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The Effect of Modern Total Knee Arthroplasty on Muscle Balance at the Knee

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Abstract— **Total Knee Arthroplasty (TKA) may affect the muscles operating at the flexion/extension (FE) or internal /external rotation (IE) axes. This study tested the hypothesis that a modern posterior stabilizing TKA will change the mechanical balance of the knee joint by altering the moment arms of muscles acting about two separate axes of rotation. Moment arms were determined for the normal knee, the knee after resection of the Anterior Cruciate Ligament (the ACL – knee) and the knee after a PCL-sacrificing TKA. Five fresh cadaver hemi pelvis specimens were used with 5 posterior stabilizing prostheses (a single model available from one manufacturer). Moment arms for the individual muscle tendons were multiplied by the muscle's tension fraction (fractional physiological cross-sectional area [PCSA]) to estimate its potential for moment production relative to the other muscles at the knee, and this value was labeled as the muscle's moment potential. Unlike earlier studies that looked at TKA across many manufacturers' types, this study concluded that there were no significant differences in muscle balance when comparing the intact knee and the posterior stabilized TKA.**

I. INTRODUCTION

PAST work in our laboratory identified the generalized effects of TKA on muscle balance, showing a significant change in the moment arms and the relative moment generating potential balance favoring flexion and external rotation relative to the normal (intact) knee (for both PCL sparing and posterior stabilized TKA) [2, 3]. The past work combined prosthesis types (PCL Sparing and Posterior Stabilized) from several manufacturers, making a general statement essentially assuming little or no difference within the two types across all manufacturers. However, there are no reliable data descriptive of the effect of any single prosthesis. This study hypothesized that using a modern TKA (Smith Nephew Journey, a posterior stabilized design) and implantation by a single surgeon in five fresh cadaver specimens would result in a change in balance similar to that exhibited by the posterior stabilized versions in the earlier studies.

II. METHODS

Five fresh hemi pelvis specimens (from 3 female and 2 male cadavers, ages 32, 49 and 84, acquired through the Texas Willed Body Program) were used in this study. Using the tendon excursion-angular motion method, moment arms of all muscles at the knee were determined for each of three conditions (intact, ACL-deficient, and prosthesis). The moment arms (for the knee at a neutral position [0 degrees internal-external (IE) and 30 degrees flexion-extension (FE)]) were then multiplied by the known muscle tension fractions (derived from Freiderich et al [5] and Wickiewicz, et al [7]) to generate each muscle's relative moment potential for each specimen across the three conditions. The resultant summed total moment potential was then examined for differences in flexion-extension and internal-external rotation components.

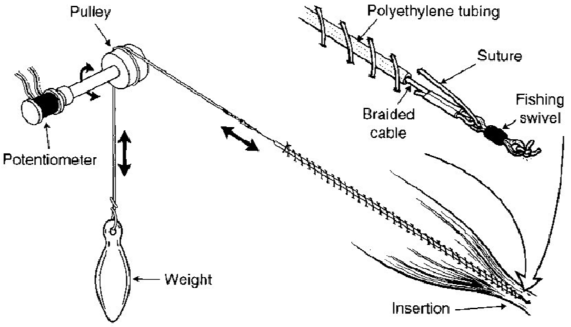

Figure 1. A Diagram showing insertion of the excursion cable into the tendon of insertion central to and just beyond the distal muscle fibers.

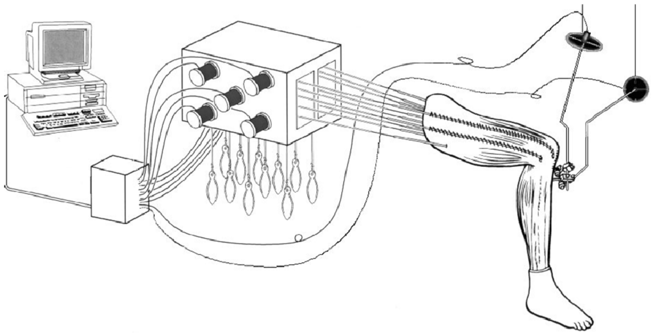

Figure 2. A diagram of the experimental setup with the FE and IE potentiometers, excursion potentiometers, and computer data acquisition system (National Instruments, Labview hardware and Software).

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All specimens were instrumented with sheathed wires attached to 10-turn pulley potentiometers in a manner that allowed for measurement of muscle tendon displacement for all 13 muscles and the patellar tendon in a free line of motion (Figures 1 and 2). Extensive description of specimen preparation and instrumentation is provided by Buford et al. [2, 3]. Two angle potentiometers were prepared according to a procedure similar to the one used by Hollister et al. [6] to allow for measurement of angular rotation about FE and IE axes.

LabView hardware and software (National Instruments, Austin, TX) was used for recording the measurements and displaying real-time data on a computer. The 10-turn precision potentiometers that connected indirectly to the different muscle tendons measured muscle/tendon excursion. Single-turn precision potentiometers measured the angular position at the IE and FE axes. The measurements for angle and excursion were calibrated, and the resultant accuracy was ±2° for angle and ±0.012 cm (0.005 in) for excursion. Proper calibration was checked for every leg before each trial.

For measurements made about the FE axis, the leg was first placed in a reference position at a 90° angle to the femur and was then manually moved to full flexion and then full extension in smooth, sweeping motions. The leg movement and data acquisition, set at a 20 Hz sampling rate, continued for 50 s to allow for at least 20 sweeps. Every leg was tested twice in the same manner. The measurements made about the IE axis were made with the leg beginning at 0° of IE rotation and manually rotated through full internal rotation and then full external rotation. This was performed with the knee at six different FE positions (full extension, 30°, 50°, 70°, 90°, and full flexion). The same experiments about the FE and IE axes were repeated on all the knees after total knee arthroplasty was performed.

The angle and excursion data were used to calculate moment arms according to the tendon displacement calculation method described by An et al. [1], where the moment arm m is equal to the derivative of excursion r with respect to the derivative of angle Θ, or m = dr/dΘ. Moment arms were calculated in this manner for all muscle/tendon units in the normal knee, the ACL – knee, and the prosthesis-replaced knee.

Student's t-test in Microsoft Excel was used to test the null hypothesis of no difference in muscle balance across the conditions of the study (intact knee, ACL – knee and Knee with total arthroplasty).

Note: *In the following sections we define and display the "relative moment potential" for each muscle group. For example, the relative moment potential vector components for the extensor group is the algebraic summation of each of the quads moment arm component times each muscles tension fraction (the ratio of each muscles physiological cross-sectional area (PCSA) to the total PCSA of all muscles at the knee*[5,7]*). Thus the axes in Figures 6 and 7 are not labeled [technically they would be (mm2/mm2) X mm which reduces to mm, but the intent of the Figures is to convey the relative moment potentials so they are left unit-less]. The Resultant in Figure 6 (labeled R in Figure 7) is the algebraic sum of all relative moment potentials and a way of looking at it is to assume that if one could excite all muscles at the knee maximally simultaneously then this is where the lower leg would tend to move with respect to the upper leg.*

III. RESULTS

Average moment arm results for typical flexor-extensor and internal-external muscles are shown in Figures 3 and 4. The average moment arm components for each muscle at a knee neutral position of 30 degrees flexion and 0 degrees IE rotation were calculated for all muscles studied. These are tabulated here (units are mm, extension and external rotation values are arbitrarily assigned a negative sign). The summary moment arm components for the intact knee at this neutral position are depicted in Figure 5.

Flexion - Extension MA at 30

Condition	ST	VI	SM	BFL	VM	Gr	RF	BFS	Sar	GL	VL	GM
Intact	41.81	-16.13	35.51	24.11	-26.52	29.41	-17.39	21.23	17.77	23.26	-22.27	24.93
ACL -	42.16	-18.77	36.02	24.79	-29.24	29.35	-21.95	21.75	17.45	23.35	-25.46	25.38
Journey	42.29	-15.10	35.49	22.77	-24.45	27.36	-19.21	19.34	15.72	22.10	-23.10	25.65

Internal - External MA at neutral

Condition	ST	VI	SM	BFL	VM	Gr	RF	BFS	Sar	GL	VL	GM
Intact	4.19	4.04	9.23	-19.86	1.23	8.71	3.20	-17.18	9.50	0.03	1.33	-1.98
ACL -	4.05	2.35	8.14	-25.00	0.29	7.20	2.02	-22.44	9.72	1.17	1.05	-1.14
Journey	4.28	0.67	6.66	-6.15	-1.41	6.88	1.42	-5.19	9.67	0.89	0.56	-0.37

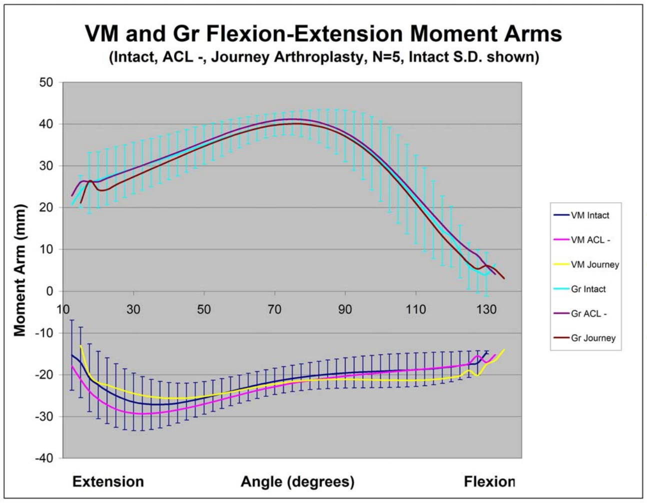

Figure 3. Average Moment arm results of the Vastus Medialis and Gracilis muscle for the 3 conditions of the study. (flexors were arbitrarily assigned a positive sign). The standard deviation for the intact condition is shown. Typically, there were no significant differences in individual muscle FE moment arms over the three conditions of the study.

To simplify the analysis the muscles were combined into three groups (extensors [Rectus Femoris, RF, and the vasti: medialis, VM, intermedius VI, and lateralis, VL], flexor/internal rotators [semi membranosis, SM and tendinosis, ST, gracilis, Gr, sartorious, SAR and Gastrocnemius medialis, GM] and flexor/external rotators [biceps femoris long, BFL and short, BFS and the gastrocnemius lateralis, GL]). A vector summation of the product of each muscles tension fraction times each component moment arm was then created for each of the three principal muscle groups as well a total vector sum. The corresponding relative moment potential balance (the three muscle groups plus the overall vector summation) is depicted in Figure 6 for each condition of the study.

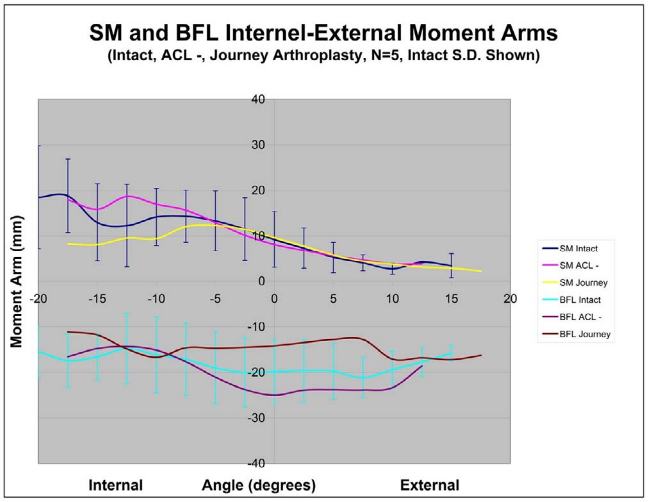

Figure 4. Average Internal-External rotation moment arm results for the Semimembranosis (SM) and Biceps Femoris Long (BFL) muscles for the knee at 30 degrees of flexion (external rotators were arbitrarily assigned negative moment arms). These also did not exhibit significant differences over the study conditions.

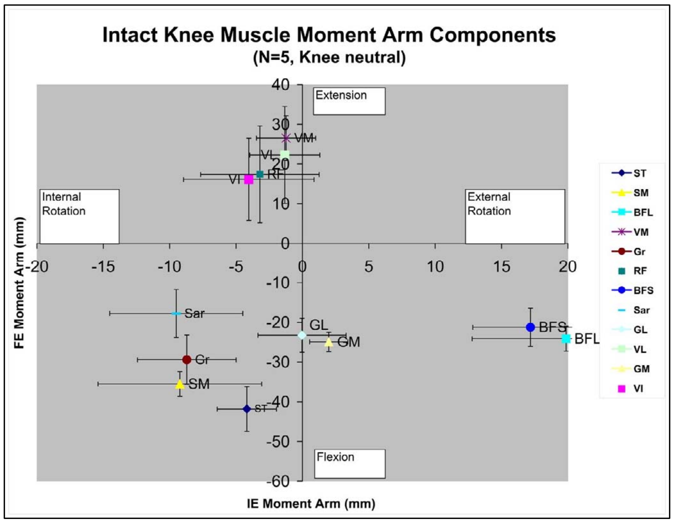

Figure 5. Intact knee average moment arm components for all muscles at the knee with the knee at a representative mid-functional, neutral position. The knee is at 0 degrees IE and 30 degree flexion. Component standard deviations are included.

Testing the null hypothesis at the p = 0.05 level, there were no significant differences in either resultant vector component (FE or IE) for intact versus either the ACL deficient condition (FE, p=0.62, IE, p=0.49) or arthroplasty (FE, p=0.99, IE, p=0.82). Also, TKA agreed more closely with the intact knee than did the ACL deficient condition.

IV. DISCUSSION AND CONCLUSIONS

Thus, we reject the hypothesis that a modern TKA (Journey) performs as projected by past generic results, and conclude that modern TKA effectively reconstructs the balance of the intact knee. This improves prospects for rehabilitation following TKA.

This result is contrary to the results reported in [4] so some discussion is warranted. The results for the intact (normal) knee and the knee with posterior stabilized TKA from the earlier references study are included in Figure 7. That study concluded the resultant vector for TKA was significantly different from the resultant for the intact knee. The sample space in the current study (N=5) was much

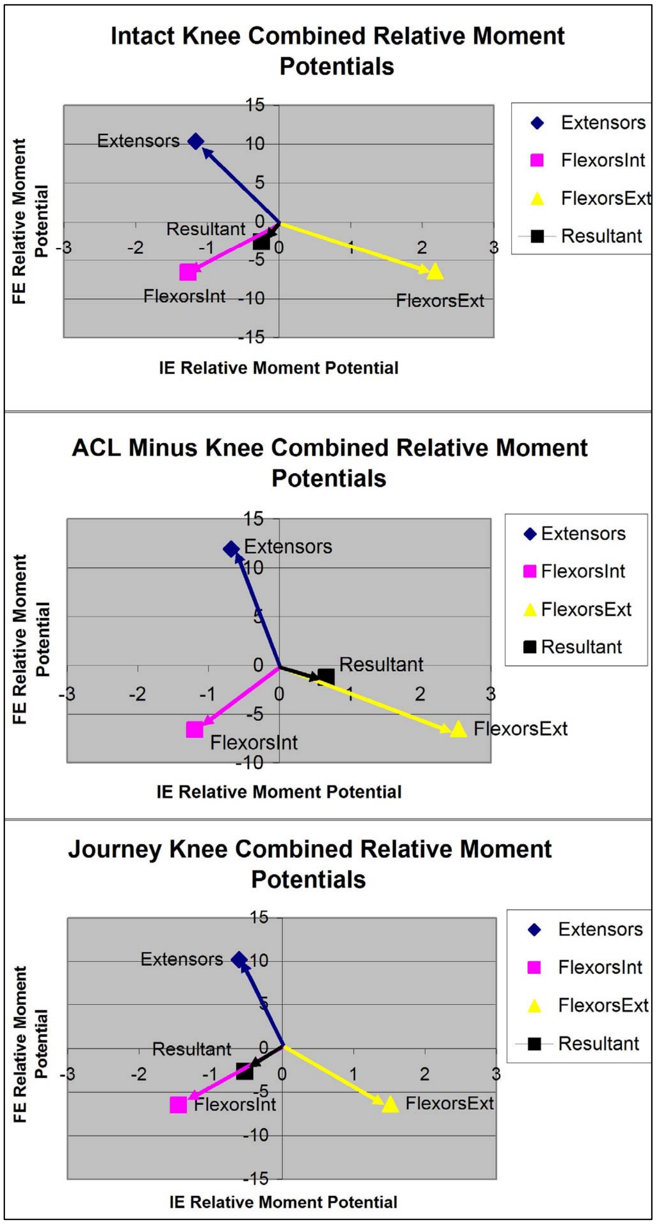

Figure 6. Relative moment potential vector plots for the three muscle groups and the summed total moment potential vector at the knee. Top - Intact Knee, middle - ACL minus knee, bottom - arthroplasty knee.

smaller than that of the earlier study (N=15). The earlier study combined posterior stabilized TKA over numerous manufacturers and models and because no single prosthesis was tested more than twice, no reasonable statement could be made regarding individual prosthesis effects upon muscle balance (this was the reason for combining types across all manufacturers).

The major contributor to the change in balance in the earlier study was the reductions in the extension and internal rotation components for the extensors. The extensors in the current study also had a reduction in the internal rotation component but this was offset by a concomitant reduction in the flexor/external rotators external rotation component. Also, in the current study, neither the extensor nor the flexor components were affected by the TKA.

The major conclusion of the earlier study, that TKA results in significant changes in muscle balance favoring flexion over extension relates to TKA over a large general set of arthroplasties that have been in use for several years and in fact agrees with long held empirical views that rehabilitation therapies should concentrate upon extension strengthening exercises. The result of the current study, which is to our knowledge the first such study to repeat the process with a single TKA model (Smith Nephew Journey) in five hemi pelvis specimens, cannot be compared with clinical experience since the model is so new. Both studies employed the identical method and all arthroplasty procedures were performed by a single experienced surgeon.

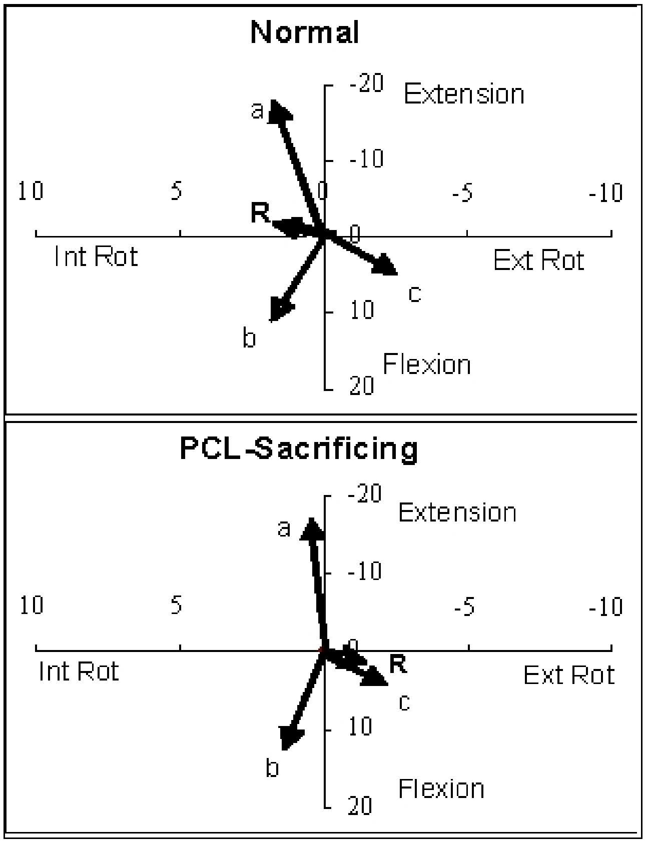

Figure 7. Results from the earlier study (Buford, et al [4]) that determined significant difference between the relative moment potential balance in the normal (intact) knee and the knee with TJA (posterior stabilized, also called PCL-Sacrificing as shown here). In both vector plots, **a** represents the extensors, **b** the flexor/internal rotators, **c** the flexor/external rotators, and **R** the resultant total muscle potential balance.

ACKNOWLEDGMENT

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