

## The contact locations in the knee during high flexion

Gokce Yildirim<sup>a</sup>, Peter S. Walker<sup>a,\*</sup>, Jon Sussman-Fort<sup>c</sup>, Gaurav Aggarwal<sup>b</sup>,  
Brian White<sup>a</sup>, Gregg R. Klein<sup>a</sup>

<sup>a</sup> NYU-Hospital for Joint Diseases, New York, NY, United States

<sup>b</sup> CUNY, City College of New York, New York, NY, United States

<sup>c</sup> Columbia University, New York, NY, United States

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### Abstract

The aim was to determine the contact locations in the knee in a simulation of a deep squatting position, for both neutral and after tibial rotation. A rig was constructed to load the knee under quadriceps action at flexion angles from 135 to 155° flexion, with a mechanism for rotating the tibia internally or externally. Fiducial points on each bone were digitized in each position of the knee. After all of the tests, the entire bone surfaces were digitized, enabling computer reconstructions to be made of the multiple positions. The software then produced color maps of the contact areas. Six cadaveric knees were tested. On the patella, contact occurred over an arcuate band across the superior, lateral and medial edges, including the medial ‘odd facet’. On the upper tibia, the medial contact was close to the center of the condyle, while on the lateral side, the contact was posterior. As a result, impingement occurred between the posterior tibial edge and the femoral cortex on the medial side. However, lateral impingement also occurred when the tibia was externally rotated. Due to the stiffness of the knee at these high flexion angles, the maximum tibial rotation between external and internal averaged only 16°. During this rotation, there was twice as much displacement of the lateral contact than the medial contact, indicating greater stability on the medial side. In all rotations, the medial contact moved inwards to engage the intercondylar eminence which appeared to act as the pivot area. The small rotational range implied that correct foot placement was necessary for optimal mechanics during squatting activities.

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### 1. Introduction

Many different methods have been used for determining the kinematics and the contact locations in the knee during flexion–extension, both in specimens and in the living knee. Early studies of the femoro-tibial joint [1–3] and of the patello-femoral joint [4,5] used castings, dye staining, or pressure sensitive film to determine contact areas, but flexion angles were 120° or less. More recently, CT or MRI modeling [6,7], as well as stereophotogrammetric techniques [8], has been used to estimate both areas and pressures, but

again, high flexion was not examined. Magnetic resonance imaging [9] and fluoroscopy [10] were used to study meniscal movements up to 150° flexion, which also indicated the positions of the femur on the tibia. Extensive studies of both cadaveric knees and living subjects used cut slices and MRI sections to plot the projection of a transverse femoral axis through the centers of the posterior femoral condyles on to the upper tibia [11,12]. A transverse axis through the epicondyles was used to study high flexion, using a robot to move the knee specimens at discrete flexion angles through a neutral path [13]. The different definitions of the transverse axis in the above two studies made a difference to the results, while the position of the axes would indicate only the general locations of the contact areas due to the curvatures of the tibial surfaces and the effect of the menisci. More recently, contact areas and pressures were measured directly on cadavers in conditions representing

\* Corresponding author. Laboratory for Minimally-Invasive Surgery, VA Medical Center, 423 East 23rd Street, Annex Building #2, Room 206A, New York, NY 10010, United States. Tel.: +1 212 686 7500x6444; fax: +1 212 951 3432.

E-mail address: [ptrswlkr@aol.com](mailto:ptrswlkr@aol.com) (P.S. Walker).

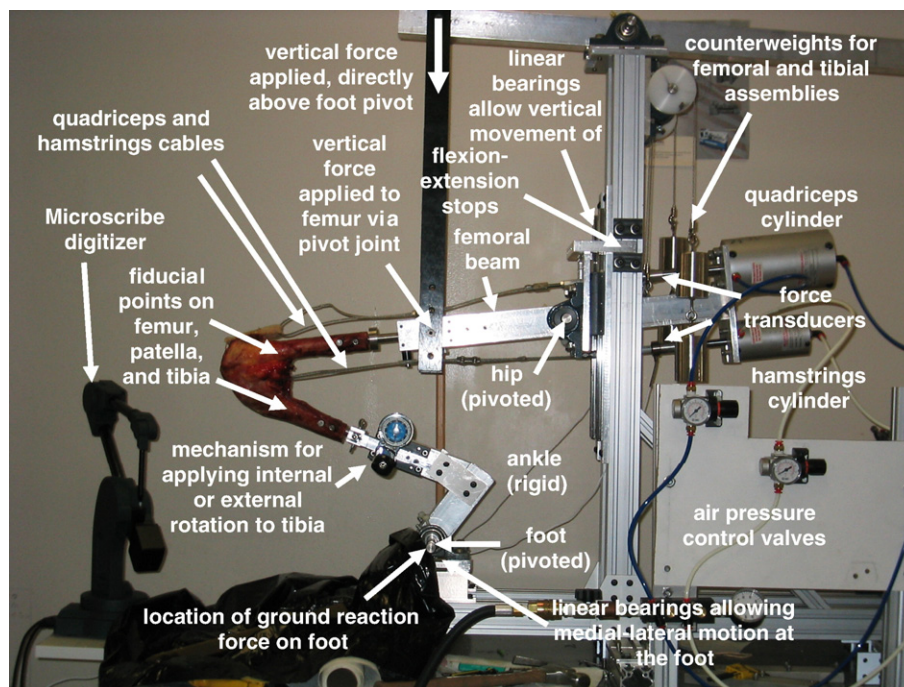


Fig. 1. The high-flexion test rig showing a test knee at 155° flexion.

deep flexion up to 120° flexion [14]. In test rigs to study squatting and kneeling in cadavers, beads in the bone were tracked using fluoroscopy to measure motion, while Tekscan was used to measure contact areas and pressures directly [15,16].

In the above studies, high flexion was characterized by an internal tibial rotation such that the medial contact on the tibia remained relatively immobile, while the lateral contact

position translated posteriorly [9,11,17–20]. In extreme flexion up to 162°, the lateral femoral condyle reached the posterior edge of the tibial plateau, while the medial contact on the tibia displaced posteriorly from the center by only a few millimeters. Forcing the flexion to this point caused a hinging of both the lateral and medial femoral condyles over the posterior horns of the menisci [18]. Recent studies showed that in high flexion the medial joint surfaces can separate and there can be some anterior force on the tibia due to thigh–shank contact, displacing the tibia anteriorly and even reducing the forces across the femoral tibial bearing surfaces [15,16,21].

Experiments were carried out to assess whether the internal rotation described above is obligatory [12]. Subjects who squatted from standing, starting with their feet in either in an externally or internally rotated position, did display different contact patterns, but in this study the flexion angle was limited to only 90°. In the robotic studies, the authors

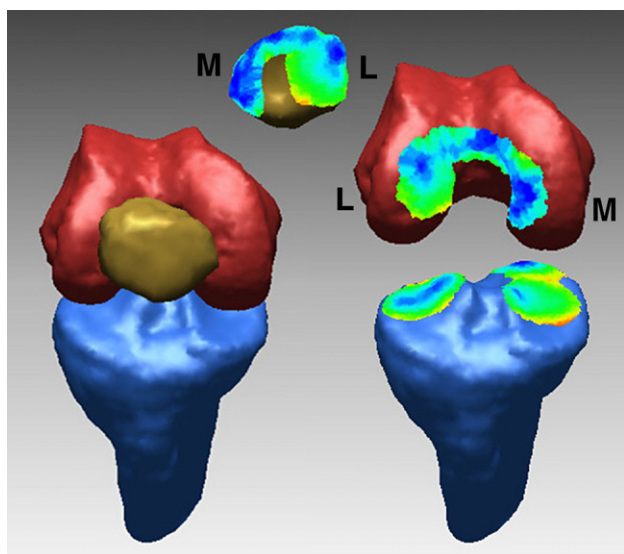


Fig. 2. A computer reconstruction of the femur, tibia and patella in their actual positions at 155° flexion in the test rig. The color contour maps show the local separations between the opposing articular surfaces and indicate the contact areas: dark blue = 0–1 mm; light blue = 1–2 mm; green = 2–3 mm.

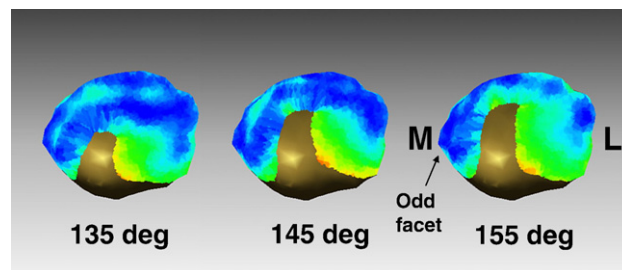


Fig. 3. The arcuate band of contact on the patella extended distally for a reduction from 155 to 135° flexion, and involved the 'odd facet' on the medial side.

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