distribution and contact. This study assessed the ability of feedback-assisted weight bearing magnetic resonance imaging to detect changes in tibiofemoral contact associated with lateral wedging.
Methods: One knee in each of fourteen subjects with symptomatic knee osteoarthritis was studied, without specification of compartmental involvement. Knees were imaged during upright standing and at 20° knee flexion. Bilateral external heel wedges were used to provide non-wedged and 5° lateral wedging conditions. Computer modeling was used to measure the medial and lateral compartment contact patch center coordinates on the tibial plateau and the respective contact areas.
Findings: Lateral heel wedging in flexion was associated with a significant anterior shift of the contact patch of the lateral femoral condyle. Changes with knee flexion were similar to previous reports: both medial and lateral contact centers moved posteriorly with flexion, and lateral condyle contact also moved laterally. Lateral condyle contact area significantly reduced with flexion, while lateral wedging did not significantly affect contact areas.
Interpretation: In symptomatic knee osteoarthritis patients standing in knee flexion, weight bearing magnetic resonance imaging recorded an anterior shift of lateral condyle contact in response to lateral heel wedging. Future studies may investigate lateral wedging effects more specifically in candidates for this clinical intervention.

1. Introduction

Scientific questions arising in the study of clinical issues such as the initiation and progression of knee osteoarthritis (OA), the effectiveness of joint reconstruction surgeries, and the origins of patellofemoral pain, have motivated the development of techniques for functional in vivo investigations of the knee joint. Examples of these include techniques based on modalities such as weightbearing magnetic resonance imaging (MRI) (Besier et al., 2005; Nicholson et al., 2012), dynamic fluoroscopy combined with CT scanning (Tashman et al., 2004), and dynamic fluoroscopy combined with MRI (Li et al., 2005).

An important question arising in the study of knee OA is that of how lateral and medial shoe wedge orthoses may change loading distribution across the joint surfaces. These devices have been studied clinically and mechanistically, although consistent clinical effectiveness has yet to be demonstrated (Parkes et al., 2013; Reilly et al., 2006). A mechanism for pain relief through functional unloading of the medial tibiofemoral compartment has been proposed (Maly et al., 2002); such a mechanism would be consistent with the fact that although no cartilage has no pain receptors, there are nerve fibers in the subchondral bone and underlying bone marrow (Felson, 2005). Changes in joint contact and loading have also been implicated in mechanobiological mechanisms of cartilage degeneration (Andriacchi et al., 2004; Chaudhari and Andriacchi, 2006). The low cost of footwear interventions, combined with the potential for clinical impact in view of the prevalence and cost of knee OA (Buckwalter et al., 2004; Hootman and Helmick, 2006; Peat et al., 2001), motivates the development of imaging methodology that can elucidate such mechanisms of pain and disease progression.

Recognition of these needs motivated our development of a feedback-assisted weight bearing imaging technique, and the execution of a study of its ability to measure changes in medial and lateral contact conditions associated with lateral shoe wedging. The methodology employs vertically open MRI and three-dimensional (3-D) computer modeling to measure changes in medial and lateral tibiofemoral contact areas and locations. To assess any impact of associated pain and weakness on the applicability of the methodology in clinical populations,

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http://dx.doi.org/10.1016/j.clinbiomech.2014.08.014
0268-0033/

we selected a study sample with symptomatic knee OA. We studied the effects of an external lateral shoe wedge, as well as the effects of knee flexion angle, on several descriptors of contact as calculated by the technique. The study's first hypothesis was that tibiofemoral contact changes associated with these footwear modifications would be detectable using the weightbearing MRI methodology. The second hypothesis was that knee flexion angle would influence tibiofemoral contact. We also proposed that knee flexion might modulate or interact with the effects of wedging.

2. Methods

2.1. Human subjects

Fourteen individuals (7 male, 7 female, mean 53.9 years, SD 17.0) with symptomatic unilateral or bilateral knee OA were enrolled in the study. A physical evaluation was conducted to verify the presence of knee OA signs. Subjects with knee OA were enrolled to assure compatibility with a relevant population based on symptoms that might limit performance of required tasks, and enrollment was not predicated on clinical indications for lateral wedging such as an isolated or most significant finding of medial compartmental involvement. The presence of one or more positive findings (abnormal knee flexion and extension ranges, laxity of any of the major ligaments as documented by measured medial-lateral and/or anterior-posterior drawer signs, tenderness along the joint lines, effusions, positive patellofemoral grind-compression, positive McMurray or Apley signs, etc.) that were consistently reproducible and correlated to the clinical complaints was considered sufficient confirmation of knee OA in one or more of the three compartments. Besides the detailed knee examination, the hip and ankle joints' ranges of motion were measured and examined to rule-out any potential biomechanical interactions that could affect the gait or weight-bearing tolerance, and/or confuse the knee findings. All subjects were required to be able to walk unassisted, and any individuals with significant cardiovascular, neurological or systemic problems, weakness in any lower extremity muscle group, signs of infection, or BMI > 35, were excluded. Subjects completed the Western Ontario & MacMaster Universities Osteoarthritis Index (WOMAC) (McConnell et al., 2001) survey in order to record self-reported knee pain and disability. The pain measure used in the study was each subject's description of the pain experienced in each knee within the 48 h prior to the survey. Pain level was described according to the following scale: 1 = no pain, 2 = mild, 3 = moderate, 4 = moderately severe, or 5 = severe pain. The study was approved by the Institutional Review Board of the Kessler Foundation Research Center, and all the participants gave informed consent prior to testing.

2.2. External shoe wedging

The effects of an externally applied heel wedge, rather than clinically typical in-shoe orthoses, were tested. The rationale for this was to avoid the need to remove footwear between scans, potentially introducing variability in foot placement and other aspects of subject positioning. Three pairs (small, medium, large sizes) of custom shoes with external heel wedging adjustable by the investigator were fabricated for the study (Fig. 1a). The nylon heel wedges could be rotated to provide neutral (0°) and 5° lateral wedging conditions. One of the three pairs of shoes was selected to comfortably fit each subject. Heel wedge settings were applied symmetrically to both limbs for all trials.

2.3. Weightbearing MR imaging

One knee of each subject was imaged in full upright weightbearing using a 0.6 T vertically open scanner (Upright MRI, Fonar, NY). The study knee was selected as that with more severe self-reported pain, or by randomization when no difference was reported. Subjects were scanned in two angles of knee flexion (Fig. 1b): neutral (0° flexion) standing in full weightbearing, and a bilateral, full weightbearing squat at 20° knee flexion. The 20° angle was chosen as representative of the peak flexion angle in normal gait during loading response (Saunders et al., 1953), and also on the basis of tolerability by the subject population for the imaging duration required. Positional biofeedback was provided to subjects to assist them in achieving and maintaining the desired joint angles with minimal movement during the scan. An MRI compatible fiber optic knee angle sensor (ShapeSensorMRI, Measurand Inc., Frederickton, NB) was positioned on the lateral aspect of the knee to be scanned, and angle feedback along with a target angle were displayed on the TV screen visible to patients during clinical scans. The accuracy of this device and the compatibility of the scanning techniques with clinical populations were previously tested (Dubowsky et al., 2009a,b; Gade et al., 2011). The MRI receiving coil was suspended around the knee using hook-and-loop fastened bands around the waist and thigh, and a system of descending straps.

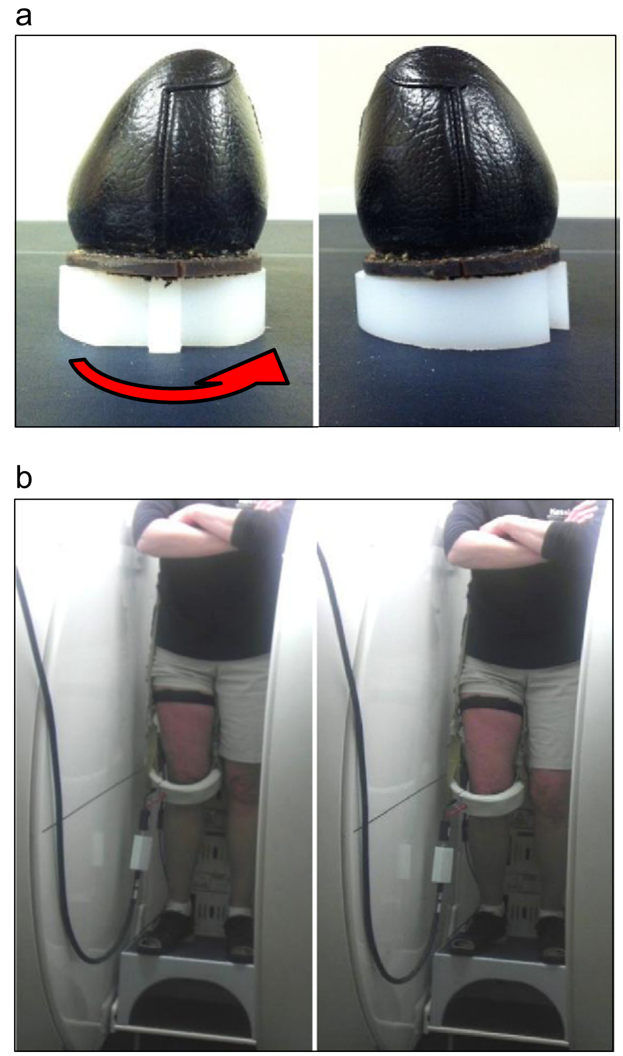

Fig. 1. Test conditions for imaging: (a) A 5° externally moveable nylon heel wedge allowed testing in neutral (left) and laterally wedged (right) positions. (b) Visual feedback of the instrumented knee angle was used to allow positioning in neutral/0° (left) and 20° (right) flexion angles.

MRI scanning was performed using a 3D steady state GRE free precession sequence (FOV 250 mm, Matrix repetition time 16.6 ms, echo time 5.6 ms, flip angle 60°). A high-definition voxel shift reconstruction (Du et al., 1994) yielded 512 × 512 matrix images with 0.488 mm pixel spacing across a 250 mm sagittal plane field of view. Two variations of