Association Between Femoral Component Sagittal Positioning and Anterior Knee Pain in Total Knee Arthroplasty

A 10-Year Case-Control Follow-up Study of a Cruciate-Retaining Single-Radius Design

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Background: Anterior knee pain is the most common complication of total knee arthroplasty (TKA). The purpose of this study was to assess whether sagittal femoral component position is an independent predictor of anterior knee pain after cruciate-retaining single-radius TKA without routine patellar resurfacing.

Methods: A prospective cohort study of 297 cruciate-retaining single-radius TKAs performed in 2006 and 2007 without routine patellar resurfacing identified 73 patients (25%) with anterior knee pain and 89 (30%) with no pain (controls) at 10 years. Patients were assessed preoperatively and at 1, 5, and 10 years postoperatively using patient-reported outcome measures (PROMs), including the Short Form-12 (SF-12), Oxford Knee Score (OKS), and satisfaction and expectation questionnaires. Variables that were assessed as predictors of anterior knee pain included demographic data, the indication for the TKA, early complications, stiffness requiring manipulation under anesthesia, and radiographic criteria (implant alignment, Insall-Salvati ratio, posterior condylar offset ratio, and anterior femoral offset ratio).

Results: The 73 patients with anterior knee pain (mean age, 67.0 years [range, 38 to 82 years]; 48 [66%] female) had a mean visual analog scale (VAS) score of 34.3 (range, 5 to 100) compared with 0 for the 89 patients with no pain (mean age, 66.5 years [range, 41 to 82 years]; 60 [67%] female). The patients with anterior knee pain had mean femoral component flexion of −0.6° (95% confidence interval [CI] = −1.5° to 0.3°), which differed significantly from the value for the patients with no pain (1.42° [95% CI = 0.9° to 2.0°]; $p < 0.001$). The patients with and those without anterior knee pain also differed significantly with regard to the mean anterior femoral offset ratio (17.2% [95% CI = 15.6% to 18.8%] compared with 13.3% [95% CI = 11.1% to 15.5%]; $p = 0.005$) and the mean medial proximal tibial angle (89.7° [95% CI = 89.2° to 90.1°] compared with 88.9° [95% CI = 88.4° to 89.3°]; $p = 0.009$). All PROMs were worse in the anterior knee pain group at 10 years ($p < 0.05$), and the OKSs were worse at 1, 5, and 10 years ($p < 0.05$). Multivariate analysis confirmed femoral component flexion, the medial proximal tibial angle, and an Insall-Salvati ratio of <0.8 (patella baja) as independent predictors of anterior knee pain ($R^2 = 0.263$). Femoral component extension of ≥0.5° predicted anterior knee pain with 87% sensitivity.

Conclusions: In our study, 25% of patients had anterior knee pain at 10 years following a single-radius cruciate-retaining TKA without routine patellar resurfacing. Sagittal plane positioning and alignment of the femoral component were associated with long-term anterior knee pain, with femoral component extension being a major risk factor.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

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Anterior knee pain is the most common complication of total knee arthroplasty (TKA), with a prevalence of 8% to 36% at 1 year[1]. There are few reports on long-term anterior knee pain, but rates of 45% have been reported at 10 years[1,2]. Determinants of anterior knee pain are multifactorial, and risk factors predicting whether this complication will be present at long-term follow-up remain unclear[1-3].

The single-radius TKA concept is based on the principle of a common flexion-extension axis at the knee with consistent relationships with the patellofemoral joint axis[4] and the tibial longitudinal rotational axis[5]. This principle appears consistent in varus and valgus knees[5]. The single-radius design is thought to be patellofemoral "friendly": a posterior flexion-extension axis lengthens the quadriceps moment arm, reducing patellofemoral joint reaction force. Other modern TKA design concepts, such as left and right-specific femoral components and deeper trochlear grooves, improve patellar glide. These features may reduce the requirement for primary patellar resurfacing, a topic that remains controversial with marked geographic variation[6].

Recent biomechanical studies have suggested that sagittal component alignment is more important than rotation in determining patellofemoral kinematics[7] and that, despite patellofemoral-friendly features, deep-flexion patellofemoral pressures are often excessive as a result of artificially maintained patellar offset[8]. The primary aim of this study was to investigate sagittal femoral component position as a predictor of anterior knee pain at long-term follow-up after cruciate-retaining single-radius TKA without routine patellofemoral resurfacing. The null hypothesis was that sagittal femoral component positioning did not determine anterior knee pain.

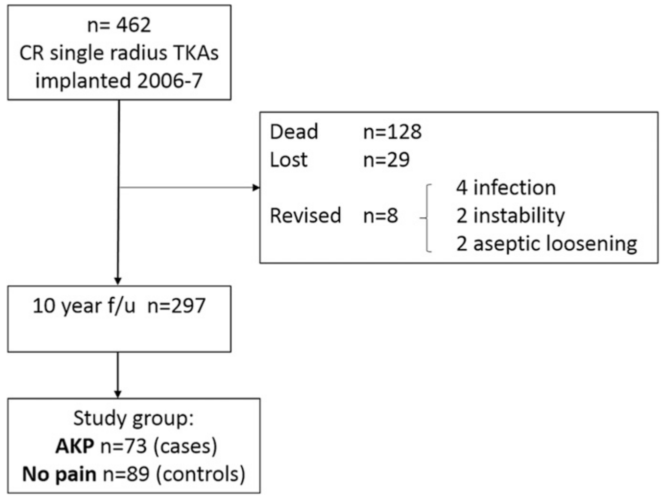

Fig. 1

Study group details. CR = cruciate-retaining, f/u = follow-up, and AKP = anterior knee pain.

Materials and Methods

Ethical approval was obtained for this prospective study (Scotland [A] Research Ethics Committee 16/SS/0026). From 2006 to 2007, data were recorded for 462 patients undergoing Triathlon single-radius TKA (Stryker Orthopaedics) (Fig. 1). The TKAs were performed by 7 surgeons at a large orthopaedic teaching hospital[9]. At 10 years, 326 patients were alive with an intact TKA. Cemented, cruciate-retaining TKAs were performed via a medial parapatellar approach and with use of a measured resection technique. Patellar resurfacing was performed, rarely, at the surgeon's discretion to address

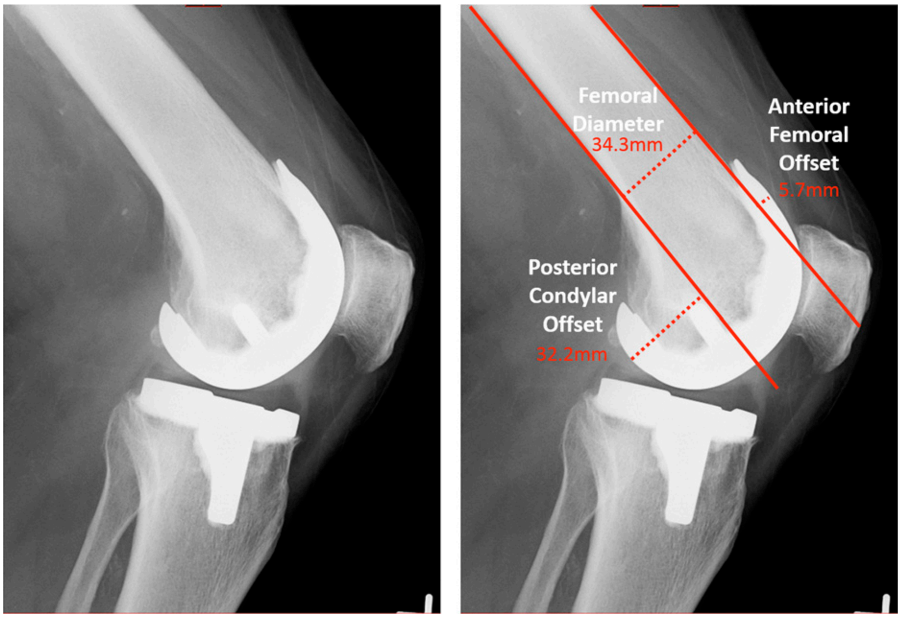

Fig. 2

Anterior femoral offset ratio (anterior femoral offset/femoral diameter) and posterior condylar offset ratio (posterior condylar offset/femoral diameter) measured on an adequate lateral radiograph.

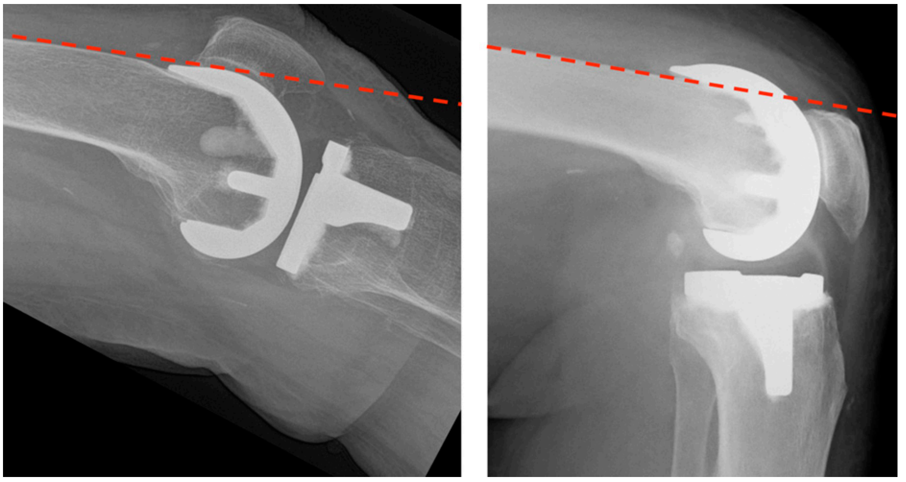

Fig. 3
Examples of a flush femoral component (left) and a femoral component that is not flush (right).

inflammatory arthropathy or patellofemoral osteoarthritis. All patients followed a standardized postoperative rehabilitation protocol.

General health (Short Form [SF]-12[10]) and knee-specific (Oxford Knee Score [OKS][11]) patient-reported outcome measures (PROMs) were collected prior to surgery and at 1, 5, and 10 years following surgery via postal questionnaire. Satisfaction was measured at 1, 5, and 10 years[12]. Expectation fulfilment was measured at 5 years using the Hospital for Special Surgery (HSS) Knee Surgery Expectations survey[13]. The SF-12 is a validated questionnaire with physical and mental component summary (PCS and MCS) scores. The OKS is a validated knee score containing 12 questions (each with 5 possible answers); the total score ranges from 0 to 48, with higher scores indicating better function. The HSS Expectations score is validated[13] to measure expectation fulfilment for 17 activities following knee surgery[14]. Collection of data was independent of routine clinical care. Patients who did not respond by mail were telephoned. Full details and analysis of the entire cohort (n = 462) have been published previously[9].

At 10 years after the TKA, the patients were asked to record pain scores on a visual analog scale (VAS) ranging from 0 to 100. When pain was present, they were asked to identify its location within the knee as at the "front," "back," "inside edge," "outside edge," "all over," or "other." Those reporting anterior knee pain at 10 years (n = 73) formed our case group and those reporting no pain in any area (n = 89) were the control group. Those indicating diffuse pain all over the knee were not included in either group.

Patient demographics, comorbidities, the indication for the TKA, surgeon, side, complications, and reoperations were recorded. Radiographic analysis was performed on short-leg weight-bearing radiographs using a picture archiving and communication system (PACS) measurement tool (Kodak Carestream) on the earliest acceptable postoperative lateral image. All follow-up radiographs were examined to assess loosening or other causes of pain, details of which have been published previously[9]. Those with radiographic evidence of loosening as a potential source of pain were excluded. Radiographs were examined by 2 independent reviewers (C.E.H.S. and L.Z.Y.) who had no clinical contact with the patients. Implant alignment[15], posterior condylar offset[16], and anterior femoral offset[17] were measured using published methods (Fig. 2). This analysis required adequate lateral radiographs with aligned and superimposed femoral component pegs facilitating femoral flexion measurement against the femoral anatomical axis (Figs. 2 and 3). Posterior condylar offset and anterior femoral offset were converted into ratios (the posterior condylar offset ratio and the anterior femoral offset ratio) relative to the femoral diameter. The Insall-Salvati ratio was calculated, and patella baja was defined as an Insall-Salvati ratio of <0.8. Femoral component oversizing was defined as an anterior femoral offset ratio of >15% and a posterior condylar offset ratio of >95%.

TABLE I Location and Severity of Pain 10 Years Following Cruciate-Retaining Single-Radius TKA without Routine Patellar Resurfacing (N = 297*)

Location of Pain	No. (%) of Patients	Mean VAS Pain Score (95% CI)
Anterior	73 (25)	34.3 (28.5 to 40.6)
Posterior	16 (5)	44.1 (29.7 to 59.8)
Medial	35 (12)	29.2 (20.7 to 38.2)
Lateral	32 (11)	35.7 (26.8 to 45.4)
Diffuse	80 (27)	51.4 (46.2 to 57.0)
Other	6 (2)	30.5 (11.3 to 50.6)
No pain	89 (30)	0

*Some patients reported pain in >1 location.

TABLE II Preoperative Characteristics of Patients with Anterior Knee Pain Compared with Those with No Pain at 10 Years

Variable	Anterior Knee Pain (N = 73)	No Pain (N = 89)	P Value	95% CI for Difference in Group Means
Female sex*	48 (66)	60 (67)	0.539†	
Age‡ *(yr)*	67.0 (64.9 to 69.0) (38-82)	66.5 (64.6 to 68.4) (41-82)	0.79§	−2.31 to 3.21
BMI‡ *(kg/m²)*	31.6 (29.8 to 33.3)	30.6 (29.1 to 32.1)	0.401§	−1.29 to 3.20
Right-sided TKA*	40 (55)	38 (43)	0.125†	
Comorbidities*				
Depression	6 (8)	3 (3)	0.297#	
Pain in other joints	28 (38)	25 (28)	0.132†	
Back pain	21 (29)	20 (22)	0.332†	
Indication*				
Osteoarthritis	62 (85)	77 (87)	0.0845†	
Inflammatory arthropathy	5 (7)	5 (6)		
Other	6 (8)	7 (8)		
PROMs‡				
SF-12 PCS	32.2 (29.8 to 34.5)	29.3 (27.5 to 31.4)	0.495§	−2.83 to 5.82
SF-12 MCS	50.3 (46.7 to 54.0)	51.5 (48.3 to 54.6)	0.423§	−7.21 to 3.05
OKS	18.9 (17.2 to 20.6)	18.3 (16.0 to 20.6)	0.688§	−2.34 to 3.54

*The values for the pain and no-pain groups are given as the number of patients with the percentage in parentheses. †Chi-square test. ‡The values for the pain and no-pain groups are given as the mean with the 95% CI in parentheses, with the second parentheses for "Age" showing the range. BMI = body mass index. §Student t test. #Fisher exact test.

Statistical Analysis

Data were analyzed using SPSS version 21.0 (IBM). A single-measure (2-way mixed) intraclass correlation coefficient was used to quantify interobserver reliability (values of >0.75 indicate satisfactory reliability). Categorical variable correlation was calculated using the kappa statistic. Univariate analysis

TABLE III Radiographic Measurements in Patients with Anterior Knee Pain Compared with Those with No Pain at 10 Years

Variable	Anterior Knee Pain (N = 62)	No Pain (N = 71)	P Value	95% CI for Difference in Group Means
Femorotibial angle* *(°)*	175.1 (171 to 179)	177.9 (177 to 178)	0.993†	−0.8 to 0.8
Coronal plane*				
Medial proximal tibial angle *(°)*	89.7 (89.2 to 90.1)	88.9 (88.4 to 89.3)	0.009†	0.2 to 1.4
Lateral distal femoral angle *(°)*	85.7 (85.3 to 86.1)	85.7 (85.3 to 86.1)	0.969†	−0.6 to 0.6
Sagittal plane*				
Posterior tibial slope *(°)*	4.5 (3.8 to 5.2)	5.3 (4.6 to 5.9)	0.107†	−1.7 to 0.16
Femoral component flexion *(°)*	−0.6 (−1.5 to 0.3)	1.4 (0.9 to 2.0)	<0.001†	−3.0 to −1.0
Posterior condylar offset ratio *(%)*	94.0 (90.6 to 97.4)	97.3 (93.8 to 100)	0.192†	−0.08 to 0.02
Anterior femoral offset ratio *(%)*	17.2 (15.6 to 18.8)	13.3 (11.1 to 15.5)	0.005†	0.01 to 0.07
Insall-Salvati ratio*	1.01 (0.95 to 1.07)	1.01 (0.98 to 1.05)	0.938†	−0.07 to 0.6
Patella baja (Insall-Salvati ratio <0.8)‡	10 (16)	5 (7)	0.100§	
Femoral component flush anteriorly‡	13 (21)	28 (39)	0.016§	
Femoral component oversizing‡	19 (31)	16 (23)	0.228§	
Tibial underhang* *(mm)*	0.15 (−0.22 to 0.52)	0.21 (−0.15 to 0.57)	0.817†	−0.6 to 0.5

*The values for the pain and no-pain groups are given as the mean with the 95% CI in parentheses. †Student t test. ‡The values for the pain and no-pain groups are given as the number of patients with the percentage in parentheses. §Chi-square test.

TABLE IV Intraclass Correlation Coefficients for Radiographic Measures and Ratios

Measure/Ratio	Intraclass Correlation	95% CI	P Value
Coronal			
Lateral distal femoral angle	0.856	0.80 to 0.89	<0.001
Medial proximal tibial angle	0.914	0.88 to 0.94	<0.001
Sagittal			
Posterior tibial slope	0.810	0.75 to 0.90	<0.001
Femoral diameter	0.986	0.98 to 0.99	<0.001
Femoral flexion	0.913	0.88 to 0.94	<0.001
Ratios			
Posterior condylar offset ratio	0.956	0.94 to 0.97	<0.001
Anterior femoral offset ratio	0.524	0.39 to 0.64	<0.001
Insall-Salvati ratio	0.900	0.86 to 0.93	<0.001

was performed using parametric (Student t test: paired and unpaired) and nonparametric (Mann-Whitney U) tests to assess differences in continuous variables between groups. Nominal categorical variables were assessed using the chi-square or Fisher exact test. The Pearson correlation was used to assess correlation between linear variables. Variables significantly associated with anterior knee pain at the <10% level were entered stepwise into a multivariate binary logistic regression analysis using an enter methodology to identify independent predictors of anterior knee pain. A p value of <0.05 was considered significant.

Receiver operating characteristic (ROC) curve analysis was used to identify the threshold femoral component flexion and medial proximal tibial angle that identified anterior knee pain. The area under the curve (AUC) ranges from 0.5 (a test with no accuracy) to 1.0 (perfect accuracy). The threshold value is the point of maximal sensitivity and specificity in predicting anterior knee pain.

Post hoc power analysis was performed for the risk of anterior knee pain in association with an extended femoral component. Using the defined rate of anterior knee pain of 32% in patients with a flexed component (n = 84) and 71% in those with an extended component (n = 42), with an alpha of 0.05, a 2-way analysis defined the power as 99.1%.

Results

At 10 years, 297 (91%) of the 326 patients were alive, had an intact TKA, and recorded VAS scores and pain location. The 29 non-responders (8 who could not be contacted, 11 with dementia, and 10 who declined to participate) were significantly older at TKA than the 297 responders (mean age [and standard deviation], 69.9 ± 9.8 versus 66.1 ± 8.6 years; p = 0.008, unpaired t test), but there were no other significant differences in baseline demographics or PROMs. Patients reporting pain in regions not involving the anterior aspect of the knee were excluded (n = 135) (Table I), resulting in a study cohort of 162 patients: 73 with anterior knee pain and 89 with no pain at 10 years. The patients with anterior knee pain had a mean VAS pain score of 34.3 ± 25.1 (range, 5 to 100): 8 reported some additional lateral pain; 9, some medial pain; 5, some posterior pain; and 6, pain in multiple areas. The VAS score was 0 for the patients with no pain. Nine patients—4 with anterior knee pain and 5 with no pain at 10 years—had undergone primary patellar resurfacing. One patient underwent

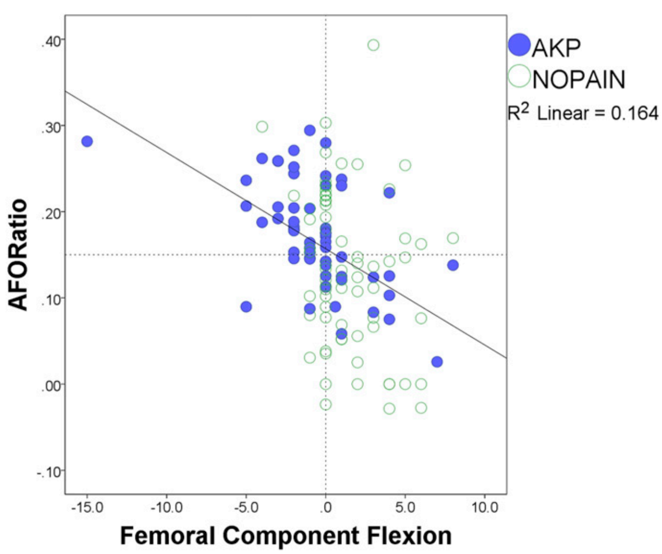

Fig. 4

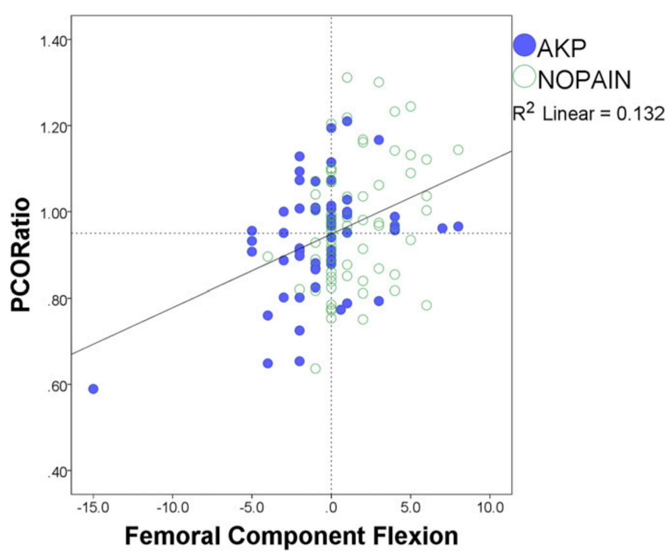

Fig. 5

Fig. 4 Graph showing the correlation between femoral component flexion and the anterior femoral offset (AFO) ratio (R = −0.405; p < 0.01, Pearson correlation). AKP = anterior knee pain. **Fig. 5** Graph showing the correlation between femoral component flexion and the posterior condylar offset (PCO) ratio (R = 0.364; p < 0.01, Pearson correlation). AKP = anterior knee pain.

TABLE V Multivariate Analysis of Predictors of Anterior Knee Pain at 10 Years

Predictors in Model (R^2 = 0.263)	Odds Ratio (95% CI)	P Value
Femoral component extension	1.39 (1.14 to 1.70)	0.001
Medial proximal tibial angle	0.74 (0.56 to 0.97)	0.027
Patella baja (Insall-Salvati ratio <0.8)	0.20 (0.05 to 0.85)	0.029
Anterior femoral offset ratio	0.04 (0 to 139)	0.444
Femoral component flush anteriorly	1.73 (0.37 to 5.42)	0.619

TABLE VI Effect of Radiographic Features on Probability of Developing Anterior Knee Pain

Radiographic Measure	Odds Ratio	95% CI	P Value
Single variable			
Anterior femoral offset ratio >15%	1.49	1.04 to 2.12	0.026
Valgus tibia	2.15	1.09 to 4.25	0.022
Extended femoral component	3.03	1.71 to 5.35	<0.001
Combination of variables			
Anterior femoral offset ratio >15% and extended femoral component	3.98	1.84 to 8.59	<0.001
Oversized and extended femoral component	4.04	1.17 to 14.0	0.015
Valgus tibia and anterior femoral offset ratio >15%	4.16	0.9 to 19.3	0.045
Valgus tibia and extended femoral component	10.9	1.42 to 83.4	0.003

secondary resurfacing and had persistent anterior knee pain thereafter.

There were no significant differences in preoperative characteristics between the patients with and those without anterior knee pain (Table II). Early complications (wound leakage/dehiscence, cellulitis, deep infection, venous thromboembolism, and myocardial infarction) were not associated with 10-year anterior knee pain (p = 0.580, chi-square test). Early stiffness requiring manipulation under anesthesia was not associated with late anterior knee pain, with 3 of the 73 with pain and 1 of the 89 without pain having such stiffness (p = 0.253).

Radiographic Analysis

Lateral radiographs were inadequate to determine the posterior condylar offset ratio and anterior femoral offset ratio measurement in 11 of the 73 patients with anterior knee pain and 18 of the 89 with no pain, and these patients were excluded from radiographic analysis. The results of the radiographic analysis of the remaining 133 patients are given in Table III. Intraclass correlations are shown in Table IV. The femoral component flexion, anterior femoral offset ratio, and medial proximal tibial angle differed between the patients with and those without anterior knee pain (Table III). When the femoral component was flush with the distal part of the femur (Fig. 3),

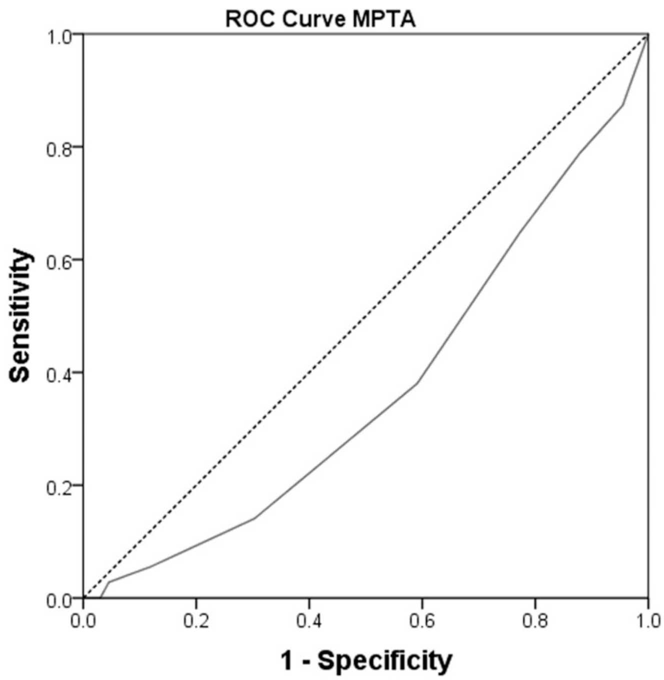

Fig. 6

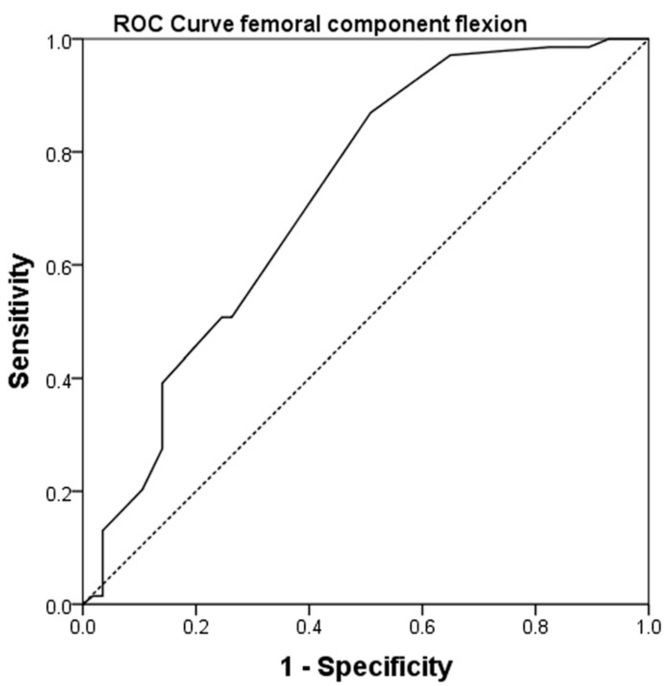

Fig. 7

Fig. 6 ROC curve for anterior knee pain and the medial proximal tibial angle (MPTA) (AUC = 0.372). **Fig. 7** ROC curve for anterior knee pain with a threshold value of −0.5° of femoral component flexion (AUC = 0.721).

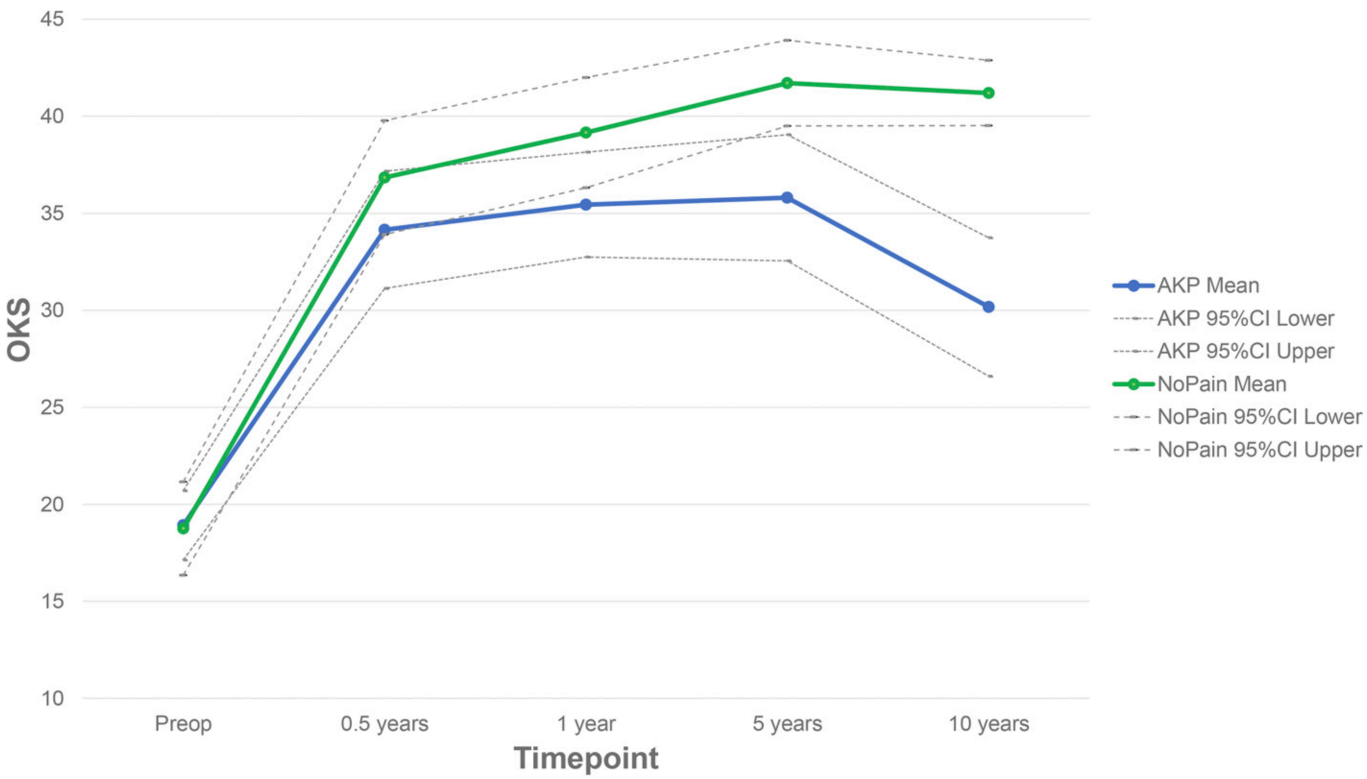

Fig. 8
Longitudinal OKSs in patients with anterior knee pain (AKP) and those with no pain at 10 years.

the patient was less likely to have anterior knee pain than when the component was not flush; 13 (21%) of the 62 patients with anterior knee pain and 48 (68%) of the 71 with no pain had a flush component (p = 0.016). There was excellent interobserver agreement in defining whether the femoral component was flush (Cohen kappa = 0.915; p < 0.001). Femoral component

TABLE VII PROMs of Patients with Anterior Knee Pain Compared with Those with No Pain at 10 Years by Follow-up Time Point

Follow-up Time/Score	Anterior Knee Pain (N = 73)	No Pain (N = 89)	P Value
1 yr			
PCS*	41.9 (10.0) (19 to 61)	44.6 (11.0) (14 to 58)	0.219†
MCS*	51.4 (9.8) (29 to 65)	53.2 (11.1) (24 to 66)	0.178†
OKS*	35.5 (8.5) (16 to 48)	37.2 (9.1) (11 to 48)	0.035†
Dissatisfied‡	3 (4)	1 (1)	0.565§
5 yr			
PCS*	40.9 (11.1) (19 to 57)	43.1 (11.4) (19 to 61)	0.287†
MCS*	51.1 (9.7) (27 to 71)	52.7 (10.7) (26 to 67)	0.186†
OKS*	35.7 (10.2) (5 to 48)	39.6 (9.2) (14 to 48)	0.010†
Dissatisfied‡	5 (7)	3 (3)	0.045§
10 yr			
PCS*	35.5 (11.6) (15 to 57)	43.4 (10.6) (21 to 57)	<0.001†
MCS*	48.5 (9.4) (26 to 67)	51.5 (9.7) (28 to 65)	0.037†
OKS*	29.6 (10.9) (7 to 48)	40.1 (7.1) (17 to 48)	<0.001†
Dissatisfied‡	14 (19)	4 (4)	<0.001§

*The values given as the mean with the standard deviation in the first parentheses and the 95% CI in the second. †Mann-Whitney U test. ‡The values are given as the number of patients with the percentage in parentheses. §Chi-square test.

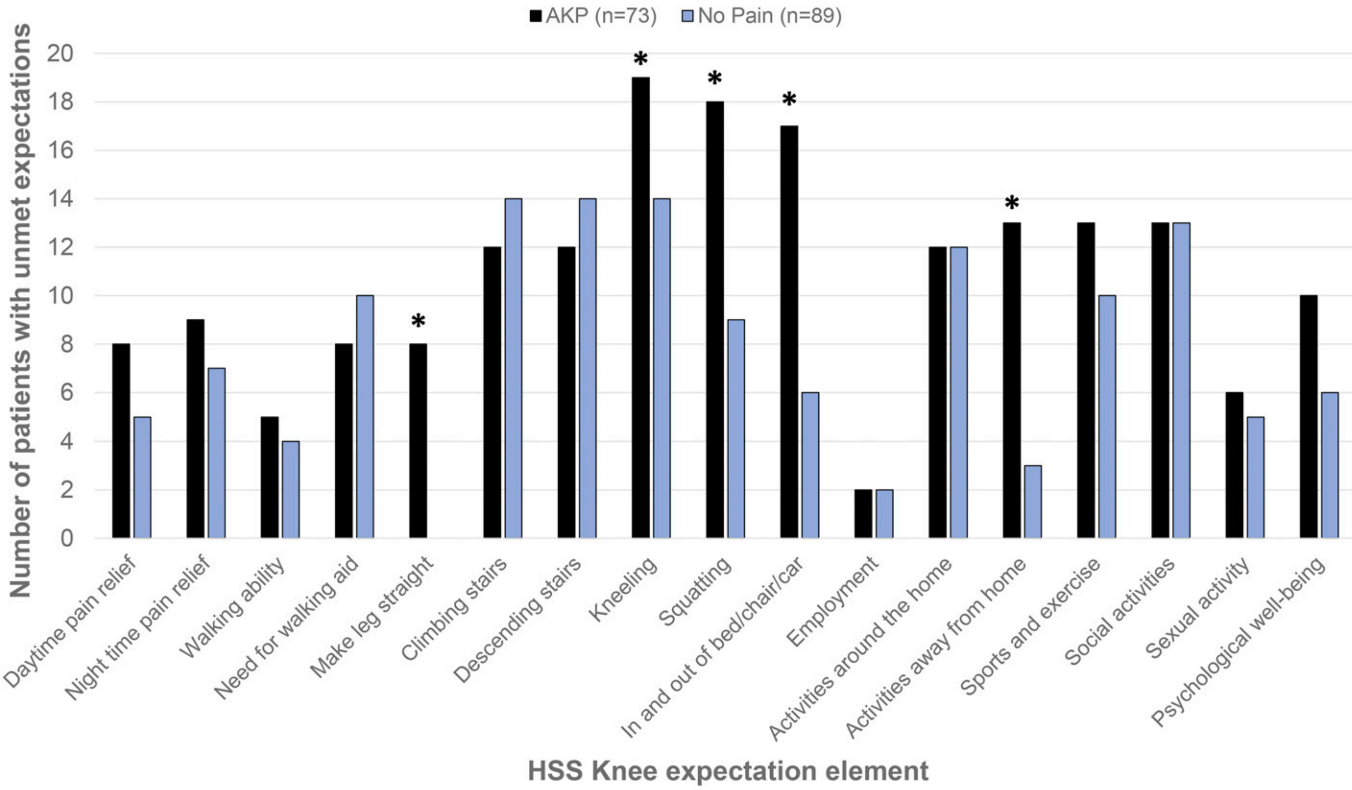

Fig. 9

Unmet expectations as measured using the HSS Knee Surgery Expectations score in patients with anterior knee pain (AKP) and those no pain at 10 years. *Indicates questions with significant differences between the anterior knee pain and no-pain groups ($p < 0.05$).

oversizing was not associated with anterior knee pain ($p = 0.228$, chi-square test). Those with an anterior femoral offset ratio of >15% of the femoral diameter (the median anterior femoral offset ratio) were more likely to have anterior knee pain (35 [56%] of 63) than were those with an anterior femoral offset ratio of <15% (23 [36%] of 64; $p = 0.026$).

Femoral component flexion correlated with a reduced anterior femoral offset ratio ($R = -0.405$; $p < 0.01$, Pearson correlation) (Fig. 4) and an increased posterior condylar offset ratio ($R = 0.364$; $p < 0.01$, Pearson correlation) (Fig. 5). Flush femoral components were more flexed (mean and standard deviation, 1.77° ± 2.4°; 95% confidence interval [CI] for differences in means −5° to 7°) than those that were not flush (mean, −0.8° ± 3.0°; −15° to 8°; $p = 0.001$; 95% CI = 0.77° to 2.9°).

Multivariate analysis (Table V) showed femoral component flexion, the medial proximal tibial angle, and patella baja (Insall-Salvati ratio of <0.8) to independently predict anterior knee pain at 10 years ($R^2 = 0.263$). Odds ratios are reported in Table VI.

ROC curve analysis demonstrated that the medial proximal tibial angle could not be used to identify patients with anterior knee pain (AUC = 0.372, Fig. 6). ROC analysis using femoral component flexion to predict anterior knee pain gave an AUC of 0.721 (95% CI = 0.63 to 0.81; $p < 0.001$) (Fig. 7): a threshold of −0.5° of femoral flexion had an 87% sensitivity and a 51% specificity.

PROMs

OKSs were worse starting from 1 year in the anterior knee pain group ($p < 0.05$, Fig. 8). All other PROMs were worse at 10 years (Table VII). A higher percentage of patients with anterior knee pain were dissatisfied at 10 years (19% compared with 4% of the patients with no pain; $p < 0.001$, chi-square test) because of unmet expectations regarding the TKA making the leg straight, kneeling ability, squatting ability, getting in and out of a bed/chair/car/bus, ability to perform activities outside the home, and ability to take part in recreational activities (Fig. 9). Dividing the OKS into constituent questions showed that patients with anterior knee pain had worse scores for getting in and out of a car/public transport, pain at night, shopping, and descending stairs ($p < 0.05$) compared with those with no anterior knee pain. Ten-year OKSs correlated with femoral flexion (Pearson correlation = 0.224; $p = 0.013$), the anterior femoral offset ratio (Pearson correlation = −0.183; $p = 0.04$), and the posterior condylar offset ratio (Pearson correlation = 0.187; $p = 0.038$) but not with the medial proximal tibial angle (Pearson correlation = −0.42; $p = 0.631$).

Discussion

A quarter of patients alive with an intact single-radius cruciate-retaining TKA who had not undergone routine patellar resurfacing reported anterior knee pain at 10 years. Patients with anterior knee pain at 10 years reported worse

PROMs (OKS) beginning at 1 year. Radiographic measures including femoral component flexion, anterior femoral offset ratio (absolute and >15% of the femoral diameter), whether the femoral component was flush with the distal part of the native femur, and the medial proximal tibial angle, all with strong interobserver agreement, were significantly associated with anterior knee pain. Multivariate analysis indicated that, in this TKA design, femoral component flexion, tibial component coronal alignment (medial proximal tibial angle), and patella baja independently predicted long-term anterior knee pain. When the analysis was corrected for those variables, the anterior femoral offset ratio and a flush femoral component were no longer significant predictors, possibly reflecting the relationship between femoral flexion and the anterior femoral offset ratio. ROC curve analysis confirmed that femoral component extension of ≥0.5° correctly identified patients with anterior knee pain 87% of the time.

Postoperative anterior knee pain is the most common complication following TKA, and its association with PROMs confirms its importance. Post-TKA anterior knee pain has been reported in 80% to 85% of patients during chair rising and in 90% on stair climbing[18]. There have been few reports on anterior knee pain in 10-year cohorts[1], but the rates reported in association with multi-radius designs (26% after cruciate-retaining TKA[3] and 30% after posterior-stabilized TKA with resurfacing[2]) are comparable with our results. A number of variables have been considered as potential causes of anterior knee pain, including patellar resurfacing, "overstuffing," denervation, fat-pad excision or retention, component rotation, joint-line alteration, sagittal alignment, and medial/lateral translation[1]. The roles of these variables have not been consistently reported, and the multitude of different TKA designs and resurfacing combinations makes comparisons difficult[1]. When present, anterior knee pain is difficult to manage, with 60% of cases persisting after secondary patellar resurfacing[19].

Routine patellar resurfacing was not performed for our patient cohort. Meta-analysis of numerous randomized controlled trials demonstrated no difference in anterior knee pain between resurfaced and non-resurfaced patellae[20], although reoperation rates were higher after TKAs that did not include patellar resurfacing, a fact confounded by the bias inherent in secondary resurfacing being possible[20]. Primary resurfacing rates vary internationally, with rates of 4% in Norway and 82% in the United States[6]. Across multiple national joint registries, the rate of primary resurfacing in TKAs was 35% in 2010[6]; thus, the results of TKAs without resurfacing are applicable to the majority of TKA cases worldwide.

The influence of patellofemoral overstuffing and anterior femoral offset on anterior knee pain has been investigated previously[17,21,22]. Pierson et al.[21] examined changes in anterior femoral offset in 838 patients (86% with a cruciate-retaining TKA, all with patellar resurfacing), concluding that overstuffing (arbitrarily defined as any anterior femoral offset increase or anterior patellar displacement of >15%) had no effect on range of motion or Knee Society Scores in comparative groups with different sample sizes (ranging from 19 to 41 in the "stuffed" group versus 723 to 769 in the "unstuffed" group). Sagittal femoral alignment was not considered. Matz et al.[22] evaluated 970 patients who underwent posterior-stabilized TKA with resurfacing and divided them into 3 groups: increased, decreased, and unchanged anterior femoral offset. They found no difference in Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) scores among the groups, concluding that there were no consequences of patellofemoral overstuffing. Beldman et al.[17] investigated overstuffing (any increase in anterior femoral offset or posterior condylar offset) in 193 patients treated with posterior-stabilized TKA with resurfacing and found anterior overstuffing in 43%, posterior overstuffing in 87%, and total overstuffing in 80%. They reported no effects of overstuffing on anterior knee pain or WOMAC scores at 1 year. In all 3 studies, the authors used arbitrary definitions of overstuffing, considered only absolute values, and identified associations with overstuffing rather than anterior knee pain. Defining any increase in offset as overstuffing may mask effects of truly significant overstuffing by dilution.

Despite the patellofemoral-friendly features of the TKA design used in our study, anterior knee pain was reported in 25% of our patients at 10 years. Although modern femoral component trochleae are designed to reproduce anatomical patellar tracking, cadaveric studies suggest that physiological kinematics are not restored[8]. Artificially maintained patellar offset throughout motion increases patellofemoral pressures and may cause anterior knee pain[8]. Limiting the anterior femoral offset ratio by femoral component flexion may reduce this effect. Tibial component rotation was found to affect peak retropatellar pressures in cadavers[23]. However, a recent study of 46 TKAs performed with computer navigation showed sagittal alignment to have a greater effect on patellofemoral kinematics (patellar tilt and medialization) than did rotational alignment[7]. Although we did not measure component rotation, an important study weakness, this study supports the importance of femoral sagittal alignment on patellofemoral biomechanics. We are unable to comment on the effect of patellar resurfacing as we did not include a comparison group with that procedure; however, a beneficial effect of resurfacing has not been proven[20].

The cohort in this study consisted of the first single-radius TKAs performed at our institution, so it includes our learning curve. Initially, the 7° anterior femoral flange was often implanted more parallel to the anterior aspect of the femur than we would now advocate, resulting in component extension and an increased anterior femoral offset ratio. Femoral component flexion is now achieved by utilizing a posterior femoral entry point. The results of this study appear to support this strategy. The importance of sagittal component alignment in predicting long-term anterior knee pain, and thus PROMs, in patients with this TKA is a novel finding and is relevant in an age of precision implantation and robotic technology. Although these data identify sagittal component positioning as important in the long-term success of single-radius

TKA, it cannot be ascertained whether this variable alone causes anterior knee pain. Further research is required to investigate additional variables such as joint-line restoration, coronal alignment, and component rotation, which were not assessed here.

Limitations of this study include no comparison with preoperative radiographs and no measurement of implant rotation or joint-line restoration. Hip-knee-ankle radiographs were not used for measurement of coronal alignment, making interpreting medial proximal tibial angle results difficult. Lateral radiographs were adequate to define anterior and posterior femoral cortex alignment and thus the distal femoral axis (Fig. 2), but full femoral bowing was not measured. Fat-pad resection was not documented, although its effect on anterior knee pain has not been proven in the longer term[24]. The patella was rarely resurfaced, so conclusions cannot be drawn regarding TKA with resurfacing. Postoperative skyline radiographs were unavailable, and patellar offset and tilt were not assessed. There was no formal recording of intraoperative patellar tracking. Anterior knee pain rates were measured at 10 years only. Previous studies have shown variation in anterior knee pain over time[1]. However, as implant survival is routinely reported at 10 years this was considered an acceptable time point. Nine percent of patients were lost to follow-up.

Conclusions

Despite a patellofemoral-friendly design, anterior knee pain was reported by 25% of patients alive with an intact prosthesis at 10 years after receiving a single-radius cruciate-retaining TKA without routine patellar resurfacing. When anterior knee pain was present it was associated with inferior PROMs, including an OKS that was worse starting at 1 year. Multivariate analysis showed femoral component flexion, tibial component coronal alignment (medial proximal tibial angle), and patella baja to independently predict long-term anterior knee pain in patients treated with this TKA design. ROC curve analysis demonstrated that femoral component extension predicted anterior knee pain with 87% sensitivity. ■

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