ACL Damage and Deficiency is Associated with More Severe Preoperative Deformity, Lower Range of Motion at the Time of TKA

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Abstract *Background:* ACL status varies in the arthritic knee during TKA. *Questions/Purposes:* The purpose of this study was to examine clinical features and intraoperative findings associated with stages of ACL degeneration. *Methods:* Coronal deformity, ROM, intra-articular degenerative patterns, and ligament releases were assessed for 1656 knees during TKA. Common patterns of deformity and severity of degenerative change were assessed as a function of the severity of ACL deficiency. *Results:* Of the 1656 knees assessed, 27% had a normal ACL, 55% exhibited damage, and 18% exhibited complete absence of the ACL. Increased coronal deformity and lower preoperative ROM was associated with ACL deficiency. Increased chondral and meniscal damage and more extensive osteophyte formation were also found. More extensive ligament releases were required in ACL-deficient knees. *Conclusions:* The status of the ACL is predictive of the need for increased surgical deformity correction. A better understanding of ACL status

is an important consideration during in choosing TKA as opposed to unicompartmental arthroplasty. The status of the ACL should be considered in planning for implant choice in TKA.

Keywords anterior cruciate ligament (ACL) · range of motion · TKA · ligament balancing · kinematic alignment

Introduction

The status of the ACL associated with end-stage degenerative joint disease presenting for TKA varies [2–6, 8–10, 19–21]. Complete ACL deficiency in the end-stage degenerative knee has been reported to be between 12 and 39% [3, 6, 8, 9, 20]. Multiple authors have also reported degenerative changes being more severe with typically multiple compartment involvement of the knee with ACL deficiency [5, 8, 10]. It is not known whether ACL deficiency is the cause of this more extensive degenerative change in the knee or if attritional ACL degeneration is part of end-stage osteoarthritis.

Knowing the status of the ACL in the degenerative knee is important as one of the indications of candidacy for partial knee replacement [4, 9, 22]. The intact ACL is part of the important four bar linkage involving the collateral and cruciate ligaments directing knee kinematics. In spite of the development of osteoarthritis in the knee, the role of the ACL in guiding knee kinematics is often maintained [22].

It has been suggested that various degrees of preoperative ACL deficiency may precipitate certain degenerative patterns adversely affecting knee kinematics [4, 7–10]. Previous studies have observed that tibial wear defects associated with osteoarthritis are most often confined to the anterior portion of the medial tibial plateau in knees with intact ACLs as observed on the lateral x-ray [21] or MRI [5, 21].

Level of Evidence Therapeutic Study Level IV

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To further highlight differences between knees with an intact and deficient ACL, we sought to investigate the association between progressive ACL degeneration and the clinical presentation for TKA. We found no prior studies that determined correlations between degree of preoperative ACL status and clinical deformity. We hypothesized that as ACL integrity deteriorates and as intra-articular degenerative changes progress, intraoperative degenerative patterns will become more severe, which may be associated with a different clinical presentation, and unique surgical correction needs. The purpose of this study was to compare the differences in clinically and radiographic deformities of knees presenting for TKA with intact or deficient ACL. We also assessed differences in pre-operative range of motion as well as the complexity of the ligament releases performed during the TKA.

Patients and Methods

The data from this retrospective analysis was obtained from our longstanding institutional database. Between February 5th, 2002 through December 30th, 2012, a total of 1656 TKAs were performed at our center utilizing the Biomet Vanguard series TKA (Biomet, Warsaw, IN). Implant articular designs included, cruciate-retaining (CR, Modular) (471 knees, 28%), posterior stabilized (PS, Modular) (789 knees, 48%), and monolock cruciate-retaining (non-modular) (396 knees, 24%). Implant selection was based on surgeon selection and not on deformity or ACL status. Patient demographics included a mean patient age of 66.7 years, mean body mass index (BMI) of 32.6, and mean length of follow-up of 4.3 years. Osteoarthritis was the primary indication for surgery (1649, 99.6%), with osteonecrosis (3, 0.2%) and rheumatoid arthritis (3, 0.2%) also present in this study cohort. Of the 1656 knees assessed, 443 (26.8%) exhibited a normal ACL (class 0), 917 (55.5%) exhibited some loss of ligamentous integrity with damaged fibers (class 1 and 2), and 291 (17.6%) were completely ACL deficient (class 3). Five cases had missing ACL assessments and were excluded from the study. Knee society scores were recorded preoperatively (Table 4). Patient age was similar between the groups but BMI was larger in the ACL deficient patients (Table 1).

Preoperative x-rays were made on all patients in a standard format. Standing A/P, supine lateral, and sunrise radiographs were obtained. Coronal alignment was measured with a goniometer either manually for standard x-rays or with a digital goniometer when our system transitioned to a digital format during the study. Radiographic measurements were performed by the operating surgeon or their assistant using a standard protocol [1]. Magnetic resonance imaging or other methodologies to assess the ACL status were not performed. ACL assessment was done purely based on intraoperative observation. Multiple measurements were not obtained for each visit but patients had follow-up visits every 2 years. Range of motion was assessed in a seated

position with a manual goniometer and using a standardized technique throughout the study period [11, 12, 14, 16–18]. Tibio-femoral varus alignment is reflected with negative numbers and valgus with positive numbers. This has been consistent in the database at our center for many years [14–20].

The quality of the ACL at the time of surgery was classified by the operative surgeon after arthrotomy and recorded at the time of TKA as follows: *class 0*—normal, *class 1*—present but lax, *class 2*—non-functioning band, or *class 3*—absent. The criteria for class 0 included a normal ACL with an intact ligamentum synovial layer and intact fibers. Class 1 had disruption in the synovial layer and damage to the ACL fibers resulting in some anterior ligamentous laxity. Class 2 ACLs were those with a non-functioning band as evidence by damage to greater than 50% of the fibers and limited functional integrity. For class 3, no intact ACL fibers present.

For the statistical analysis, groups 1 and 2 were combined into one cohort of “damaged” as the differences between these cohorts is subjective, leaving three groups for comparison including normal, damaged and absent. The compartment surface chondromalacia, meniscal degeneration, and osteophyte formation was graded on a similar scale for the medial, lateral, and patellofemoral compartments. Normal cartilage (grade 0) was smooth without chondromalacia. Grade 3 had eburnated bone. 1–2 mm osteophytes were categorized as grade 1, 3–4 mm grade 2, and larger than 5 mm impinging on soft tissues and ligaments was grade 3. Each structure was assessed a separate grade at the time of surgery and recorded on an optical Scantron form [19]. Reproducibility measures were not made in this study; however, all six surgeons utilized the same data collection system.

Data was analyzed by one-way ANOVA, with *p* values given by the least squares means test (based on the method of maximum likelihood) in lieu of the post hoc tests of Tukey, LSD, Bonferroni, Scheffe, Dunnett, etc. due to the unbalanced counts occurring among the various levels of preoperative ACL condition. Significance level was set at $p < 0.05$, and all data was analyzed by SAS 9.2 (Cary, NC).

Results

There was an observed increase in coronal varus alignment in knees with an absent ACL. (Table 2) BMI was higher in patients with an absent ACL. (Table 1) The average preoperative range of motion was less when the ACL was absent versus the normal ACL cohort (96° vs. 108° , $p < 0.0001$) (Table 4). Knees with an absent ACL were noted to have increased chondral damage, meniscal degeneration, and osteophyte formation in the medial compartment ($p < 0.001$) (Table 3). Preoperative knee scores were lower in knees with an absent ACL ($p < 0.0001$). A higher percentage of knees required medial release 41 vs. 25% when the ACL was absent versus normal. Additionally, posterior osteophyte and capsular release was needed in 7% of knees with an absent vs. normal ACL.

Table 1 Demographics and alignment

	Class 0		Class 1 and 2		Class 3			Overall	
	Avg (Std)	Range or %	Avg (Std)	Range	Avg (Std)	Range or %	P value	Avg (Std)	Range
Age	67.2 (± 9.0)	[39, 89]	66.3 (± 9.1)	[41, 92]	67.2 (± 9.6)	[39, 87]	$p = 0.1850$	66.7 (± 9.2)	[39, 92]
BMI	31.8 (± 5.1)	[18.3, 47.3]	33.4 (± 6.6)	[18.9, 56.2]	34.3 (± 6.9)	[19.5, 53.0]	$p = 0.0001$	33.2 (± 6.5)	[18.3, 56.2]
Gender F	$n = 283$	28.3%	$n = 563$	56.4%	$n = 150$	15.0%	$p = 0.0007$	$n = 996$	60.1%
Gender M	$n = 160$	24.4%	$n = 353$	53.8%	$n = 141$	21.5%		$n = 654$	39.5%
Overall pre-op alignment	0.7 (± 7.9)	[-14, 25]	-0.3 (± 8.7)	[-15, 25]	0.9 (± 12.3)	[-30, 28]	$p = 0.6725$	0.4 (± 9.6)	[-14, 25]
Pre-op varus	-2.2 (± 3.6)	[-14, 0]	-3.3 (± 4.1)	[-15, 0]	-4.2 (± 6.1)	[-30, 0]	$p = 0.0396$	-3.3 (± 4.6)	[-30, 0]
Pre-op valgus	2.9 (± 6.1)	[0, 25]	3 (± 6.2)	[0, 25]	5.1 (± 8.3)	[0, 28]	$p = 0.2086$	3.7 (± 6.9)	[0, 28]
Follow-up (years)	4.4	[2.0, 9.4]	4.3	[2.0, 9.0]	4.2	[2.0, 8.3]	$p = 0.0279$	4.3	[2.0, 9.4]

Discussion

We sought to investigate the association between progressive ACL degeneration and clinical presentation for TKA. We also investigated the surgical correction requirements during TKA based on ACL status. We found no prior studies that determined correlations between degree of preoperative ACL status and clinical deformity. The clinical presentation was different in knees with no ACL. There was an increase in flexion contracture and lower total flexion. Knee society scores were lower and there was more difficulty with stair climbing in our series (Table 4).

There are several limitations inherent in this retrospective study. The intraoperative scoring systems are subjective and slightly variable for intermediate grades. No intraobserver or interobserver variability analysis was performed. Anatomic axis analysis is not as applicable as an analysis of pre-op deformity using mechanical axis deviation using standing full length X-rays. Greater deformity and flexion contracture requires greater soft tissue releases, and these cannot be entirely explained by ACL deficiency and may merely be an association observed in this series. We did not control for other confounding factors that contribute to coronal plane deformity and flexion contracture. We did not control for other potential contributors to coronal plane deformity or flexion contracture. In addition, we did not grade the severity of osteoarthritis using for example a Kellgren-Lawrence scale. It is assumed all knees were bone on bone and had failed non-surgical treatments leading to TKA. Furthermore, many knees with an intact ACL were treated with partial knee replacement, which selects out many knees that would perhaps

be treated with a TKA at other centers. While we observed some interesting associations, we cannot comment on a causative relationship due to the retrospective nature of the study. Further, without post-op follow-up data the significance of this findings cannot be determined as of yet.

Douglas, et al. found no difference in a variety of preoperative scores (ACLQoL, SF12, IKDS, OKS) in knees with an intact and those with an absent ACL [3]. We found that there was less coronal plane deformity when the ACL was intact. ACL deficient knees were more likely found in patients with higher BMI's. Mullaji, et al. also found ACL deficiency was more common with a higher BMI [10]. Hill, et al. found no statistical association with ACL deficiency and increased BMI [5]. We also observed males were more likely to have ACL deficiency (Table 1). Hodge, et al. noted differences based on ethnicity, which was not evaluated in our study [6]. ACL deficiency was also associated with more significant varus or valgus coronal malalignment (Table 2). All of these preoperative patient and clinical factors can be combined to identify knees that may have an intact vs. an absent ACL. This is important in patient selection for partial knee replacement in which an intact ACL is a necessity and also to determine the probability of more significant ligament balancing demands during TKA.

There was an increased need for ligament balancing techniques including posterior capsular release during TKA in knees with an absent ACL (Table 3). These releases were more frequent in knees in order to correct deformity and obtain kinematic balance at the time of TKA indicating more fixed deformity associated with ACL deficiency. Preoperative

Table 2 Extreme and ranges of preoperative deformity (percentage or mean $\pm$ 1 standard deviation)

Pre-op deformity ^a	Class 0	Class 1 and 2	Class 3	P value
Pre-operative varus < -8 ($n = 31$) ^b	8%	13%	21%	0.1360
Pre-operative valgus > 11 ($n = 35$) ^b	6%	13%	26%	0.0811
Average pre-operative varus when < 5 ($n = 177$) ^c	-2.7 (± 3.9)	-4.0 (± 4.5)	-6.2 (± 6.5)	0.0058
Average pre-operative valgus when > 10 ($n = 37$) ^c	17.2 (± 4.5)	17.0 (± 4.2)	18.6 (± 4.3)	0.6089
Overall average pre-operative alignment	0.7 (± 7.9)	-0.3 (± 8.7)	0.9 (± 12.3)	0.6823

^a Numerical alignment is in degrees on the anatomical axis, with varus and valgus indicated to identify direction relative to anatomic neutral

^b Preoperative malalignment deformity leading to decreased prosthesis survival reported in reference 21

^c Varus and valgus deduction thresholds as defined in the Knee Society Knee Score, reference 22

Table 3 Intraoperative decisions and status

		Class 0 (normal) (%)	Class 1 and 2 (damaged) (%)	Class 3 (absent) (%)	P value
Deformity	Medial tibial chondromalacia (% at most extreme condition)	78	79	87	<0.0001
	Medial tibial osteophytes (% at most extreme condition)	17	26	48	<0.0001
	Medial meniscus (% at most extreme condition)	7	12	52	<0.0001
	Medial tibial deformity (% at most extreme condition)	9	14	32	<0.0001
Ligamentous	PCL relaxation (% Yes)	61	47	38	<0.0001
	PCL excised (% yes)	37	49	56	<0.0001
	Any medial relaxation (pre-operative alignment <5)	25*	17*	41	0.0139
	Any lateral relaxation (pre-operative alignment >10)	77	88	81	0.5970
(n = 176)	No posterior release	5	1	2	0.1025**
(n = 32)	Posterior osteophyte removal	88	44	64	
(n = 53)	Posterior osteophytes and release	7	55	32	
(n = 1164)					
(n = 632)					

*Combined class 0 and class 1 (giving 20.1%) for this grouping since this was not monotonically increasing or decreasing like other findings

**Chi-square test: class 0 vs. combined class 1, 2, and 3

Table 4 Pre operative clinical scores

	Class 0	(±Std)	Class 1 and 2	(±Std)	Class 3	(±Std)	P value
Pain	12.8	±8.5	11.1	±8.3	12.6	±6.5	0.3267*
Stairs	30.4	±7.3	28.8	±8	28.8	±7.7	0.1157
Flexion	109.8	±12.5	103.7	±12.7	99.1	±16	<0.0001
Extension	1.7	±5.4	1.7	±7.9	3.5	±8.6	0.0380
ROM	108.1	±14.2	102.0	±15.9	95.6	±21	<0.0001
Extensor Lag	0.4	±2.6	0.4	±3.3	0.8	±5.4	0.5145
Function score	54.3	±16	50.0	±14.7	50.4	±15	0.0074**

*Class 0 and 3 versus class 1 and 2

**Class 0 versus class 1, 2, and 3

recognition of this intraoperative need is helpful for planning the surgical workflow and possible additional articular geometry needs. Patients with an absent ACL (class 3) exhibited more advanced articular cartilage and meniscal degeneration. Patients with an absent ACL degeneration have significantly more cartilaginous deterioration on both the medial and lateral tibial plateau rather than isolated to one compartment. This finding is also important in consideration of partial knee replacement surgery indications. It is unclear if ACL deficiency is the causative in this relationship or whether this represents a simultaneous degenerative pathophysiology. Other authors have observed this finding as well [9, 10].

This study demonstrated the ACL deficiency was associated with lower pre-op ROM, higher BMI, decreased pre-op function, lower pre-op stair climbing ability, and increased coronal deformity [13]. The status of the ACL is predictive of the need for increased surgical correction and may be an important consideration as surgeons consider risks and benefits of “kinematic alignment” purported to reduce ligament release and patient specific guides which only assist with bony correction. Further, a better understanding of ACL status is an important consideration for partial knee replacement where patient selection is critical to long-term success.

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Compliance with Ethical Standards

Conflict of Interest: Michael E. Berend, MD, John B. Meding, MD, Michael D. Jackson and Kenneth E. Davis MS have declared that they have no conflict of interest. Philip M. Faris, MD reports grants from Biomet, Inc, during the conduct of the study. Merrill A. Ritter, MD reports grants from Biomet, Inc, during the conduct of the study; personal fees from Iconacy Orthopaedic Implants, LLC, outside the work. Robert A. Malinzak, MD reports grants from Biomet, Inc, during the conduct of the study. John B. Meding, MD reports grants from Biomet, Inc, during the conduct of the study; personal fees from Biomet, Inc, outside the work.

Human/Animal Rights: All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5).

Informed Consent: Informed consent was waived from all patients for being included in the study.

Required Author Forms Disclosure forms provided by the authors are available with the online version of this article.

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