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Fluoroscopic motion study confirming the stability of a medial pivot design total knee arthroplasty

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ABSTRACT

Background: The ideal total knee arthroplasty should provide maximum range of motion and functional stability for all desired daily activities. The SAIPH™ (MatOrtho; UK) knee has a medial pivot knee kinematic pattern designed to achieve medial stability and an asymmetric posterior translation of the lateral femoral condyle during knee flexion and in this way attempts to mimic the natural knee motion. This study aims to analyze knee kinematics of the SAIPH™ total knee arthroplasty (TKA) by videofluoroscopy during four different weightbearing activities.

Methods: Fourteen consecutive patients operated on by a single surgeon, with a minimum follow-up of 24 months were included in this IRB-approved study. There were no exclusions based on patient's functional level. A medially conforming knee was implanted in all cases. Participants in the study were asked to perform the clinically relevant functional activities of pivoting, kneeling, lungeing and step-up/down activities while their knee motion was recorded by videofluoroscopy.

Results: Maximum knee flexion during the kneeling activity mean 127° (100°–155°). An asymmetric posterior translation of the lateral femoral condyle (LFC) was observed during pivoting, kneeling, lungeing and stepping. No paradoxical anterior translation of the femoral condyles was observed in any activity.

Conclusion: The kinematics observed in this implant are similar in pattern, although smaller in magnitude, to normal functional knees, showing a posterior translation of the lateral femoral condyle during knee flexion, with internal rotation of the tibia, and no paradoxical anterior motion in any of the four weight bearing activities.

1. Introduction

Total knee implants partially replace the function of lost structures through intrinsic constraints, including the shape of the articular surfaces, ligament substituting mechanisms, and guided motions. Many current designs of total knee arthroplasty (TKRs) do not provide normal kinematics and some are prone to "paradoxical" anterior slide of the femur on the tibia during weight bearing knee motion, which can lead to negative consequences [1]. Dennis et al. has reported that paradoxical anterior femoral translation results in a more anterior axis of flexion, lessening maximum knee flexion. The quadriceps moment arm is decreased, resulting in reduced quadriceps efficiency. In addition the anterior sliding of the femoral component on the tibial polyethylene surface may accelerate polyethylene wear [1,2].

It is reasonable, therefore, to question the kinematics of new implant designs and whether the motions are consistent over the functional range of motion. Because joint motions have a direct impact on patient function and implant wear [3–5], it is critically important to understand the relationship between implant design and functional joint motions. Aside from pain relief, the most important goals after TKR are to achieve stability, kinematics that mimic the normal knee and a functional range of motion. Lifestyles throughout much of Asia and the Middle East demand significant flexion of the knee. Moreover, TKA patients are younger and more active, so their expectations in terms of function after knee replacement are higher.

The SAIPH™ (MatOrtho; Surrey, United Kingdom) TKR is a fixed bearing prosthesis based on the successful design of the Medial Rotational Knee (MRK) concept. The purpose of this study was to measure in vivo knee kinematics of this medial conforming knee arthroplasty design during several weightbearing clinically relevant functional activities using videofluoroscopy, and to compare the results with published work on other knee replacement designs.

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We hypothesized that the design features of this implant will allow a medial pivot kinematic pattern, allowing greater stability in all positions of flexion, and avoiding "paradoxical" anterior femoral translation during weight-bearing activities.

2. Material and methods

Institutional review board (reference number 149) approval was obtained for this study, and all subjects provided written informed consent after the nature of the study had been fully explained. All patients included in the study underwent a total knee arthroplasty through a medial parapatellar arthrotomy. The posterior cruciate ligament was excised in all knees. No lateral retinacular releases were needed for optimal intraoperative patello-femoral tracking. Femoral and tibial components were cemented. The patella was resurfaced in three cases by selective decision of the treating surgeon depending on the grade of patellar osteoarthritis and anterior location of knee pain. Intramedullary alignment was used for the femur, and extramedullary alignment for the tibia. All patients had identical postoperative care and rehabilitative protocol. The first 14 consecutive patients, seven males and seven females with a mean age of 69 years (51–83), operated on by a single surgeon were included. There were no exclusions based on the patient's functional levels. All patients had a preoperative diagnosis of end-stage medial compartment osteoarthritis of the knee, postoperative collateral ligament stability, a range of motion more than 90°, and an ability to kneel on their replaced knee.

A medially conforming prosthesis (SAIPH™, MatOrtho, Surrey, UK) was used in all knees with a minimum follow-up after surgery of 24 months. This knee design achieves stability principally by the conformity of the medial articular surface, (ball in a socket design) [Fig. 1a, b] and an anatomically lateralized patella groove providing an optimization of the patello-femoral tracking [Fig. 2]. The lateral compartment has less anteroposterior tibiofemoral conformity [Fig. 3] which allows asymmetric posterior translation of the femoral condyles in relation to the tibial sulcus. The lateral femoral condyle translates posteriorly during flexion, while the medial femoral condyle remains stable in the sagittal plane.

All patients completed the Veterans Rand-12 [25], the Oxford Knee Score [22], the Knee Injury and Osteoarthritis Outcome Score (KOOS) [23,24], the Kujala Scoring Questionnaire [26] and the EuroQol (EQ-5D) [27] at the time of the study. Each subject completed four weight-bearing activities during fluoroscopic imaging: pivoting, kneeling, lungeing, and stepping.

For the pivoting activity, subjects were aligned for a lateral view of the study knee while twisted their body to allow maximum tibial external rotation. Fluoroscopic images were recorded as the subject pivoted their body on a fixed foot to impart the maximum range of tibial internal rotation.

Kneeling was performed with the implanted knee placed on a padded chair at approximately 90° flexion, while the extended contralateral limb supported most of the body weight. Subjects were asked to bend from 90° flexion to their maximum comfortable flexion while lateral fluoroscopic images were recorded.

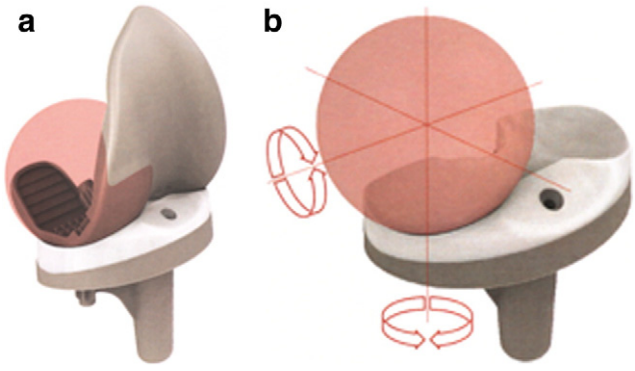

Fig. 1. a. SAIPH™ Ball on a socket design in the medial articular surface. b. The medial congruity of the implant provides stability through all range of motion.

Fig. 2. Lateralized trochlear groove providing an optimization of the patello-femoral tracking.

Lungeing was performed with the subject's foot placed upon a 30 cm riser. The subjects were asked to slowly bend to their maximum comfortable knee flexion, in an exaggerated shoe-tying posture, while images were recorded. Their motions were not constrained and subjects were allowed to lift their heel if that permitted a greater range of flexion. An investigator offered to hold the patients' hands or forearms as a safety measure to prevent a fall.

Stair stepping was performed with the subject's foot on a 30 cm riser with the toes pointed directly forward. Images were recorded as the subject stepped up directly into full weight-bearing extension on the replaced knee, without swinging through the opposite leg, and then immediately reversed direction and lowered themselves to rest upon the other leg.

Images were recorded at eight frames/s using pulsed fluoroscopy (Multi-Diagnost 4, Philips Medical, The Netherlands; 30 cm field of view; 1024 × 1024 pixel images recorded to DICOM). The optical geometry of the fluoroscopy system (principal distance, principal point) was determined from images of a calibration target. The implant surface model was projected onto the digitized image, and its three-dimensional pose was iteratively adjusted to match its silhouette with the silhouette of the subject's knee components. The results of this shape-matching process have standard errors of approximately 0.5°–1.0° for rotations and 0.5–1.0 mm for translations in the sagittal plane [6].

Joint kinematics were determined from the three-dimensional pose of each TKA component using standard angle and translation parameters.

3. Results

At the time of the study the mean follow-up after surgery was 34 months (range 30–36 months). The mean Veterans–Rand 12 score was 50 (range 14–67) for the mental scale and 45 (range 28–56) for the physical scale. Oxford Knee scores mean 39 points (range

Fig. 3. Smaller and less conforming lateral side allowing internal rotation of tibia around a medial stable femur.