Effect of total knee arthroplasty on sagittal and frontal dynamics in osteoarthritis subjects

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Abstract- There is still no consensus about the benefits of a postero-stabilized prosthesis (PS) versus a bicruciate preserving prosthesis (2C) following a total knee arthroplasty (TKA). Whereas clinical outcome parameters could not conclude on each prosthesis advantages, little is known on the knee dynamics using both prostheses. In this work, six TKA candidates walked at self-selected speed, once before the TKA, then one year after. Three had a PS and three had a 2C. Five control subjects were also evaluated. Knee moments in the sagittal and frontal planes were computed. In the frontal plane, external adduction moments generally decreased between pre-op and post-op. In the sagittal plane, external knee flexion moments were strongly reduced for one PS subject and for two 2C subjects between pre-op and post-op evaluations. In the frontal plane, external adduction moments were reduced for two PS subjects and one P2C subject between pre-op and post-op evaluations.

Keywords- Total knee arthroplasty, Knee osteoarthritis, Gait analysis, Inverse dynamics

1 INTRODUCTION

Many factors affect postoperative motion in total knee arthroplasty (TKA): component design, ligament and muscle tension, component alignment, and the change in joint line before and after component implantation [1]. In normal knees, it has been suggested that the so-called screw-home mechanism occurs as a result of the function of active stabilizers, in combination with geometric and ligamentous restraints [2]. Clinical outcome parameters such as the American Knee Society Scores cannot provide a consensus on the benefits of posterior-stabilized (PS) versus bicruciate-preserving (2C) TKA [3]. On the other hand, knee joints dynamics in the sagittal and frontal planes remain unclear between pre and post-operation with respect to normal gait profiles [4], [5]. Dynamic knee adduction moments have been reported to be reduced after TKA using a posterior-stabilized prosthesis. It was found in [6] that peak adduction moment was reduced to 85% of the preoperative level at 6 months but increased to 94% of the preoperative level at 1 year. The authors concluded that the posterior-stabilized TKA reduces knee adduction moment at 6 months, but this effect is lost with time i.e. after one year [6]. The purpose of this study is to test the effect of two types of prosthesis: a posterior-stabilized prosthesis (PS) and a bicruciate-preserving prosthesis (2C), in the progression of the sagittal and frontal patterns of knee joint moment one year after total knee arthroplasty. In this work, the six first subjects of a large-scale study were evaluated before and one year after TKA. Sagittal and frontal knee moment patterns are reported.

2 MATERIAL AND METHODS

2.1 Subjects

Six patients with knee osteoarthritis who underwent TKA and five healthy control subjects participated in this study. TKA patients were separated in two groups: three patients received a posterior-stabilized prosthesis (PS) and three received a bicruciate-preserving prosthesis (2C). Both PS and 2C were Ceraver Osteal total knee replacement prostheses. This study was addressed to any eligible TKA patient being candidate to a prosthesis that preserves both cruciate ligaments. The subjects must present a disabling knee osteoarthritis with failure of the conservative treatment; must be 70 years old or less; have intact cruciate ligaments; present a coronal knee misalignment of 10 degrees or less; have a knee flexion contracture of 10 degrees or less and a minimal flexion of 90 degrees; and surgical exposure of their knee must be sufficient to allow preservation of both cruciate ligaments. The excluding criteria included morbid obesity, and the incapacity to walk on a treadmill or to squat.

Table 1 Subjects' anthropometrics

Group	**Control**						**PS**				**2C**			
Subject	**S1**	**S2**	**S3**	**S4**	**S5**	**Av.** *s.d.*	**PS1**	**PS2**	**PS3**	**Av.** *s.d.*	**2C1**	**2C2**	**2C3**	**Av.** *s.d.*
Sex	M	M	F	M	F	-	F	M	M	-	F	F	F	-
Age (1st eval)	39	66	57	61	60	58.6 *10.6*	56	65	68	63.0 *6.25*	61	55	53	56.3 *4.2*
Weight (kg)	77	54	58	82	61	66.8 *11.1*	99	88	80	89.0 *9.54*	86	94	74	84.6 *10.1*
Height (m)	1.73	1.50	1.66	1.81	1.64	1.67 *0.10*	1.64	1.66	1.66	1.65 *0.01*	1.63	1.60	1.52	1.58 *0.06*
BMI	25.7	24	21.0	25.0	22.7	23.8 *1.7*	36.8	31.9	29.0	32.6 *3.9*	32.4	36.7	32.0	33.7 *2.6*
Side	R	L	L	R	L	-	R	R	R	-	L	L	L	-
Pre-op walk speed (m/s)	1.0	0.4	0.7	0.8	0.8	0.74 *0.22*	0.6	0.8	0.5	0.63 *0.15*	0.8	0.5	0.5	0.60 *0.17*
Post-op walk speed (m/s)	-	-	-	-	-	-	0.4	0.6	0.8	0.60 *0.20*	0.7	0.4	0.3	0.47 *0.21*

The control subjects were age-matched and must not have a history of lower body injuries or pain. The protocol was approved by the Ethics Committee of the École de technologie supérieure, Montréal, and by the Ethics Committee of CHUM Research Centre.

The anthropometric characteristics of the subjects are shown in Table **1**. Before the experiments, all subjects were subjected to a knee examination performed by an orthopaedic surgeon to detect the presence and severity of knee osteoarthritis.

2.2 Methods of experiment

The experiments took place at the Notre-Dame hospital of the Centre Hospitalier de l'Université de Montréal (CHUM). TKA subjects were evaluated just before their operation, and one year after. Control subjects were evaluated once.

Subjects were asked to wear a pair of orthopaedic sandals (Portofino Inc.). Six reflective markers were placed on each foot: on the posterior aspect of the heel, lateral and medial malleoli, navicular bone, and on the 1st and 5th metatarsi. The KneeKG (EMOVI Inc., Laval, Canada) measurement system was used to assess the absolute position and orientation of the tibia and femur. This system consists in three rigid bodies that were fixed quasi-rigidly to the tibia, femur and pelvis, each rigid body featuring three reflective markers.

Three-dimensional position of the reflective markers was measured using twelve T20-S cameras (Vicon Motion Systems Ltd., Oxford, UK) placed all around the subjects, with a sampling rate of 200 Hz. The three forces and moments applied by each foot were measured using two ADAL force platforms mounted under each belt of a split-belt treadmill (Medical Developpement, Andrezieux-Boutheon, France) with a sampling rate of 2 kHz. The force platforms and cameras were synchronized and recorded at the same time using the Vicon Nexus Software.

Subjects were asked to walk at a self-selected speed. Walking speed was first adjusted to 0.15 m/s and increased gradually until the subject felt this corresponded to their natural walk speed. When the subject felt confident walking on the treadmill, a 45 seconds acquisition was performed.

Then, the treadmill was stopped, and the calibration process described in [7] was used to localize the ankle, knee and hip joint centers and to define the reference frames of the foot, tibia and femur relative to the markers.

2.3 Data processing

Kinematic and kinetic data were processed in Matlab (The Mathworks Corp.). Joint placement and axes were defined based on [7]. Flexion and adduction moments at the knee were obtained using a tridimensional inverse dynamics method based on quaternion algebra [8]. Inertial parameters of the lower limbs were estimated from anthropometric data [9].

Gait cycles were extracted from gait trials, based on a vertical ground reaction force (Fz) threshold of 10 % body weight. The 20 most repetitive gait cycles were identified based on Fz. To this effect, we kept the 20 gait cycles that minimized RMS error between Fz on one cycle and Fz averaged on all 20 cycles. For each subject, flexion and adduction moments were averaged on the 20 most repetitive gait cycles.

3 RESULTS

3.1 Walking speed

Walking speed for control, PS and 2C subjects are shown in Table **1**. PS and 2C subjects selected a mean pre-op walking speed of 0.6 m/s, which was noticeably slower than control subjects (0.74 m/s). After operation, all subjects but PS3 decreased their walking speed by an amount of -0.1 to -0.2 m/s.

3.2 Knee moments

Computed flexion and adduction knee moments are shown in Figure **1** and Figure **2**. Control moments are shown as the average ± standard deviation of the control subjects' computed moments.

Figure **1** shows the pre-operation and post-operation moments for PS subjects. We observe that prior to the surgery, PS1 and PS3 had a sagittal moment pattern similar to the control group; PS1 changed from a biphasic moment pattern to a monophasic extension pattern during the stance phase at post-op. PS2 improved his sagittal moment pattern while PS3 kept his pattern similar to the control group. On the other hand, only PS1 had an adduction pattern similar to the control group prior to the surgery; PS1, PS2 and PS3 all had their adduction pattern closer to the control group at post-op.

Figure **2** shows the pre-operation and post-operation moments for 2C subjects. Prior to the surgery, 2C1 and 2C3 had their sagittal moments pattern similar to the control group. However, none had such a pattern after the operation. Moreover, 2C1, 2C2 and 2C3 all had their adductor moment pattern comparable to the control group before the surgery; only 2C1 and 2C2 had such a pattern at post-op.

4 DISCUSSION

Generally in post-operation evaluations, subjects walked with a pattern that prevented internal knee extension moment compared to pre-operation evaluations and control subjects. This was observed by several authors and is hypothesized to be a consequence of quadriceps avoidance, a mechanism to minimize pain due to femoropatellar compression [10]. It is still unclear though why knee extension was avoided only after the operation and not before. More insight would be gained by recording muscle activity using electromyography.

Progression of adduction moments from pre-operation to one-year post-operation agrees with [6]: we observed a reduction of adduction moment in all cases after surgery, independently of the kind of prosthesis.

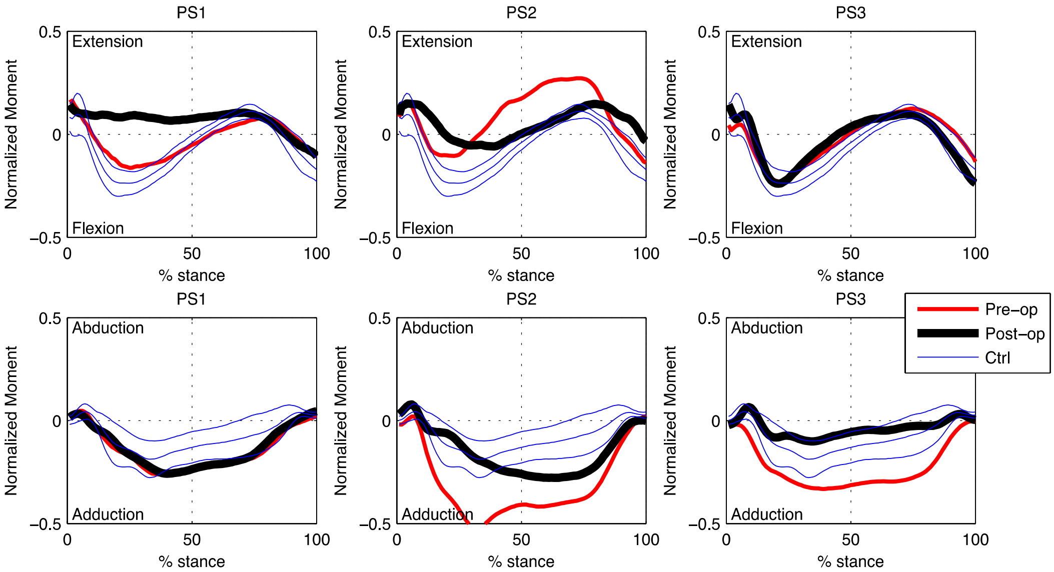

Figure 1. PS subjects' external flexion/extension and adduction/abduction knee moments before and after TKA

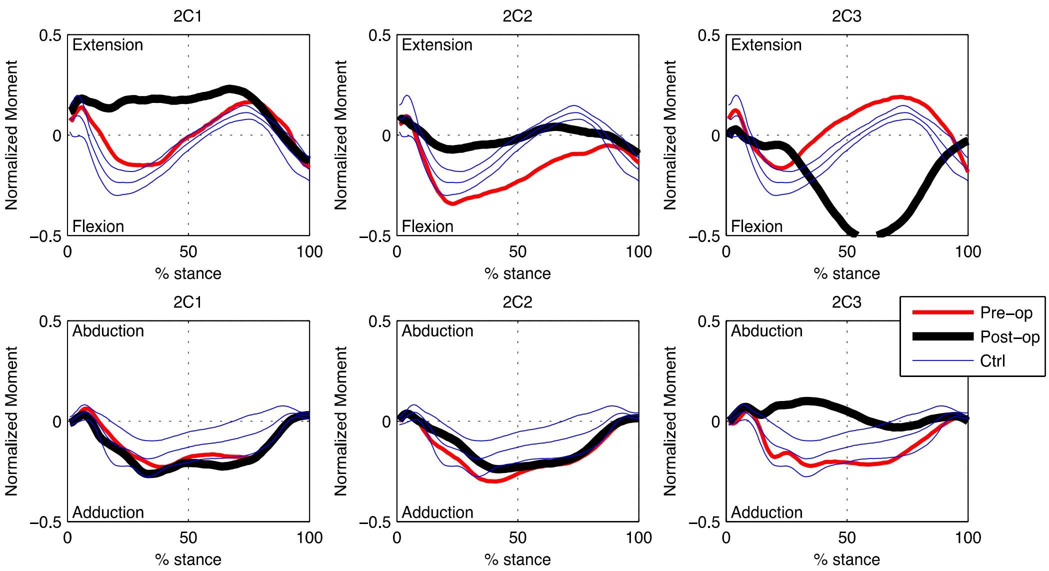

Figure 2. 2C subjects' external flexion/extension and adduction/abduction knee moments before and after TKA

Difference in walking speed between pre-op and post-op evaluations may have contributed to the observed differences in knee dynamics. This is particularly true for 2C3, who shows singular post-operation knee dynamics. During this evaluation, this subject walked at a very low speed of 0.3 m/s. Differences in walking speed between control and TKA subjects may also affect the comparison between normal and TKA knee dynamics. Limitations of this study include the small sample of subjects. This study is still ongoing and more subjects of each class will be available in a near future.

5 ACKNOWLEDGMENT

This work was funded by the Fonds de recherche du Québec - Santé (FRQS) and by the Fonds de recherche du Québec - Nature et technologies (FRQNT). Special thanks go to Thierry Cresson, Michèle Kanhonou, Pierre-Olivier Lemieux, Laurence Marck, Fidaa Al-Shakfa and Lysianne Soucy for their participation in this project.

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