Journal of Biomechanics 48 (2015) 1707–1712

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Altered frontal and transverse plane tibiofemoral kinematics and patellofemoral malalignments during downhill gait in patients with mixed knee osteoarthritis

Shawn Farrokhi [a,*], Brad Meholic [b], Wei-Neng Chuang [b], Jonathan A. Gustafson [c], G. Kelley Fitzgerald [d], Scott Tashman [e]

[a] Human Movement Research Laboratory, Departments of Physical Therapy & Bioengineering, University of Pittsburgh, Pittsburgh, PA, USA
[b] Department of Physical Therapy, University of Pittsburgh, PA, USA
[c] Department of Bioengineering, University of Pittsburgh, PA, USA
[d] Department of Physical Therapy, Physical Therapy Clinical and Translational Research Center, University of Pittsburgh, Pittsburgh, PA, USA
[e] Director of Biodynamics Laboratory, Department of Orthopaedic Surgery, Department of Bioengineering, University of Pittsburgh, PA, USA

ARTICLE INFO

Article history:
Accepted 15 May 2015

Keywords:
Patellofemoral joint
Tibiofemoral joint
Knee osteoarthritis
Biomechanics
Kinematics

ABSTRACT

Patients with knee osteoarthritis often present with signs of mixed tibiofemoral and patellofemoral joint disease. It has been suggested that altered frontal and transverse plane knee joint mechanics play a key role in compartment-specific patterns of knee osteoarthritis, but in-vivo evidence in support of this premise remains limited. Using Dynamic Stereo X-ray techniques, the aim of this study was to compare the frontal and transverse plane tibiofemoral kinematics and patellofemoral malalignments during the loading response phase of downhill gait in three groups of older adults: patients with medial tibiofemoral compartment and coexisting patellofemoral osteoarthritis ($n=11$); patients with lateral tibiofemoral compartment and coexisting patellofemoral osteoarthritis ($n=10$); and an osteoarthritis-free control group ($n=22$). Patients with lateral compartment osteoarthritis walked with greater and increasing degrees of tibiofemoral abduction compared to the medial compartment osteoarthritis and the control groups who walked with increasing degrees of tibiofemoral adduction. Additionally, the medial and lateral compartment osteoarthritis groups demonstrated reduced degrees of tibiofemoral internal rotation compared to the control group. Both medial and lateral compartment osteoarthritis groups also walked with increasing degrees of lateral patella tilt and medial patella translation during the loading response phase of downhill gait. Our findings suggest that despite the differences in frontal and transverse plane tibiofemoral kinematics between patients with medial and lateral compartment osteoarthritis, the malalignments of their arthritic patellofemoral joint appears to be similar. Further research is needed to determine if these kinematic variations are relevant targets for interventions to reduce pain and disease progression in patients with mixed disease.

1. Introduction

Osteoarthritis (OA) is one of the leading causes of mobility limitation and chronic disability in the elderly (Ma et al., 2014). With nearly a 50% lifetime risk of developing symptomatic disease, the knee is one of the joints most commonly affected by OA (Murphy et al., 2008), with up to 13.3 million cases of knee OA in the US alone (Dillon et al., 2006). Although knee OA can develop in either the medial or the lateral tibiofemoral (TF) joint, medial compartment OA appears to be more common than lateral compartment disease (Dillon et al., 2006; Felson et al., 2002). To this end, frontal-plane mechanics of the TF joint have been deemed as a key determinant of compartment-specific patterns of TF OA. Whereas the more commonly observed genu varum malalignment of the TF joint leads to higher mechanical loading and increased risk of medial compartment OA development, genu valgum increases the risk of lateral TF compartments involvement (Sharma et al., 2010; Tanamas et al., 2009; Yang et al., 2010).

Different and diverging patterns of frontal and transverse plane TF joint motion and loading patterns have also been previously reported during gait for patients with medial and lateral compartment knee OA (Butler et al., 2011; Weidow et al., 2006). More specifically, patients with medial compartment OA generally walk

* Correspondence to: Department of Physical Therapy, University of Pittsburgh, 6035 Forbes Tower, Pittsburgh, PA 15260, USA. Tel.: +1 412 648 1332.
E-mail address: Farrokhi@pitt.edu (S. Farrokhi).

http://dx.doi.org/10.1016/j.jbiomech.2015.05.015
0021-9290/

with greater frontal plane knee adduction angles and moments that are believed to lead to increased loading of the medial TF compartment (Zhao et al., 2007). Conversely, patients with lateral TF OA commonly walk with increasing knee abduction angles but lower peak knee adduction moments that are thought to shift a greater portion of the compressive knee joint loads to the lateral TF compartment (Agneskirchner et al., 2007). Reduced transverse plane TF joint internal rotation has also been reported for patients with medial compartment OA compared to those with lateral compartment disease (Weidow et al., 2006). It has been suggested that the reduction in TF internal rotation may be a compensatory mechanism to decrease anterior translation of the medial TF condyle over the central and anterior regions of the medial TF compartment, where cartilage damage is commonly observed (Saari et al., 2005; Weidow et al., 2002).

Although, knee OA is predominantly viewed as a disease that affects the TF joint; the involvement of the patellofemoral (PF) joint has gained more attention as of late. In a recent magnetic resonance imaging assessment of 970 knees, PF joint structural damage was deemed to be at least as common as, if not more common than, TF Joint damage (Stefanik et al., 2013). Evidence further suggests that the prevalence of mixed TF and PF OA in older adults with painful knees is much higher (40%) compared to either TF OA (4%) or PF OA (24%) in isolation (Duncan et al., 2006). Given the inherent anatomical relationship between the TF and PF joints, it has been suggested that the abnormal frontal and transverse plane motions of the TF joint can influence the congruency of the patella within the trochlear groove, leading to altered stress distributions that can contribute to the pathomechanics of the PF joint (Powers, 2003). For instance, excessive TF abduction is thought to increase the lower extremity *Q*-angle (the angle between the quadriceps load vector and the patellar tendon load vector), leading to increased lateral patella tilt, lateral patella translation, and greater lateral patella facet compressive forces (Huberti and Hayes, 1984; Mizuno et al., 2001). Conversely, excessive TF adduction is thought to decrease the *Q*-angle, increasing the medial patella tilt and translation, thus leading to increased compressive loading of the medial patella facet (Huberti and Hayes, 1984; Mizuno et al., 2001). Similarly, while excessive TF external rotation in the transverse plane increases the contact stresses on the lateral PF joint facet, excessive internal rotation of the TF joint places greater loads on the medial side of the PF joint (Lee et al., 1994).

Currently, direct in-vivo quantification of the joint contact loads in patients with mixed knee OA is not feasible. However, considerations for knee joint kinematics can describe the relative positioning of the articular surfaces with respect to the line of action of the ground reaction and muscle forces to provide a surrogate indicator of how contact loads are distributed within the TF and PF joints. Therefore, the aim of the current study was to compare the frontal and transverse plane kinematics of the TF joint along with measures of PF joint malalignment during the loading response phase of downhill gait in three groups of older adults: patients with medial TF compartment and coexisting PF OA (medial OA); patients with lateral TF compartment and coexisting PF OA (lateral OA); and an OA-free control group (control). It was hypothesized that patients with medial compartment OA would walk with greater degrees of TF joint adduction/external rotation and greater medial patella tilt/translation compared to the control group. It was also hypothesized that patients with lateral compartment OA would walk with greater TF joint abduction/internal rotation and greater lateral patella tilt/translation compared to their control counterparts.

Table 1
Mean subject demographics.

Demographics	OA-free-control ($N=22$)	Medialknee OA ($N=11$)	Lateralknee OA ($N=10$)	*P*-value
Age (years)	68.1 (7.0)	70.3 (10.0)	73.1 (9.5)	0.31
Female (%)	11 (50.0)	7 (63.6)	3 (30.0)	0.30
Height (cm)	174.8 (13.0)	171.4 (11.9)	172.7 (6.7)	0.72
Weight (kg)	77.1 (16.6)	86.8 (17.9)	77.5 (7.5)	0.22
BMI (kg/m^2)	25.1 (3.7)	29.6 (5.7)[a]	26.0 (1.6)	0.01

OA=osteoarthritis; BMI=body mass index; values are mean (SD) or N (%).
[a] Significantly different than the control group.

2. Materials and methods

2.1. Participants

Forty-three participants were recruited for this study (Table 1). All participants with knee OA met the American College of Rheumatology clinical classification criteria for knee OA (Altman et al., 1986) and had evidence of radiographic TF and PF OA of grade II or greater according to the Kellgren and Lawrence (KL) scale (Kellgren and Lawrence, 1957). Participants with primary medial compartment TF OA and coexisting PF OA comprised the medial OA group, whereas those with primary lateral compartment TF OA and coexisting PF OA made up the lateral OA group. In addition, 22 subjects without evidence of radiographic TF or PF OA who reported no history of knee pain served as the control group. Subjects were excluded if they required an assistive device or a rest break to ambulate a distance of 30.5 m (100 feet) or reported two or more falls within the past year. All participants signed a consent form approved by the Institutional Review Board of the University of Pittsburgh prior to participation in the study.

2.2. Dynamic Stereo X-ray testing

Dynamic Stereo X-ray (DSX) methods were used to quantify 3-dimensional (3D) TF and PF joint kinematics from biplane radiographic images. The biplane X-ray system contained two X-ray gantries that were configured with their beam paths intersecting at 60° in a plane parallel to the floor. Each gantry contained a 100 kW pulsed X-ray generator (CPX 3100CV; EMD Technologies, Quebec, Canada), a 40 cm image intensifier (Thales, Neuilly-sur-Seine, France), and a high-speed 4 megapixel digital video camera (Phantom v10, Vision Research, Wayne, New Jersey, USA). The X-ray generators were customized to provide short-duration pulses at very high repetition rates. For the current study, radiographs were generated with a 1 ms pulse width at 100 Hz, with a maximum radiographic protocol of 90 kVp/200 mA and a 1 s collection time (100 ms total X-ray exposure) per trial.

Participants' knees were imaged during a downhill gait condition (7% grade, 0.75 m/s) on an instrumented treadmill (Bertec Corp., Columbus, OH, USA). The decision to use a downhill gait condition was made based on our previous clinical experience with patients with knee OA and PF dysfunction who reported frequent difficulty and pain while walking downhill, most likely due to increased knee flexion angles, vertical ground reaction forces and knee joint moments as compared to level gait (Kuster et al., 1995; Lay et al., 2006; McIntosh et al., 2006; Redfern, 1997). Additionally, a relatively slow gait velocity of 0.75 m/s was chosen for our experimental set up based on the result of our pilot testing demonstrating that most patients with knee OA had difficulty walking downhill at higher gait speeds. Our pilot testing also revealed that the magnitude of the ground reaction forces and the external moments placed on the knee joint were comparable