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Review

Squatting, lunging and kneeling provided similar kinematic profiles in healthy knees—A systematic review and meta-analysis of the literature on deep knee flexion kinematics☆

Catherine R. Galvin [a,c,*], Diana M. Perriman [a,b,c], Phillip M. Newman [a,d], Joseph T. Lynch [b,c], Paul N. Smith [b,c], Jennie M. Scarvell [a,c]

[a] Faculty of Health, University of Canberra, Locked Bag 1, 2601, Australia
[b] The Australian National University, Acton, ACT 2601, Australia
[c] Trauma and Orthopaedic Research Unit, Canberra Hospital, Garran, ACT, 2605, Australia
[d] University of Canberra Research Institute for Sport and Exercise (UCRISE)

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ABSTRACT

Background: Understanding healthy deep flexion kinematics will inform the design of conservative clinical rehabilitation strategies for knee osteoarthritis and contribute to improved knee prosthesis design. This study is a systematic review and meta-analysis of the kinematic outcomes measured at the healthy tibiofemoral joint during loaded deep knee flexion.
Methods: A computerised literature search and bibliography review without date restriction identified twelve studies with 164 participants aged 25–61 years in-vivo, and 69–93 years in-vitro. Flexion higher than 120° was achieved by squatting, lunging or kneeling. Measurement technologies in-vivo included radiographs, open MRI and 2D–3D MRI or CT image registration on fluoroscopy. Microscribe was used in-vitro.
Results: Outcomes were either six degrees-of-freedom based on femur movement or contact patterns on the tibial plateau. The meta-analysis demonstrated that in-vivo, between 120° and 135° of flexion, the tibia *internally* rotated (mean difference (MD) = 4.6°, 95% CI 3.55° to 5.64°). Both the medial-femoral-condyle and lateral-femoral-condyle translated posteriorly, (MD = 10.4 mm, 95% CI 6.9 to 13.9 mm) and (MD = 5.55 mm, 95% CI 4.64 to 6.46 mm) respectively. There was some evidence of femoral medial translation (3.8 mm) and adduction (1.9° to 3.3°), together with medial compression (1.7 mm) and lateral distraction (1.9) mm.
Conclusions: Across the in-vivo studies, consistent kinematic patterns emerged; despite the various measurement technologies and reference methods. In contrast, in-vivo and in-vitro results were contradictory.
Trial registration: This systematic review protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO) on 25 February 2017 (registration number: 42017057614).

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* Corresponding author at: Faculty of Health, University of Canberra, Locked Bag 1, 2601, University Drive, Bruce, ACT 2617, Australia.
E-mail addresses: catherine.galvin@canberra.edu.au, (C.R. Galvin), diana.perriman@act.gov.au, (D.M. Perriman), phillip.newman@canberra.edu.au, (P.M. Newman), joe.lynch@act.gov.au, (J.T. Lynch), psmith@orthoact.com.au, (P.N. Smith), jennie.scarvell@canberra.edu.au. (J.M. Scarvell).

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1. Introduction

The American College of Rheumatology and the American Academy of Orthopaedic Surgeons [1] recommend a range of rehabilitation strategies for the conservative treatment of knee osteoarthritis including strength, aerobic exercise and neuromuscular education. These recommendations are broad and demonstrate the need for a deeper understanding of the knees' response to different rehabilitation programmes [2] and the effects of knee osteoarthritis. Accurate clinical evaluation and effective rehabilitation programmes for various flexion demands can be informed by the measure of deviation away from healthy motion [3]. With younger and more culturally diverse patients, there is a high demand for deep flexion, including 135° of flexion for getting into a bath [2], 150° of flexion for yoga and gardening [2] and up to 165° of flexion for kneeling and squatting [4]. Total knee replacement patients have also indicated that deep flexion is an important postoperative outcome [5,6]. Thus an understanding of healthy deep flexion can contribute to improving rehabilitation programmes.

Various methods have recorded three-dimensional (3D) knee kinematics, including skin-mounted markers, bone-pins, radio-stereometric-analysis, dual-plane radiographs, fluoroscopy, transverse CT scans, microscribe digitising, and two dimensional (2D)–3D magnetic resonance imaging (MRI) or computer tomography (CT)–fluoroscopy image registration. The most accurate technique is radio-stereometric-analysis, but it is highly invasive-involving dual X-rays and the insertion of tantalum beads into bone. Bone-pins are also highly invasive. Consequently, radio-stereometric analysis and bone-pins can be used for in-vitro studies or post-surgical studies, but not in-vivo healthy knee studies. Skin markers are non-invasive, but their accuracy is affected by marker movement and skin deformation-producing errors of a scale that limit their use in tibiofemoral kinematic measurement. These limitations led to the development of a non-invasive method combining fluoroscopy with either MRI or CT [8]. Fluoroscopic and 3D images are registered (shape-matched) to determine the precise movements of the bones, and soft tissues (MRI only) in the knee joint; revealing the complex interactions of translations and rotations in three dimensions [9].

Different reference systems have been used to describe knee kinematics. Early investigations were interested in the anterior–posterior path of the contact points of femoral condyles on the tibial plateau, with tibial rotation calculated from the difference in medial and lateral contact-point translation [10]. Unfortunately, this system was limited to the sagittal plane. However, knee motion is three-dimensional, a mechanical linkage with six-degrees-of-freedom (6DOF) [8] and needed a more comprehensive system [11]. Grood and Suntay in 1983 developed a joint coordinate system with knee flexion as the reference motion [11]. They defined knee motion in 6DOF and related it to clinical descriptions [11]. Grood and Suntay [11] make it possible to set the femoral axis in various ways, including; using anatomical landmarks, and by fitting a circle or sphere over the sagittal femoral condyle. To date, there are no studies that compare the results of these various systems to that of healthy knee motion in deep flexion.

Early anatomical studies observed that during flexion, there is little medial femoral condyle movement compared to the posterior translation of the lateral femoral condyle [12]. During passive deep flexion, both femoral condyles translated posteriorly; rolling back onto the posterior horn of the tibial plateau [13]. Skin-marker motion analysis (up to 120° of flexion) found during squatting, kneeling and praying, that with increasing age, the rate of internal tibial rotation and knee abduction increases [14–17]. Contact-point mapping found no significant difference between left and right knee kinematics [4,10]. Early fluoroscopy studies found a difference between loaded and unloaded kinematics in-vivo as unloaded kinematics can be influenced by the laxity of soft tissue constraints [17]. Fluoroscopic analysis has shown that while lunging up to 120° of flexion, the healthy knee tibia