Single-Radius vs J-Curved Femoral Designs during Walking and Squatting

Bernardo Innocenti[1*], Giulia Rosellini[1], Silvia Pianigiani[1]
[1] *BEAMS Department, Université Libre de Bruxelles, Bruxelles, Belgium; *bernardo.innocenti@ulb.ac.be*

***Abstract*—Single-radius and J-Curved femoral components are two currently available designs used for femoral components of total knee arthroplasty (TKA). Apart from clinical studies, no literature work compares, biomechanically and exhaustively, these two TKA solutions up to now. This research study aim at investing the effect of the two different femoral designs during daily activities, as walking and squat, using finite element analysis. Comparing TKA kinetics and kinematics between the two designs, the main differences were identified only for high flexion activities, after 80° of knee flexion.**

***Keywords*—TKA, Single-Radius, J-Curved, Walking, Squat.**

I. Introduction

Up to the last decade, native knee joints were thought to present multiple instantaneous centers of knee flexion/extension rotation, therefore the femoral components shapes for TKA purposes were designed with a progressive decrease of the radius of curvature. This approach is followed in the design of the so called J-Curve femoral component that are widely used, providing successful clinical outputs. Their success can be attributed to the claimed reduction in mobility and pain caused by usual diseases such as osteoarthritis, post-traumatic or rheumatoid arthritis. Such design feature, changing the radius from 0° and 90°, could be linked to the "Mid-range instability" because it allows ligament slackness and instability during knee flexion. For this reason, single-radius designs have been introduced. This design is claimed to ensure consistent tension in the collateral ligaments throughout the functional range of movement. This philosophy is based on the isometry of the superficial medial collateral ligament, and that is widely accepted as basis of soft tissue tensioning in knee replacement.

However, it is reasonable to hypothesize that single-radius design modification in the geometry may induce changes in the functional performance of the artificial joint, leading to a different load distribution and, therefore, different polyethylene stress, different kinematics and different strains in the ligaments.

To check this assumption, in this study, the biomechanical behaviour of the two different femoral designs was analyzed and compared during walking and squatting. In particular, the tibio-femoral contact forces and kinematics, together with the collateral ligament strain, were analyzed and compared using a previously validated finite element model.

II. Materials and Methods

Physiological three-dimensional tibial and femoral bone models were generated from computer tomography images of a left, fourth generation, composite tibia and femur, size medium. Such models are widely used for numerical and experimental tests [1,2]. The tibial and femoral bone model consists of three parts: cortical bone, cancellous bone and the intramedullary canal.

Starting from a conventional J-Curved femoral component, the correspondent single-radius design was developed. The two femoral components were coupled with the same tibial insert defining two separate implant models. The TKA design was implanted on the femoral and tibial bone according to the surgical guidelines provided by the manufacturer. Each of them was investigated during a walking and squat motor task.

The analysis was performed by means of finite element models that were defined, in terms of the geometry, materials (Table I), ligament pre-strain following a previous validated published model [3-5]. For the walking activities the load conditions were based according to the (ISO 14243-1) [6], while for the squat they follow the one measured during an experimental activity [7,8].

In this study, the investigated parameters were:

- implant contact areas and forces,
- bone and polyethylene stresses,
- ligaments strains,
- tibio-femoral kinematics.

TABLE I: Material Models and Properties used in this study. The third axis was taken parallel to the anatomical axis.

Material	*Material Model*	*Elastic Modulus [GPa]*	*Poisson Ratio*
Cortical bone	Transversally isotropic	$E_1 = 11.5$ $E_2 = 11.5$ $E_3 = 17.0$	$\upsilon_{12} = 0.50$ $\upsilon_{13} = 0.30$ $\upsilon_{23} = 0.30$
Cancellous bone	isotropic	E= 2.1	$\upsilon = 0.31$
CoCr	isotropic	E= 240	$\upsilon = 0.30$
UHMWPE	isotropic	E= 0.72	$\upsilon = 0.46$
LCL	isotropic	E= 0.11	$\upsilon = 0.45$
aMCL	isotropic	E= 0.20	$\upsilon = 0.45$
pMCL	isotropic	E= 0.20	$\upsilon = 0.45$

III. Results

For walking (Figure 1), no significant differences were noticed between the two designs both in kinematics and kinetics outputs (changes in contact forces and ligament strains lower than 1%).

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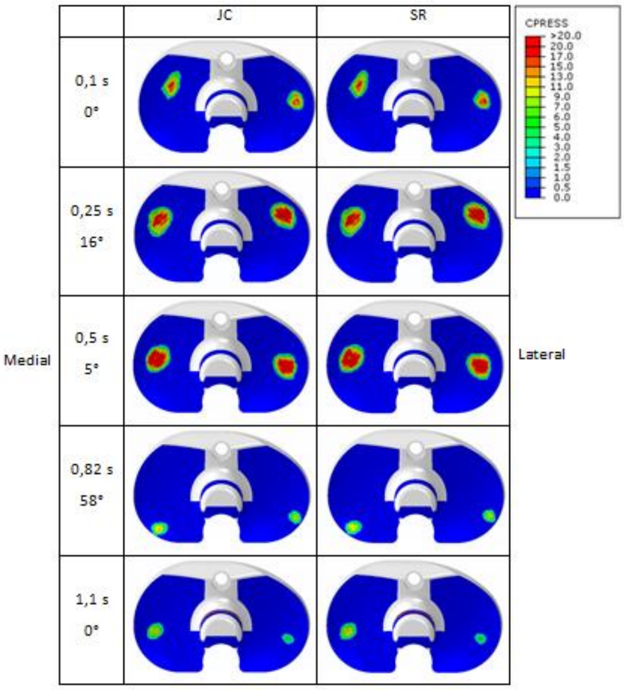

Figure 1: Contact pressure [MPa] and area distribution and location for J-Curved (JC) and Single Radius (SR) during walking.

During the squat task (Figure 2), the two TKAs present similar behaviour, up to around 80° of flexion. After this specific flexion value, the single-radius design starts to translate more posteriorly generating a slight different kinematics with respect to the J-Curved design. Moreover, contact forces and pressure outputs were also higher, up to 25%, and the MCL strains were also slight higher.

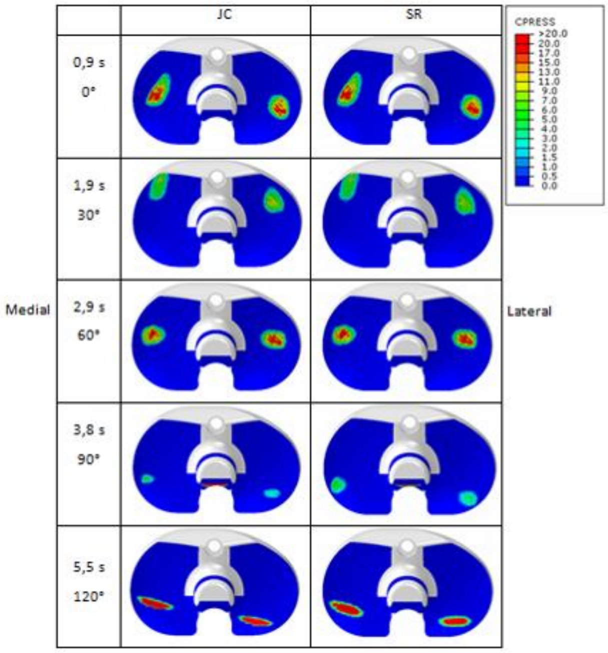

Figure 2: Contact pressure [MPa] and area distribution and location for J-Curved (JC) and Single Radius (SR) during squat.

IV. Conclusion

During walking, for which the maximum knee flexion is 60°, the two analysed TKA solutions show a similar behaviour in terms of kinematics and contact forces. However, during squatting, after 80° of knee flexion, the single-radius design determines slight differences in kinematics and higher tibio-femoral forces that could induce higher polyethylene tibial-femoral and post-cam stresses, furthermore, the MCL strain are also higher, but only after 90°. Therefore, as also reported by other authors in the literature [8-10], the results of this study did not find mid-range instability of the knees, and so they could not demonstrate enhanced mid-range stability of the single-radius TKA over the older multi-radius implant.

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