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Review

Is gait normal after total knee arthroplasty? Systematic review of the literature

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Abstract

Background. Development or retention of abnormal gait patterns after total knee arthroplasty may be related to the predictable pattern of further deterioration of other lower extremity joints. The purpose of this study was to determine whether gait mechanics are abnormal after total knee arthroplasty by conducting a systematic review of the literature.

Methods. Articles were identified by searching the following electronic databases: PubMed, Cinahl, Web of Science: 221 references were retrieved. The titles and abstracts were reviewed to identify studies that potentially met the inclusion criteria. These articles were retrieved for further assessment. Ten articles met the inclusion criteria and were included in the review.

Results. There was a lack of common variables across the studies. Studies indicated smaller peak knee flexion during weight acceptance and less knee flexion excursion in total knee arthroplasty subjects compared to controls. Knee angle at foot strike was generally similar in arthroplasty groups compared to controls. Maximum external knee flexion moment was generally lower in arthroplasty groups compared to controls. Conflicting results were found for other knee moments. Several other stance phase variables were reported by individual studies only.

Conclusions. Peak knee flexion and knee flexion excursion during weight acceptance are smaller in the operated knee following total knee arthroplasty compared to healthy controls. There may also be a smaller peak knee flexion moment after arthroplasty compared to controls. Knee mechanics in the operated knee are not normal after total knee arthroplasty. Abnormal gait mechanics may predispose the individual to further joint degeneration, particularly in the nonoperated knee. Further research should focus on the effects of unilateral total knee arthroplasty on the non-operated knee.

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Introduction

Patients expect that total knee arthroplasty (TKA) will both decrease or eliminate their knee pain and improve their walking ability.[1] In fact, most patients expect to be able to walk farther than a mile after recovery from surgery.[1] The number of primary TKA surgeries has increased dramatically in recent years, almost tripling between 1990 and 2002.[2] In 2002, there were approximately 381 000 primary TKA surgeries carried out in the United States alone.[2] It is widely recognized that increased loading as a result of obesity leads to joint degeneration.[3] Therefore, these numbers can be expected to increase in future years with aging of the ever-increasing portion of the population who are obese. With such large current increases in the number of older adults with a TKA and likely future increases, optimizing the functional outcome of the surgery and minimizing the risk of further lower extremity joint degeneration are critically important.

It is important to know whether gait is normal after TKA to reduce the risk of further damage and deterioration of lower extremity joints. Normal gait is defined as the walking pattern exhibited by healthy adults who do not have any lower extremity injuries or surgeries and are of a similar age to those with arthroplasty. Functional outcome measures are commonly used after TKA to assess whether patients have returned to normal walking. These measures include questionnaire-based assessments or other simple measures of temporospatial parameters, such as walking speed or time to rise from a chair and begin walking. These types of assessment of TKA patients after surgery consistently show substantial improvement in activities of daily living compared to the patient's status before surgery.[4] However, they only indicate whether a movement can be completed and do not consider the quality of the movements used to achieve the goal. The biomechanics of the walking pattern used to achieve these actions are important because abnormal patterns may predispose the individual to further lower extremity joint damage and degeneration. In fact, nonrandom progression of end-stage osteoarthritis has been documented after primary unilateral TKA, with the nonoperated limb more likely to show progression of osteoarthritis than the operated limb.[5] This progression of lower extremity joint degeneration highlights the importance of the biomechanics of the operated knee after arthroplasty. Using a systematic review of the literature to identify the key abnormalities in gait after arthroplasty is an important first step in developing targeted intervention strategies to reduce further lower extremity joint damage and deterioration.

It should also be noted that the total knee prosthesis is designed for use under normal gait conditions. Abnormal gait patterns after TKA may accelerate damage to and deterioration of the prosthesis itself and increase the likelihood of revision surgery in the future.

The purpose of this study was to determine whether the mechanics of gait are abnormal after primary TKA by conducting a systematic review of the published literature. The objective of the systematic review was to combine the results of multiple studies to enable a consensus to be established regarding study conclusions by providing an alternative statistical analysis of the available data. Additionally, specific areas for further research were highlighted.

Materials and methods

The following electronic databases were searched for articles to include in the review: PubMed, Cinahl, and Web of Science. The following search terms were used in combination: total knee replacement, total knee arthroplasty, biomechanics, kinematics, kinetics, force, angle, moment, power, velocity, acceleration, stride, walk, gait, ambulation (Table 1). Only references in the English language were included. A total of 221 references were retrieved.

Table 1. Example of search strategy used

Search no.	Strategy
1	Total knee replace*
2	Total knee arthoplast*
3	1 or 2
4	Biomechanic*
5	Kinematic*
6	Kinetic*
7	Force*
8	Angle*
9	Moment*
10	Power*
11	Velocit*
12	Acceleration*
13	Stride
14	4 or 5 or . . . or 12 or 13
15	Walk*
16	Gait
17	Ambulat*
18	15 or 16 or 17
19	3 and 14 and 18

Study inclusion

The titles and abstracts were reviewed to determine whether the study potentially met the following five inclusion criteria: (1) TKA patients had to be at least 4 months postoperative to reduce the effects of surgery and healing on gait. (2) Subjects must not be using assistive devices as they would have a large influence on gait. (3) An age-matched control group was used as the comparator as gait changes with age. (4) Osteoarthritis data were presented separately from those of subjects with rheumatoid arthritis (if any) because rheumatoid arthritis is a systemic, not loading-related, disease. (5) Stance phase variables were included in the analysis because gait mechanics when the limb is loaded are likely important in terms of joint deterioration. If the article appeared to meet the inclusion criteria or if it was unclear whether the study met the inclusion criteria from the title and abstract, it was retrieved and assessed against the inclusion criteria. Initially, 40 articles were retrieved for further assessment. On further assessment, 10 articles were found to meet the inclusion criteria and were included in the review.

Statistical methods

Because of the differences in the specific variables collected between the studies reviewed, only a limited statistical comparison of the data was possible. Where mean and standard deviation values for the total knee arthroplasty and control groups were provided, they were used to calculate an effect size for the difference between groups for each stance phase variable. Cohen's effect size is a statistical procedure used to determine whether a difference between groups was meaningful.[6] Its advantage for use in systematic reviews is that it is not directly affected by sample size. Individual studies often have a small sample size, which may result in low statistical power to detect clinically meaningful differences between groups, a type two error. Effect size helps to overcome this limitation, although it is acknowledged that the small samples may not be fully representative of the TKA population with osteoarthritis as a whole, this is a limitation that cannot be overcome. Directly pooling values for common variables that were calculated in several studies was avoided as differences in the data-processing models used may increase the variability in the pooled groups, masking potential differences. The relative comparison made between TKA and control groups in a study using effect size avoids this problem.

Effect size is the difference between two means divided by the pooled standard deviation. The effect size is interpreted as being small ($0.2 \le ES < 0.5$), moderate ($0.5 \le ES < 0.8$), or large ($ES \ge 0.8$).[6] A moderate or greater effect size is considered meaningful in clinical studies.

$$ES = \frac{mean_1 - mean_2}{(SD_1 - SD_2)/2}$$

To facilitate comparison of joint moments between studies, reported values were recorded as external moments and converted to "% body weight × height" normalization where possible. For example, a reported internal knee flexion moment is equivalent to an external knee extension moment of the same magnitude. Data normalized to body mass were further divided by "gravity × height" and multiplied by 100% to achieve "% body weight × height" normalization. Group mean height was used in this calculation.

Results

Of 221 studies identified initially, 10 were included in the review (Table 2). In terms of the comparison of interest in this review between TKA patients and healthy controls, all 10 studies were case-control studies, which is a III level of evidence. Comparisons between aspects of surgery were not the focus of this review. Of these studies, two included multiple follow-up visits,[7,8] with the remaining eight being cross-sectional studies with data collected at a single time point only. Two studies were limited to female subjects,[7,9] whereas the other eight studies included both male and female participants. The number of subjects per group ranged from 7[10] (arthroplasty subjects without rheumatoid arthritis) to 38[11] (arthroplasty group), with an average across all arthroplasty and control groups of 17. Three of the ten studies included two subgroups of TKA subjects (short and longer follow-up periods[7]; posterior cruciate ligament retaining or stabilizing[12]; patella resurfacing and nonresurfacing[13]). It should be noted that the two studies by Smith et al.[13,14] appear to report on the same TKA and control patients, focusing on anterior knee pain in one report[14] and patellar resurfacing in the

Table 2. Outline of studies included in the review

Study and groups	No. of subjects	F/U (months)	Velocity (m/s)	Stance variables
Benedetti[8]				
TKA	9 (6F)	6, 12, 24	0.85, 0.97, 0.96	K angles, moments
Controls	10 (4F)		1.22	
Brugioni[10]				
TKA	7 (4F)	18	~1.0	K moments
Controls	15 (9F)		~1.0	
Ishii[12]				
TKA	20 (10F)	18	Free	K angles
Controls	10 (?F)			
Lee[9]				
TKA	20 (20F)	12	0.97	GRF regression
Controls	35 (35F)		1.13	
Otsuki[7]				
TKA	16 (16F)	6, 12, 58	Free, barefoot	Average vGRF
Controls	14 (11F)		Free, barefoot	
Saari[11]				
TKA	38 (24F)	12–24	1.0	Median K moments
Controls	18 (9F)		1.2	
Simon[15]				
TKA	12 (7F)	39	1.05	K, H angle, K moment
Controls	15 (8F)		1.14	
Smith[14]				
TKA	34 (?F)	12–18	1.05	K angles, moments
Controls	20 (?F)		1.08	
Smith[13]				
TKA	41 (19F)	12–18	1.06	K angles, moments
Controls	20 (10F)		1.07	
Wilson[16]				
TKA	16 (10F)	46	1.07	K angles
Controls	16 (13F)		1.11	

F, female; F/U, follow-up; TKA, total knee arthroplasty; K, knee; H, hip; vGRF, vertical ground reaction force other.[13] Across studies, follow-up periods ranged from 6[7,8] to 58[7] months. Two studies provided repeated measures over time: Otsuki et al.[7] at 6, 12, and 58 months after surgery; and Benedetti et al.[8] at 6, 12, and 24 months after surgery. The number of TKA subjects per group ranged from 9[12] to 38.[11] Walking was at a self-selected speed in nine studies, with only Brugioni et al.[10] choosing a different method; they chose to process the trials closest to 1.0 m/s. Most studies found no significant difference in walking velocity between arthroplasty and control groups,[11,13–16] and others implied it[12] or reported no difference in stance time rather than velocity[7]. Lee et al.[9] and Benedetti et al.[8] reported slower walking in their arthroplasty group than in the control group. Due to variation in the variables reported, specific knee kinematics and kinetics variables were reported in no more than 6 of the 10 studies; no variables were common across all 10 studies included in this review.

Knee kinematics

Knee kinematics were determined in six studies.[8,12–16] Peak knee flexion during weight acceptance was reported in all six studies (Fig. 1). Reported values for peak knee flexion in TKA subjects ranged from 9.8°[12] to 16.0°,[13,15] with the corresponding figures for control subjects being 16.0°[15] to 19.7°.[8] Absolute differences of 0°[15] to 9.3°[8] in peak knee flexion between TKA subjects and controls were reported. Although only one study reported a significant difference in peak knee flexion between the groups,[16] effect sizes were either moderate or large (range 0.50–1.46) in the five studies for which they could be calculated.[8,12–14,16] Five of six studies indicated decreased peak knee flexion during weight acceptance in TKA subjects compared to controls, with the sixth[15] indicating no difference.

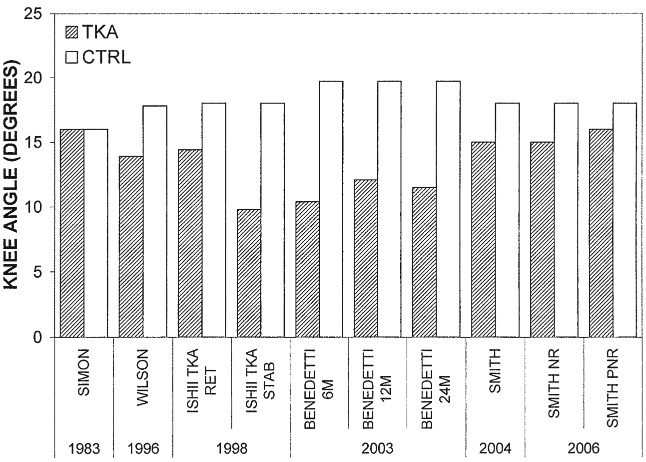

Fig. 1. Peak knee flexion during weight acceptance in total knee arthroplasty (*TKA*) and control (*CTRL*) groups across studies

Knee angle at foot strike was reported in five studies,[8,13–16] ranging from 2.3°[8] to 10°[13] in the TKA groups, and 0°[15] to 7°[13,14] in the controls (Fig. 2). Within studies, effect sizes from no effect (0) to a large effect (0.75) were found. Of six comparisons in three studies,[8,13,14] little or no effect was indicated in five, and none was reported to be significantly different.

Knee flexion excursion (range of knee flexion motion from foot strike to peak knee flexion during weight acceptance) was reported or calculated from foot strike and peak angle data in five studies.[8,13–16] In all cases, knee excursion was lower in the TKA group compared to controls, with absolute differences ranging from 3.0° to 11.2° (Fig. 3). Several studies reported these differences to be significant.[13,14,16] Furthermore, the effect size of the difference was large (0.86–1.67) in all three cases. Smith et al.[13,14] and Benedetti et al.[8] also reported

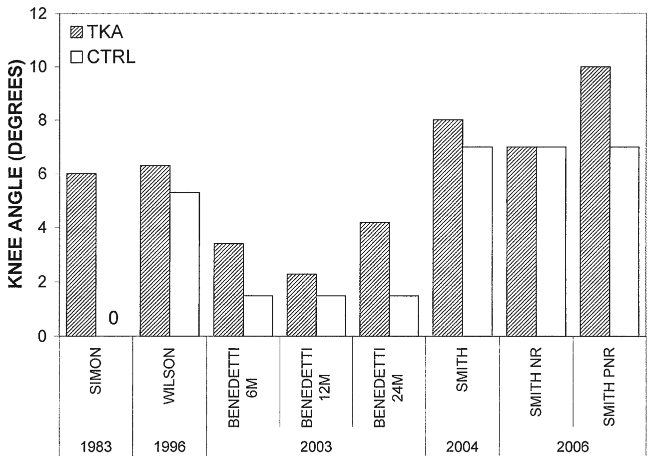

Fig. 2. Knee flexion angle at footstrike in TKA and control groups across studies

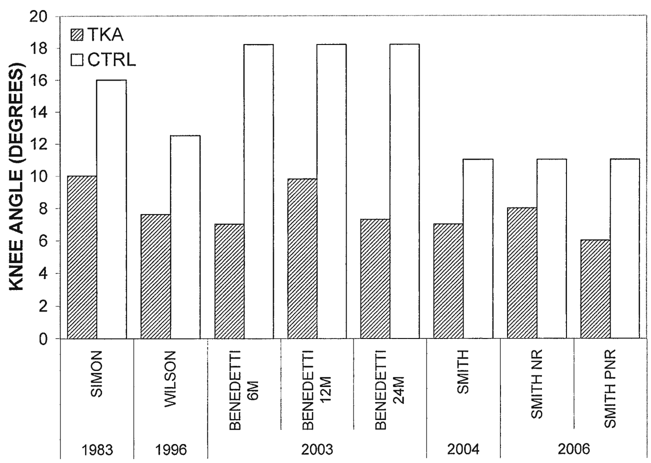

Fig. 3. Knee flexion excursion from footstrike to peak knee flexion during weight acceptance in TKA and control groups across studies

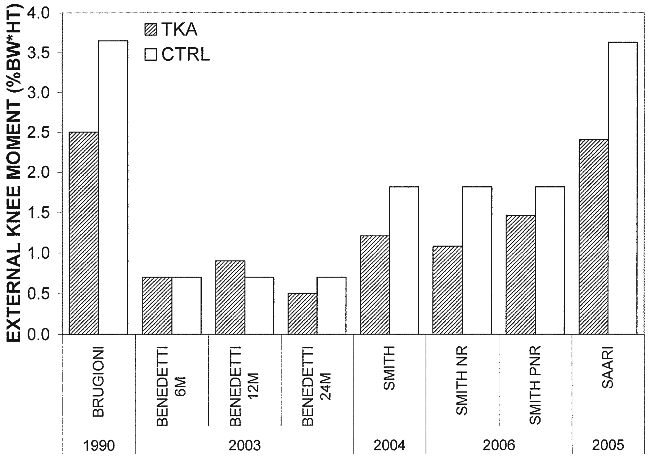

Fig. 4. Peak external knee flexion moment during stance in TKA and control groups across studies. *BW*, body weight; *HT*, height

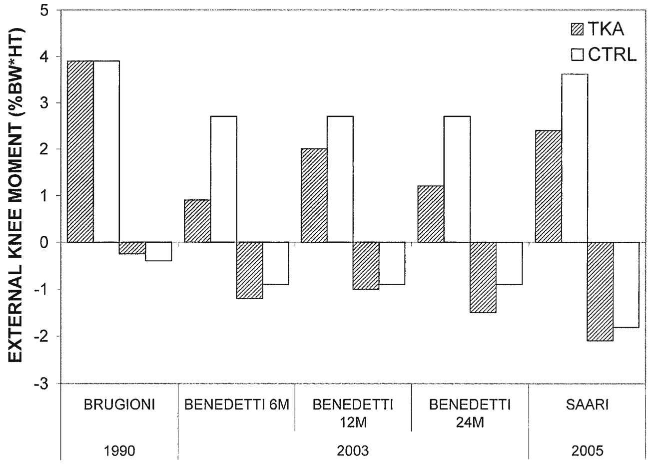

Fig. 5. Peak external frontal plane knee moments during stance in TKA and control groups across studies. Adduction moments are positive; abduction moments are negative

minimum knee flexion angle during late stance. No significant differences were found between the TKA and control groups. In addition, effect size calculations indicated either no effect or a small effect.

Knee kinetics

Peak external knee moments were also reported in five studies.[10,11,13–15] Maximum external knee flexion moment was generally lower in the TKA groups compared to controls in all studies (Fig. 4). The difference was found to be significant by Saari et al.[11] and Smith et al.[14]. Across studies, effect sizes ranged from no effect (0)[8] to a large effect (1.01).[13] Conflicting results were found across the studies regarding peak knee extension moment in terminal stance. Smith et al.[14] and Saari et al.[11] reported small, nonsignificant increases in extension moment in the TKA group (moderate effect 0.52),[14] whereas Benedetti et al.[8] reported 50% smaller values in the TKA group, which was significantly different and a large effect (1.78).

Frontal plane knee moments were reported by three groups[8,10,11] (Fig. 5). Benedetti et al.[8] found significantly lower adduction moments and higher abduction moment in the TKA group. The direction of these differences was supported by Saari et al.,[11] although the differences were not significant in this study. There were also no significant differences between the TKA and control groups in the study by Brugioni et al.[10]

Other stance phase variables

Several stance phase variables were included only in individual studies: ankle and hip angles[15] and hip moment[11] data were provided by single studies, and different aspects of ground reaction force data were provided by two studies.[7,9] Smith et al.[13] was the only study to report knee flexion velocity during weight acceptance and during terminal stance. Since these data were reported in only one study, a consensus cannot be drawn for these individual variables, and they are not discussed further.

Discussion

Knee kinematics

The aim of this study was to determine whether gait mechanics are abnormal after TKA. Evidence from multiple studies included in this review indicates that peak knee flexion during weight acceptance and knee flexion excursion are less in the operated knee after TKA than in healthy controls of a similar age. The lower knee flexion after TKA was found in five studies, which used different prostheses in different subject groups with different rehabilitation protocols in different countries. This common difference between TKA and control groups across a wide geographical and prosthetic range is a key feature of gait after TKA. Given that a typical goal of rehabilitation after TKA is to achieve at least 90 of knee flexion, the small range of flexion required during walking is well within the capacity of all implant types.

Reduced knee flexion may be a consequence of a quadriceps avoidance gait, which is common in individuals with knee pain. Quadriceps avoidance gait, characterized by reduced knee flexion, may develop as a mechanism to minimize pain in the affected knee prior to TKA. This habit may be retained after surgery even though the pain has been resolved. The longitudinal pre- and postsurgery data presented by Smith et al.[14] indicated that presurgery gait patterns were retained up to 18 months after surgery. Therefore, just because individuals are no longer suffering from pain at the knee and have the ability to move through a sufficient range of motion, it does not necessarily follow that they will spontaneously modify their gait to a more normal pattern. Given the recent report of statistically predictable deterioration of joints in the nonoperated limb following a primary unilateral TKA,[5] retention or development of an abnormal gait pattern following TKA may have important consequences over time.

The knee flexion angle at foot strike is similar to that in healthy controls after TKA. Therefore, the lower knee flexion excursion found across TKA groups when compared to matched controls is a consequence of the lower peak knee flexion angle during weight acceptance.

Knee kinetics

Differences between TKA and control groups were conflicting regarding the peak external knee flexion moment, ranging from being similar to that in the control group to significantly lower, with a large effect. Most studies have indicated a lower knee flexion angle in the TKA group. Therefore, it is also likely that the peak external knee flexion moment is smaller after TKA compared to that in controls. Although a smaller moment may seem counterintuitive in terms of abnormal gait after TKA, it can be explained by the lack of knee flexion observed in the kinematic comparison. Maintaining a more extended knee reduces the eccentric load on the quadriceps by reducing the magnitude of the external knee flexion moment. This is the key to the aforementioned quadriceps avoidance strategy. Reducing the amount of quadriceps force required to oppose the external knee flexion moment results in less joint compression due to quadriceps activity. Additionally, a more extended knee position reduces the component of the quadriceps force vector that contributes to patellofemoral joint compression. However, because the knee joint pain is resolved after arthroplasty, it is unclear why this gait pattern is retained.

Subjects walked at their freely chosen self-selected speed in most of the studies. Therefore, the gait analyzed was likely to represent the typical walking pattern of the subjects. It is noteworthy that most of the arthroplasty subjects walked at a velocity similar to that of the control group. However, arthroplasty subjects walked significantly slower than controls in two studies. Although large differences in walking velocity may influence gait biomechanics, it is important to collect data representative of the typical gait pattern of the subjects. Therefore, it was appropriate to collect biomechanical data while subjects walked at their self-selected speed.

The studies reviewed focused primarily on the operated knee; therefore, the wider effects of these abnormal knee mechanics are presently unknown. Given that the lower extremity is a linked chain, reduced knee flexion excursion during weight acceptance, which contributes to shock attenuation in the limb, may lead to compensatory effects at the hip or ankle joint. Furthermore, because gait is a reciprocal activity, defects in the operated side may be compensated for by the nonoperated side to maintain an adequate rate of forward progression. These secondary effects become of special concern given the predictable deterioration of the nonoperated side following TKA, as reported by Shakoor et al.[5] A consequence of the restricted knee mechanics that remain after TKA may be that the nonoperated side is subject to biomechanical factors that increase the rate of degeneration of the major weight-bearing joints, leading eventually to additional joint replacement surgery. No further comment can be made on either the effects of the nonoperated limb on operated limb biomechanics or the effects of the operated limb on the nonoperated limb because all but one of the studies reviewed reported only the biomechanics of the operated limb. Three studies reported that the nonoperated limb was asymptomatic at the time of data collection,[8,9,16] and one reported that the biomechanics of the operated and nonoperated limbs were similar.[15]

Future work in the area of walking mechanics after TKA should expand its focus to include the hip and the ankle as well as the nonoperated side to shed some light on the effects of a unilateral TKA on the entire lower extremity chain and the contralateral limb. The screwhome mechanism of the knee is also an important component of normal biomechanics and should be evaluated in the TKA population. More longitudinal studies that follow subjects from their preoperative status until full recovery from surgery would confirm whether the preoperative gait is being retained after joint replacement. It would also be worthwhile establishing whether the abnormal gait pattern can be modified to become more like that of a healthy older adult via specific gait-retraining interventions. This would be particularly important if deleterious effects of the primary TKA are found in the nonoperated limb, given the increased risk of deterioration in the nonoperated limb reported by Shakoor et al.[5]

Conclusion

Peak knee flexion and knee flexion excursion during weight acceptance are less in the operated knee following TKA than in healthy age-matched controls. There may also be a smaller peak knee flexion moment after TKA compared to that in controls. There is a dearth of information about the mechanics of the other lower extremity joints and of the nonoperated limb after TKA. A wider consideration of the biomechanical effects of TKA on the locomotor system could provide insight into the cause of the predictable deterioration of the nonoperated limb following unilateral TKA.

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