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# Femorotibial kinematics and load patterns after total knee arthroplasty: An in vitro comparison of posterior-stabilized versus medial-stabilized design

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## ABSTRACT

*Background:* Femorotibial kinematics and contact patterns vary greatly with different total knee arthroplasty (TKA) designs. Therefore, guided motion knee systems were developed to restore natural knee kinematics and make them more predictable. The medial stabilized TKA design is supposed to replicate physiological kinematics more than the posterior-stabilized TKA system. We conducted this study to compare a newly developed medial stabilized design with a conventional posterior-stabilized design in terms of femorotibial kinematics and contact patterns in vitro.

*Methods:* Twelve fresh-frozen knee specimens were tested in a weight-bearing knee rig after implantation of a posterior stabilized and medial-stabilized total knee arthroplasty under a loaded squat from 20° to 120° of flexion. Femorotibial joint contact pressures in the medial and lateral compartments were measured by pressure sensitive films and knee kinematics were recorded by an ultrasonic 3-dimensional motion analysis system.

*Findings:* The medial stabilized design showed a reduction of medial femorotibial translation compared to posterior-stabilized design (mean 3.5 mm compared to 15.7 mm, $P < 0.01$). In the lateral compartment, both designs showed a posterior translation of the femur with flexion, but less in the medial stabilized design (mean 14.7 mm compared to 19.0 mm, $P < 0.01$). In the medial femorotibial compartment of medial stabilized design, we observed an enlarged contact area and lower peak pressure, in contrast in the lateral compartment there was a reduced contact area and an increased peak pressure.

*Interpretation:* While posterior-stabilized design enforces a medio-lateral posterior translation, the medial stabilized arthroplasty system enables a combination of a lateral translation with a medial pivot, which restores the physiological knee kinematics better.

## 1. Introduction

Femorotibial kinematics and load patterns after total knee arthroplasty (TKA) vary greatly. Non-physiological motion after TKA, for example, paradoxical anterior translation of the femur on the tibia with flexion or posterior subluxation of the femur are described (Dennis et al., 1998, 2003). Besides the necessary stability of a TKA, physiological femoral posterior translation provides a more natural motion of the knee, resulting in a better functional outcome and satisfaction for the patient after TKA (Pritchett, 2011). Implant design directly influences the kinematics after TKA (Banks and Hodge, 2004). Therefore, "guided motion" knee systems like the PS system were developed in the late 1970s by Insall et al. (Insall et al., 1982) to restore physiological kinematics and make kinematics more predictable. A post on the inlay interacts with an integrated cam in the femoral component, providing a medial and lateral femoral posterior translation with flexion of the knee. With specific investigations of normal knee kinematics (Blaha et al., 2003; Iwaki et al., 2000), other guided motion systems were further developed in the 2000s. The MS design is supposed to provide an antero-posterior (AP) translation of the femur in the lateral compartment, while the medial condyle interacts like a "ball and socket" joint. This medial convexity of the inlay might reduce contact stress and might replicate physiological kinematics more than the PS design. On the other hand, studies have described an antero-lateral pain with guided motion TKA systems and it is assumed that a higher forced lateral AP translation might cause pain in this area (Halewood et al., 2014; Luyckx et al., 2010).

Especially for newly designed or modified implants, an in vitro analysis should be extensively performed for implementation of the implants in vivo. In vitro studies with human specimens are an

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established method of investigating femorotibial knee kinematics and load patterns after TKA (Arnout et al., 2014; Blaha et al., 2003; Heyse et al., 2010; Steinbruck et al., 2015; Varadarajan et al., 2009; Walker et al., 2011). A specific comparison in terms of kinematics and joint pressure of a PS and a MS knee system was—to the authors knowledge—not performed before. Therefore, the goal of this study was to compare a newly developed MS TKA system with a conventional PS design of the same manufacturer. We firstly hypothesized that the MS design had a higher AP translation and secondly a higher maximum pressure in the lateral femorotibial compartment during flexion of the knee. By having the same bone cuts, fixation points, and tibial baseplate for both the PS and MS knee systems, a direct comparison and interpretation of the results within every single knee specimen could be performed.

## 2. Methods

### 2.1. Human knee specimens

Twelve human knee specimens (Table 1) were used to investigate knee kinematics after TKA. The local ethics committee of the university approved the acquisition and usage of the human specimens. None of the chosen specimens had any severe varus or valgus deformity ≥ 10°. Muscles were dissected and fat tissue was removed carefully. Special care was taken to preserve the joint capsule and the tendons of the vastus medialis muscle, vastus lateralis muscle, intermedius and rectus femoris muscle, as well as the biceps femoris muscle and semitendinosus muscle. Afterwards, metallic finger traps (Bühler–Instrumente Medizintechnik GmbH, Tuttlingen, Germany) were connected to the tendons and suture material (FibreWire, Arthrex, Munich, Germany) was used to attach the tendon to the metallic mesh of the traps (Fig. 1). The fibula head was fixed to the tibia with a screw and the fibula was cut under the head. The anatomical transepicondylar axis was defined and a Kirschner wire was drilled through the femur from the medial to the lateral epicondyle with the help of a drilling sighting mechanism. The femur was cut 20 cm proximal and the tibia was cut 15 cm distal to this axis.

### 2.2. Prostheses and TKA implantation

A PS TKA design (GMK PS, Medacta International, Castel San Pietro, Switzerland) and a MS TKA design (GMK Sphere, Medacta International, Castel San Pietro, Switzerland) were used (Fig. 2). The GMK PS design is characterized by a posterior cam placed on the femoral component and a post on the polyethylene inlay. The post mechanism is engaged at approx. 80° of flexion with the femur component and forces a posterior translation of the femur. The GMK Sphere design features a fully congruent medial compartment providing high AP and medio-lateral (ML) stability during the range of motion. The lateral compartment of the inlay is completely flat with neither anterior nor posterior lips, allowing lateral mobility. In the sagittal plane the femoral component is characterized by a single radius medially and laterally from 45° to 114° flexion. The same radius is used for the frontal profile of the medial condyle, building a medial sphere.

TKA was performed using a medial subvastus approach. In coronal plane, a tibial resection of 8 mm beyond the joint line was performed, perpendicular to the bone axis using an intramedullary rod. Tibial baseplate rotation was aligned to the medial third of tibial tuberosity. An intramedullary rod aligned also the femoral component with a 6° valgus relative to the femoral shaft axis and distal cut was performed. Afterwards the anterior, posterior and chamfer femoral bone cuts were performed referenced to the anatomical transepicondylar axis and the PS TKA was implanted. In some cases, a slight medio-lateral ligament balancing was performed to guarantee well-adjusted medio-lateral stability in the whole flexion–extension cycle. Exchanging the femoral PS to MS component was possible, because both prostheses use the same bone cuts and peg holes. Additionally, both systems have the same tibial baseplate. Hence, inlays according to the femoral component design can be exchanged easily. A 10 mm polyethylene inlay was used in every TKA. The first author operated all knees. All knees were x-rayed in AP, ML and sunrise view before and after TKA.

**Table 1**
Meta-data of the tested specimens in the study.

| Parameter | Mean | Range |
|---|---|---|
| Age in years | 63.9 | 44–78 |
| Height in cm | 174.8 | 157–187 |
| Weight in kg | 75.3 | 55–90 |
| Side | – | 6 right/6 left |
| Gender | – | 8 male/4 female |

Meta-data of the tested specimens.

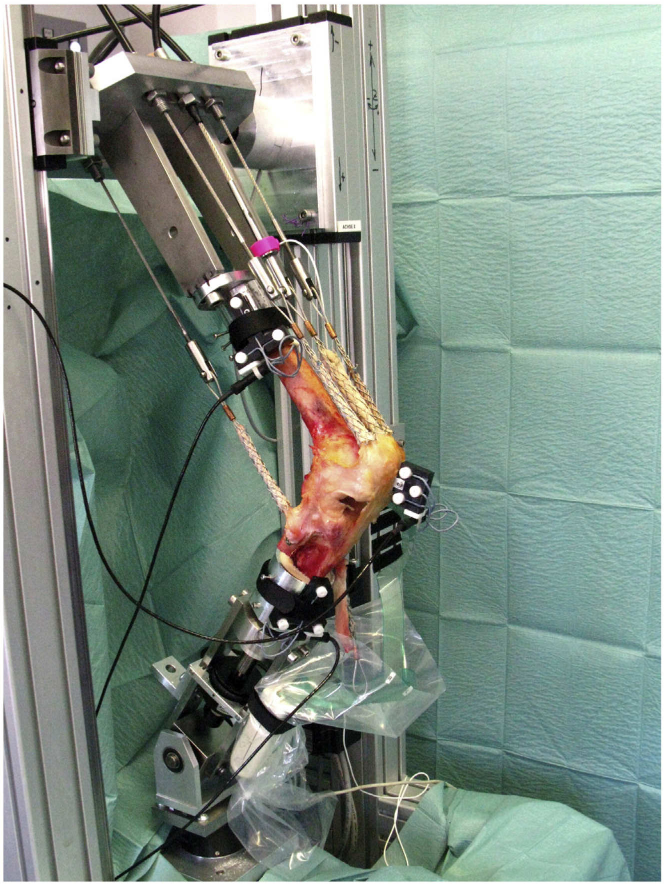

**Fig. 1.** Prepared knee specimen with finger traps and miniature transmitters mounted in the knee rig.

### 2.3. Biomechanical testing

Specimens were tested in a well-established custom-made knee rig simulating a loaded squat in six degrees of freedom (Steinbruck et al., 2013). One linear drive controlled the vertical position of the hip according to the ankle joint while a second drive controlled the ground reaction force by simulating the quadriceps load. The mean maximal quadriceps load during flexion of the knee was 503 N (standard deviation 72 N). Hamstring muscles (biceps femoris and semitendinosus), vastus lateralis and vastus medialis muscles were simulated with weights (each 20 N). The quadriceps muscle vectors were restored anatomically. The rectus muscle was orientated to the femur shaft, vastus lateralis to the greater, vastus medialis to the lesser trochanter. The knee rig simulated an active deep knee flexion from 20° to 120° of flexion