Factors Influencing Frontal Plane Kinematics and Kinetics Before and After Total Knee Arthroplasty

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INTRODUCTION

Knee osteoarthritis (OA) is associated with increased varus knee alignment, altered gait kinematics and kinetics, quadriceps weakness, and high muscle co-contraction indices (CCI), all of which negatively affect joint integrity [1-4]. Total knee arthroplasty (TKA) generally improves function and relieves pain associated with severe knee OA. However, even after TKA, more patients have difficulty with daily activities than age-matched controls (52% versus 22%) [5]. Studies have investigated changes in strength, muscle activity, knee alignment and gait before and after TKA, but they primarily studied sagittal plane kinematics or made comparisons to controls [4,6]. To assess potential contributing factors of suboptimal TKA outcomes, it is important to understand how kinematics and kinetics may be affected by CCI, strength, and knee alignment before and after TKA.

The purposes of this study were to investigate: 1) how frontal plane knee kinematics and kinetics during gait are related to CCI, knee flexion and extension strength, and standing knee alignment both before and 6 months after TKA, and 2) if preoperative variables can be used to predict postoperative kinematics or kinetics.

METHODS

19 subjects (21 knees: 4 M / 17 F, age 57.6 ± 7 y, height 1.67 ± 0.9 m, weight 93.8 ± 16 kg, BMI 34.2 ± 5.4 kg/m^2) awaiting TKA provided IRB approved consent to participate in this study. Movement analysis was performed during gait at a self-selected speed approximately 1 month before and 6 months after surgery. Knee flexion and extension strength were estimated by maximum voluntary isometric contraction measured on a Biodex System 3 Dynamometer [Biodex Medical Systems; Shirley, NY]. A modified Point Cluster Technique was used with ten motion capture cameras [MX-F40: Vicon, Oxford UK] at 150 Hz to calculate kinematics [7]. Standing knee varus alignment was extracted from static calibration trials, as similar methods have shown good correlation with radiographic alignment [8]. Ground reaction forces were sampled at 1500 Hz from Bertec 4060-10 force plates [Bertec Corp; Columbus, OH], and lower extremity joint loading was estimated with inverse dynamics. Weight acceptance (WA) was defined as the time period from heel strike to peak knee flexion angle. Peak and mean knee adduction angles and moments (pKAA, mKAA, pKAM, & mKAM) were found over WA for the involved limb.

EMG was collected at 1500 Hz for rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM), semimembranosus (SM), biceps femoris (BF), lateral gastrocnemius (LG) and medial gastrocnemius (MG). EMG was filtered with a zero lag, 4th order, 10 Hz low-pass Butterworth filter and full wave rectified. EMG was normalized to the maximum EMG measured during submaximal reference exercises, as this technique is suggested for use in pathological populations [9]. Trials with poor EMG were removed from further analysis. Average CCI for the involved limb over WA were calculated for total, medial and lateral quadriceps-hamstring (QH, MQH, and LQH), and total, medial and lateral quadriceps-gastrocnemii (QG, MQG, and LQG) co-contractions (Eq. 1) [3].

$$avgCCI = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{lower\ EMG_i}{higher\ EMG_i} \times (lower\ EMG_i + higher\ EMG_i)\right)$$

Equation 1. Average CCI over n samples during WA.

Statistical analysis was completed using Minitab 17 Statistical Software [Minitab Inc., State College, PA]. Depending on the distributions of the variables, paired t-tests or Wilcoxon Rank-Sum tests were used to test for differences between the paired preoperative and postoperative variables. Similarly, Pearson's correlation or Spearman's rank-order coefficients were calculated to estimate the association between selected pairs of independent variables.

RESULTS AND DISCUSSION

Before TKA, increased standing varus alignment was associated with increased preoperative pKAA and mKAA (Table 1). CCI and strength were not related to frontal plane knee kinematics or kinetics.

Six months after TKA, increased LQH, QH and standing varus alignment were associated with increased mKAA (Table 1). Increased LQH and standing varus alignment were also associated with increased pKAA. When standing alignment was used as a covariate, LQH remained significantly related to both mKAA and pKAA ($p \leq 0.025$), but QH was no longer significantly related to mKAA ($p=0.178$). Other CCI and strength were not related to frontal plane knee kinematics or kinetics.

Preoperative variables were not found to predict postoperative kinematics or kinetics. Preoperative standing varus alignment was not significantly related to postoperative pKAA or mKAA ($p \geq 0.453$). All frontal plane knee kinematics and kinetics, QH, LQH, and standing alignment significantly decreased after surgery ($p \leq 0.004$). Other CCI and strength were not significantly different before and after TKA.

CONCLUSIONS

While studies may disagree on whether knee varus alignment and muscle co-contractions are related, our results suggest that both factors may be related to frontal plane knee kinematics after TKA [3,6]. We did not find a relationship between preoperative standing alignment and pKAM, which contrasts previous work that found varus alignment and pKAM are related in subjects with knee OA [10]; this relationship should be further investigated in a TKA population. Regarding the second purpose of this study, significant preoperative variables were not associated to postoperative kinematics. Interestingly, standing alignment was the only variable associated with knee angles both before and after TKA, while 2 CCI parameters emerged after surgery. Since a surgeon corrects preoperative deformity during TKA, our results may suggest an interplay between postoperative limb alignment, CCI, and kinematics that warrants further investigation and could suggest an ability to leverage intraoperative measurement to predict postoperative functional outcomes of TKA.

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Table 1. Significant Correlations to pKAA, mKAA, pKAM, and mKAM Before and After Surgery.

	Sample Size	pKAA		mKAA		pKAM		mKAM	
		coefficient	p-value	coefficient	p-value	coefficient	p-value	coefficient	p-value
Preoperative Variables									
Standing alignment, °	n = 21	0.597**	0.004	0.726†***	0.000	-0.232	0.311	-0.306	0.178
Postoperative Variables									
Standing alignment, °	n = 21	0.679***	0.001	0.792***	0.000	0.217	0.344	0.307	0.176
QH	n = 15	0.466	0.080	0.543*	0.036	-0.101	0.719	-0.042	0.881
LQH	n = 16	0.566**	0.002	0.535*	0.033	0.237	0.376	0.221	0.411

Footnotes: †indicates Spearman correlation. *($p \leq 0.05$) **($p \leq 0.01$) ***($p \leq 0.001$).