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Effect of Patellar Thickness on Knee Flexion in Total Knee Arthroplasty: A Biomechanical and Experimental Study

Mansour Abolghasemian, MD [a], Saeid Samiezadeh, PhD Candidate [b], Amir Sternheim, MD [a], Habiba Bougherara, PhD, PEng [b], C. Lowry Barnes, MD [c], David J. Backstein, MD, FRCSC [d]

[a] Clinical Fellow of Arthroplasty in the Division of Orthopaedic Surgery, Mount Sinai Hospital, University of Toronto, Toronto, ON, Canada
[b] Department of Mechanical and Industrial Engineering, Ryerson University, Toronto, ON, Canada
[c] University of Arkansas for Medical Sciences, Little Rock, AR, USA
[d] Head of the Division of Orthopedic Surgery, Mount Sinai Hospital, University of Toronto, Toronto, ON, Canada

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ABSTRACT

A biomechanical computer-based model was developed to simulate the influence of patellar thickness on passive knee flexion after arthroplasty. Using the computer model of a single-radius, PCL-sacrificing knee prosthesis, a range of patella–implant composite thicknesses was simulated. The biomechanical model was then replicated using two cadaveric knees. A patellar-thickness range of 15 mm was applied to each of the knees. Knee flexion was found to decrease exponentially with increased patellar thickness in both the biomechanical and experimental studies. Importantly, this flexion loss followed an exponential pattern with higher patellar thicknesses in both studies. In order to avoid adverse biomechanical and functional consequences, it is recommended to restore patellar thickness to that of the native knee during total knee arthroplasty.

Total knee arthroplasty (TKA) is a common and generally successful operation. Numerous studies have analyzed surgical techniques and factors influencing its short-term and long-term success [1–4]. The functional outcome and survivorship after TKA are two primary factors often utilized to measure the success of the procedure. A comprehensive relationship between the biomechanical features of TKA (e.g. knee alignment, component position and size) and its function and longevity has been long recognized. Knee range of motion, as a major functional index, has been reported by several studies to influence many daily activities and patient satisfaction [5–8].

The function of the patello-femoral articulation is known to have a significant impact on the outcome of the TKA procedure [9]. Despite the controversy regarding the use of patellar resurfacing, this technique is still common in total knee arthroplasty [10]. Employing the proper technique when resurfacing the patella, is essential to avoid over-stuffing and mal-tracking which can result in anterior knee pain and sub-optimal range of motion. Yet, there is no consensus on the exact relationship between the patella–implant thickness and the biomechanical function (including range of motion) of the knee after TKA [11]. The purpose of the present biomechanical and experimental study is therefore, to determine and analyze the relationship between patellar thickness and range of motion after TKA, and to identify the factors influencing this relationship.

Materials and Methods

This study consisted of two parts: a computer-based biomechanical study and an experimental analysis using cadaveric knees in order to validate the biomechanical study. This study started after institutional review board approval.

Biomechanical Study

A biomechanical model of the human knee was made in SolidWorks software (Dassault Systèmes SolidWorks Corp, MA) based on data from previous studies [12,13]. The model consisted of the Quadriceps muscles, patella, patella ligament, femur and tibia. Virtual 3-dimensional (3D) total knee arthroplasty was performed using a computer model for the Evolution Knee Replacement System (Wright Medical Inc., Arlington, Tenn). A two dimensional (2D) model was then developed in the sagittal plane where the tracking of the patella was investigated. Since the passive knee flexion was

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Reprint requests: Saeid Samiezadeh, PhD Candidate, Department of Mechanical and Industrial Engineering, Ryerson University, Toronto, ON, Canada, M5B 2K3.

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investigated in this study, the muscles, ligaments, and the patella were replaced by lines with constant lengths. This knee system was selected because of its single radius of curvature which makes it suitable for computational studies. Fig. 1 shows the details of the biomechanical model.

The model was then used to obtain the maximum possible flexion as a function of patellar thickness, assuming that a constant flexion force is applied to the knee which is mainly due to its weight. This force was sufficient in all different conditions to stretch the quadriceps mechanism to a certain amount of excursion. A range of 15 mm to 39 mm in patellar thickness with 1 mm increments was assumed and the resulting passive knee flexions were obtained. This seemingly excessively wide range of patellar thicknesses was studied to magnify the behavior pattern of the knee in response to the patellar thickness changes.

The model took into account the effect of the joint geometry and the length of the muscles, tendons, and ligaments was considered constant due to the assumption of a constant excursion. The distance l is introduced as $l = t + d$, in which d is the distance between the anterior border of the patella and the poly and t is the poly thickness which was changed in different stages. The angle θ, representing the supplementary flexion angle, is defined as the angle between the Quadriceps muscles and the tibia as depicted in Fig. 1.

The effects of size and radius of curvature of the patellar polyethylene component were also investigated. For this purpose, three different combinations of polyethylene sizes and thicknesses were studied.

Experimental Investigation

The authors utilized two cadaveric knees of thin males with anatomically intact joints and full range of motion (ROM). Using a standard medial parapatellar approach, a cemented posterior stabilized (PS) TKA (Evolution Knee Replacement System, Wright Medical Inc., Arlington, Tenn, USA) was implanted on the right knee of each cadaver. A total of 10 mm of bone and articular cartilage was removed from each patella. Patellar prosthesis trials with variable thicknesses ranging from nine to 24 mm with 3 mm increments were implanted sequentially. This range of implant thicknesses led to an incremental increase of patellar bone–prosthesis composites from one millimeter less than the original patellar thickness to up to 14 mm thicker than the original thickness of the patella. This wide range of patellar thickness was applied to investigate the knee behavior accurately.

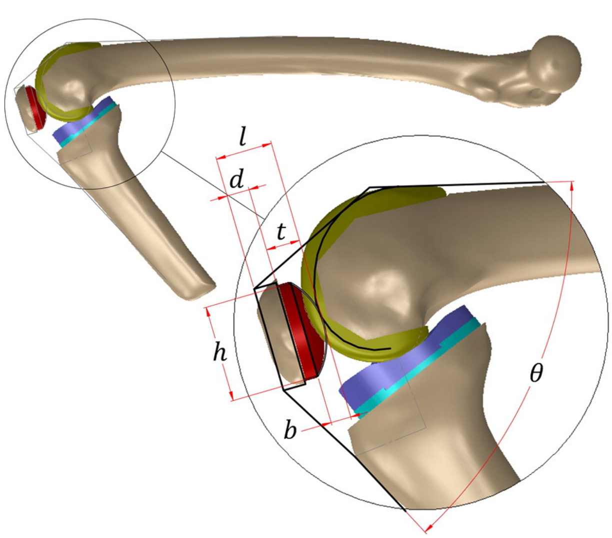

Fig. 1. The biomechanical knee model, θ represents the supplementary angle of knee flexion, l represents the distance between patella groove and the anterior border of the patella, t is the poly thickness, h is the poly size, and b is the height of poly cone.

Fig. 2. Experimental setup: showing a typical flexion angle measurement for a specific patellar thickness. Note that θ was measured instead of α for convenience.

With each successive patellar implant, the hip was held in 90° of flexion and neutral rotation. The knee was then allowed to bend passively by gravity alone without an additional force. This ensured that the flexion force applied to the knee remained constant in all trials. Using a fixed camera, photography of each trial was undertaken. Since the line of the quadriceps muscle, not the femur, was the reference in the biomechanical study, photography was assumed to be more accurate than radiography in identifying the direction of quadriceps. Subsequently, the angle of knee flexion was measured using Mimics software (Materialise, Leuven, Belgium) for each of the 12 pictures. Fig. 2 shows a typical measurement based on the photograph. The anterior border of the thigh was selected to represent the direction of quadriceps tendon and anterior border of the leg represented the direction of tibia. Angle θ, as the supplementary flexion angle, was measured for convenience and the flexion angle α was obtained using the simple equation $\alpha = 180 - \theta$.

Statistical Analysis

The significance of the changes in knee flexion was analyzed using paired T test, with a P value less than 0.05 deemed as significant.

Results

Biomechanical Investigation

For a patellar thickness spectrum ranging from 15 mm to 39 mm, maximal flexion angle changed from 149.6° to 95.9° corresponding to an average flexion loss of 2.16°/mm of increased patellar thickness (Table 1). Interestingly, this change did not follow a linear pattern and in higher thicknesses of patellae, the flexion loss was increasingly

Table 1
Knee Flexion Angle and Flexion–Change Values in Biomechanical Study.

Poly Thickness (Size 26 mm)[a]	Knee Flexion (α)	Flexion Loss/mm Thickness
3	149.65	1.32
6	145.26	1.53
9	140.19	1.78
12	134.24	2.10
15	127.12	2.52
18	119.22	2.48
21	111.26	2.69
24	103.35	2.58
27	95.90	2.41

[a] For conciseness, patellar thicknesses have been presented in 3 mm increments.