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## ■ KNEE

# Posterior condylar offset is an independent predictor of functional outcome after revision total knee arthroplasty

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## Objectives

Preservation of posterior condylar offset (PCO) has been shown to correlate with improved functional results after primary total knee arthroplasty (TKA). Whether this is also the case for revision TKA, remains unknown. The aim of this study was to assess the independent effect of PCO on early functional outcome after revision TKA.

## Methods

A total of 107 consecutive aseptic revision TKAs were performed by a single surgeon during an eight-year period. The mean age was 69.4 years (39 to 85) and there were 59 female patients and 48 male patients. The Oxford Knee Score (OKS) and Short-form (SF)-12 score were assessed pre-operatively and one year post-operatively. Patient satisfaction was also assessed at one year. Joint line and PCO were assessed radiographically at one year.

## Results

There was a significant improvement in the OKS (10.6 points, 95% confidence interval (CI) 8.8 to 12.3) and the SF-12 physical component score (5.9, 95% CI 4.1 to 7.8). PCO directly correlated with change in OKS ( $p < 0.001$ ). Linear regression analysis confirmed the independent effect of PCO on the OKS ( $p < 0.001$ ) and the SF-12 physical score ( $p = 0.02$ ). The overall rate of satisfaction was 85% and on logistic regression analysis improvement in the OKS ( $p = 0.002$ ) was a significant predictor of patient satisfaction, which is related to PCO; although this was not independently associated with satisfaction.

## Conclusion

Preservation of PCO should be a major consideration when undertaking revision TKA. The option of increasing PCO to balance the flexion gap while maintaining the joint line should be assessed intra-operatively.

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**Keywords:** Knee, Arthroplasty, Revision, Outcome, Condylar offset

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## Article focus

■ The influence of posterior condylar offset on the functional outcome of revision total knee arthroplasty.

- Single surgeon series is a potential weakness and the observed results may not be generalisable to other centres.
- Use of different implants is another limitation of this study.

## Key messages

■ Posterior condylar offset after revision total knee arthroplasty is an independent predictor of functional outcome, and should be maintained and increased to balance the flexion gap if needed.

## Introduction

The rate of total knee arthroplasty (TKA) has increased rapidly during the last decade, and approximately 64 000 are performed each year in the United Kingdom.<sup>1</sup> The frequency of revision surgery has also increased, but at a greater rate, more than doubling in number during the last decade.<sup>2</sup> This revision burden will likely continue to increase into the

## Strengths and limitations

■ The prospective data collection is a major strength of the study.

future due to the accelerating rate of primary TKA and increasing patient longevity. It is acknowledged that the outcome of revision TKA is inferior to primary TKA.<sup>3</sup>

Joint line position after primary TKA has been shown to correlate with functional outcome.<sup>4</sup> Failure to restore the joint line in revision TKA has also been demonstrated to result in a diminished functional outcome.<sup>5,6</sup> This may be related to increased patellofemoral joint contact forces, which increases with elevation of the joint line.<sup>7</sup> Due to distal femoral bone loss, elevation of the joint line in revision TKA may occur if distal femoral augments are not used.<sup>5,6,8</sup> In addition, restoration of posterior femoral condylar offset (PCO) is also an important aspect of revision TKA, providing flexion stability and potentially increasing the range of movement.<sup>9-11</sup> However, restoration of PCO during revision TKA is difficult due to posterior femoral condylar bone loss, which potentially results in undersizing of the femoral component.<sup>12</sup> Hence, to balance the knee in both flexion and extension, a thicker polyethylene insert will be needed, which will result in elevation of the joint line.<sup>12</sup> Two recent studies have highlighted increased PCO after revision TKA with improved outcomes,<sup>13,14</sup> however, whether this independently influences the functional outcome of revision TKA, remains unknown.

The primary aim of this study was to assess the independent effect of PCO on early joint specific functional outcome after revision TKA. The secondary aims were to assess the independent effect of PCO on overall generic health and patient satisfaction after revision TKA.

## Materials and Methods

**Cohort.** During an eight-year period (2004 to 2011), 107 patients with a mean age of 69.4 years (39 to 85, 59 women, 48 men) undergoing revision TKA by the senior author at the study centre had pre- and post-operative outcome data recorded. Patients requiring revision for infection were excluded ( $n = 11$ ). Revision surgery was only performed once a cause for the failure had been identified, being that of instability, polyethylene wear, and/or lysis/subsidence of the primary implant. Patient demographics and comorbidity were recorded at pre-operative assessment. Categories of comorbidity included were: heart disease, hypertension, lung disease, vascular disease, neurological problems, stomach ulcer, kidney disease, liver disease, depression, and back pain.

**Outcome.** The Oxford Knee Score (OKS)<sup>15</sup> and Short-Form (SF-) 12<sup>16</sup> were used to assess joint specific functional outcome and generic health. These were recorded pre-operatively and at one year post-operatively. The OKS consists of 12 questions assessed on a Likert scale with values from 1 to 5, a summative score is then calculated where 12 is the best possible score (least symptomatic) and 60 is the worst possible score (most symptomatic). The physical component score (PCS) of

the SF-12 was used to assess the global physical function of each patient. The mental component score (MCS) of the SF-12 was used to assess the mental health of each patient. A minimal clinically important difference, which is the smallest change in the score thought to be of clinical importance, was defined as five points for both the OKS and SF-12 PCS.<sup>17</sup>

Patient satisfaction with the revision TKA was assessed using a four-point Likert scale at one year after surgery: very satisfied, satisfied, neutral, and unsatisfied. This has been used previously to assess patient satisfaction after TKA,<sup>18</sup> using unsure and unsatisfied categories as the dissatisfied patient group.

**Implant.** During the study period the senior author used the Kinemax Plus Total Stabiliser (TS) (Stryker Howmedica Osteonics, Allendale, New Jersey) from 2004 to 2007, then from 2008 onwards used the Triathlon TS (Stryker®). The design differences are illustrated in Figure 1. The uncemented Kinemax stems were 80 mm and 155 mm in length, whereas the cemented Triathlon stems were 50 mm and 100 mm. All patients were reviewed at a pre-assessment clinic. A standardised rehabilitation protocol was used for all patients. Patients were then reviewed at six weeks, six months and 12 months post-operatively.

Bone loss was classified intra-operatively according to Anderson Orthopaedic Research Institute<sup>19</sup> classification by the senior author (RB) prospectively. Intact metaphyseal bone is defined as type 1, and metaphyseal bone loss without ligament/tendon compromise is defined as type 2. All patients with type 3 defects (metaphyseal bone loss which compromises collateral ligaments or patellar tendon) were excluded, as the implants described above are non-linked semi-constrained designs, and hence depend upon intact collateral ligaments for stability.

**Surgical technique.** All surgical exposures were performed through the original skin incision, with a standard medial parapatellar approach. No patient required a quadriceps snip or turndown, or tibial tubercle osteotomy. A full synovectomy was performed as part of the surgical exposure. The implants were removed as carefully as possible in order to preserve maximal bone stock. At that stage it was decided whether the collateral ligaments were competent. If intact, a TS TKA was used. A pin was inserted into the medial epicondyle, which was used as a reference point to ensure that the joint line and the PCO were restored intra-operatively with the revision prosthesis, using distal and posterior augments as appropriate. The PCO was increased for some patients in order to balance the flexion gap using posterior augments and in some cases increasing the size of the femoral component. The Kinemax TS relied upon hybrid fixation; using uncemented press fit stems and a cemented metaphysis. In contrast, the Triathlon TS uses cement fixation, using third-generation cementing techniques during implantation. The seven-degree anterior flange cut and

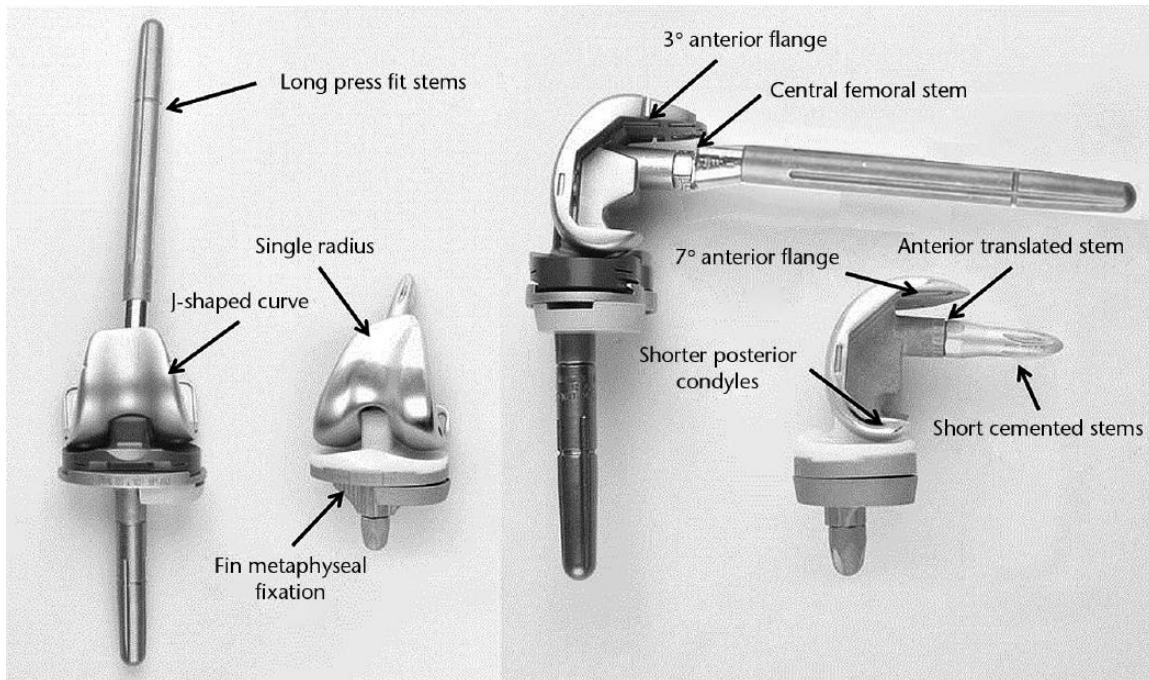


Fig. 1

Anterior and lateral views of the Kinemax TS (to the left) and Triathlon TS (to the right) revision TS TKA systems.

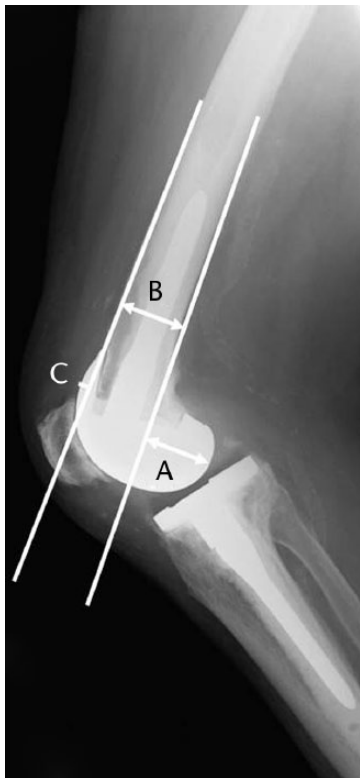


Fig. 2

Measurement of posterior condylar offset (PCO) and anterior condylar offset (ACO) on a true lateral radiograph to the distal femur. PCO was measured (A) relative to the tangent of the posterior cortex of the femur and ACO was measured (C) relative to the tangent of the anterior cortex of the femur. The PCO ratio was calculated by dividing PCO by the width of the femoral diaphysis at the level of the condylar flare (A/B). The ACO ratio was calculated by dividing ACO by the width of the femoral diaphysis at the level of the condylar flare (C/B).

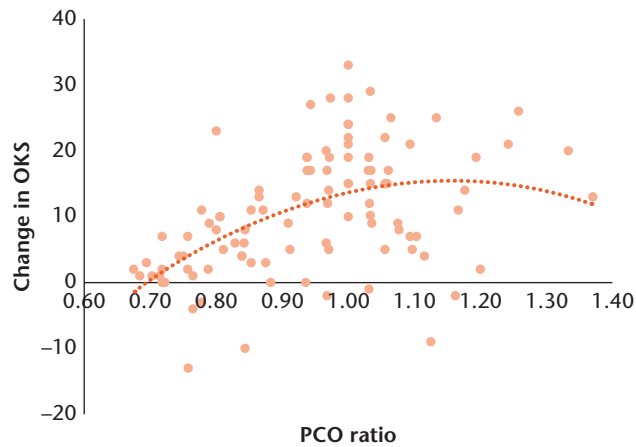
anterior translation of the femoral stem in the Triathlon TS TKA avoided extension and anterior displacement of the femoral component during implantation. The short cemented stems facilitated slight flexion of the component and allowed the PCO to be increased to balance the flexion gap. It was not standard practice to resurface the patella during the revision surgery, and was only performed if a patient displayed patellofemoral symptoms.

**Radiographic assessment.** The one-year post-operative radiograph was assessed for limb alignment, joint line position, and PCO by an independent researcher (NDC). Limb alignment was measured as described by Luo.<sup>20</sup> Joint line was measured relative to the tibial tuberosity, as described by Figgie et al,<sup>21</sup> and the difference relative to pre-operative radiographs (primary knee) was used as a linear variable to assess the effect upon outcome. PCO was measured on a true lateral radiograph according to the technique described by Bellemans et al,<sup>9</sup> and was corrected for radiographic magnification using the femoral diameter at the level of the posterior flare to calculate a ratio (Fig. 2).<sup>22</sup> Anterior condylar offset (ACO) was also measured using a similar technique, as used to assess PCO which was also corrected for radiographic magnification using the femoral diameter at the level of the posterior flare to calculate a ratio (Fig. 2).

**Statistical analysis.** The Statistical Package for Social Sciences version 17.0 (SPSS Inc., Chicago, Illinois) was used to analyse data. Parametric and non-parametric tests were used as appropriate to assess continuous variables for significant differences. All linear variables demonstrated normal distribution, except the number of

**Table I.** Outcome scores for the complete cohort (n = 107)

Score	Pre-operative	Post-operative	Difference (95% confidence interval)	p-value*
Oxford Knee Score (mean, SD)	40.6 (7.7)	30.0 (11.1)	10.6 (8.8 to 12.4)	< 0.0001
Short form-12 physical component score (mean, SD)	30.0 (8.1)	35.7 (10.6)	5.9 (4.1 to 7.8)	< 0.0001
Short form-12 mental component score (mean, SD)	47.2 (12.6)	49.5 (11.3)	2.2 (0.1 to 4.4)	0.04

\*paired student's *t*-test**Fig. 3**

Graph showing the correlation between posterior condylar offset (PCO) ratio and improvement in Oxford Knee Score (OKS) one year after revision total knee arthroplasty ( $r = 0.45$ ,  $p < 0.001$  Pearson's correlation).

comorbidities per patient. Paired or unpaired Student's *t*-tests, or a Mann Whitney U-test, were used to compare linear variables. Pearson's or a Spearman's rank correlation were used to assess the relationship between linear variables. Dichotomous variables were assessed using a chi-squared or a Fisher's exact test if one or more variables included  $< 5$ . Multivariable linear regression and logistic regression analyses were used to assess the independent effects of predictors significant to the 10% level or less on a univariable analysis, for change in outcome scores and satisfaction, respectively. A p-value of  $\leq 0.05$  was considered significant.

Ethical approval was obtained for analysis and publication of the presented data from the regional ethics committee (11/AL/0079).

## Results

The mean age of the study group was 69.4 years (SD 9.2, 39 to 85). There was a female predominance of 59 patients (55.1%), compared with 48 male patients. The mean number of comorbidities was 2 (SD 1.6, 0 to 6), with only 25 patients (23.4%) having no reported comorbidity. No patients' recovery was complicated by infection, or need for re-revision before the one-year assessment. The mean pre-operative PCO ratio was 0.782 (SD 0.160), which increased significantly ( $p = 0.001$ , paired *t*-test) post-operatively to 0.947 (SD 0.152). The joint line did not significantly change relative

**Table II.** Predictors of change in the outcome measures after revision total knee arthroplasty on univariable analysis. Numbers in bold indicate statistical significance

Predictor		Change in outcome score		
		OKS	SF-12 PCS	SF-12 MCS
Age (yrs)	Correlation	0.22	0.21	-0.08
	p-value*	<b>0.02</b>	<b>0.03</b>	0.41
Gender	Male	10.9	5.8	1.0
	Female	10.3	6.1	3.2
Comorbidities	p-value†	0.76	0.88	0.31
	Correlation	0.08	-0.13	-0.16
Pre-operative outcome scores	p-value‡	0.43	0.12	0.11
	OKS	0.14	-0.11	-0.1
SF-12 PCS	Correlation	0.15	0.26	0.37
	p-value*	0.01	-0.30	0.21
SF-12 MCS	Correlation	0.92	<b>0.002</b>	<b>0.03</b>
	p-value*	0.05	0.14	-0.56
PCO	Correlation	0.61	0.14	<b>&lt; 0.0001</b>
	p-value*	<b>&lt; 0.0001</b>	<b>0.002</b>	0.34
ACO	Correlation	-0.38	-0.21	0.51
	p-value*	<b>0.0001</b>	<b>0.03</b>	0.56
Joint line	Correlation	-0.15	-0.06	-0.21
	p-value*	0.13	0.57	<b>0.03</b>
Implant	Kinemax	8.3	3.2	0.16
	Triathlon	12.9	8.6	4.3
	p-value†	<b>0.009</b>	<b>0.04</b>	0.06

\*Pearson correlation

†Student's *t*-test

‡Spearman's rank correlation

OKS, Oxford Knee Score; SF, short form; MCS, mental component score; PCS, physical component score; PCO, posterior condylar offset; ACO, anterior condylar offset

to pre-operative radiographs (difference 2 mm,  $p = 0.12$ , paired *t*-test).

Overall, there was a significant improvement in the OKS and SF-12 PCS and MCS (Table I), of which the OKS and SF-12 PCS were beyond the minimal clinically important difference of five points. Increasing age and PCO ratio (Fig. 3), decreasing ACO ratio, and those receiving a Triathlon TS implant, were associated with a significantly greater improvement in the OKS at one year on univariable analysis (Table II). These variables were also significant predictors of improvement in the SF-12 PCS post-operatively. In addition, a poorer pre-operative SF-12 PCS was also associated with a greater improvement in this outcome measure post-operatively (Table II). In contrast, a better pre-operative SF-12 PCS was associated with a greater improvement in the SF-12 MCS

**Table III.** Multivariate linear regression analysis to identify independent predictors of improvement in outcome measures after revision total knee arthroplasty (TKA)

Predictors in model	B	95% confidence intervals		p-value*
Improvement in OKS (R <sup>2</sup> = 0.20)				
PCO ratio	27.6	16.74	38.47	< 0.0001
Constant	-15.48	-25.9	-5.06	0.004
Improvement in SF-12 PCS (R <sup>2</sup> = 0.18)				
Pre-operative SF-12 PCS	-0.36	-0.57	-0.14	0.002
PCO ratio	18.38	6.68	30.08	0.02
Constant	-0.94	-14.29	12.41	0.89
Improvement in SF-12 MCS (R <sup>2</sup> = 0.36)				
Pre-operative SF-12 MCS	-0.51	-0.66	-0.37	< 0.0001
Triathlon TS TKA (Stryker)	3.71	0.05	7.38	0.047
Constant	24.73	17.34	32.13	< 0.0001

\*Multivariate linear regression

OKS, Oxford Knee Score; SF, short form; MCS, mental component score; PCS, physical component score; PCO, posterior condylar offset; ACO, anterior condylar offset

**Table IV.** Predictors of satisfaction after revision total knee arthroplasty on univariable analysis (n = 106)

Predictor	Satisfied (n = 91)	Dissatisfied (n = 15)	Difference (95% confidence interval)	p-value
Age (yrs: mean, SD)	69.8 (8.9)	66.6 (10.3)	3.3 (-1.8 to 8.3)	0.20*
Gender (male/female)	42/50	6/9	–	0.68†
Comorbidities (n: mean, SD)	2.0 (1.6)	2.4 (1.2)	0.4 (-1.2 to 0.5)	0.38‡
Pre-operative (mean, SD)				
OKS	40.7 (7.5)	40.1 (8.8)	0.6 (-3.6 to 4.9)	0.77*
SF-12 PCS	29.4 (8.0)	31.8 (8.8)	2.3 (-6.8 to 2.1)	0.31*
SF-12 MCS	47.9 (12.9)	43.1 (11.0)	4.7 (-2.2 to 11.7)	0.18*
Change in score (mean, SD)				
OKS	12.3 (8.6)	0.3 (5.6)	12.0 (7.4 to 16.5)	< 0.0001*
SF-12 PCS	7.1 (9.5)	-1.5 (8.2)	8.6 (3.5 to 13.8)	0.001*
SF-12 MCS	2.4 (11.1)	1.0 (8.2)	1.4 (-4.9 to 7.7)	0.65*
PCO ratio (mean, SD)	0.97 (0.15)	0.82 (0.11)	0.15 (0.07 to 0.23)	< 0.0001*
ACO ratio (mean, SD)	0.15 (0.10)	0.21 (0.09)	0.06 (0.01 to 0.11)	0.002*
Joint line (mean, SD)	0.1 (4.6)	3.3 (4.5)	3.2 (0.61 to 5.76)	0.016*
Implant (Kinemax/Triathlon)	39/53	14/1	–	< 0.0001†

\*t-test

†Fishers exact test

‡Mann Whitney U test

OKS, Oxford Knee Score; SF, short form; MCS, mental component score; PCS, physical component score; PCO, posterior condylar offset; ACO, anterior condylar offset

post-operatively. There was no significant correlation between time of surgery and outcome measure for either group (Spearman  $p > 0.4$ ). Interestingly, increasing PCO ratio was associated with a greater improvement in the OKS for both the Kinemax ( $r = 0.43$ ,  $p < 0.001$  Pearson) and Triathlon ( $r = 0.45$ ,  $p < 0.001$ , Pearson) groups.

Variables from Table II, significant at the 10% level ( $p \leq 0.1$ ) on univariable analysis, were entered into linear regression models using stepwise methodology. PCO ratio was a significant independent predictor of the OKS (primary outcome) and the SF-12 PCS (secondary outcome) when adjusting for confounding variables (Table III).

The overall satisfaction rate was 85%, with 91 patients being very satisfied or satisfied with their outcome at one year. However, one patient did not complete this in their questionnaire, hence 15 patients were either unsure or dissatisfied. A greater change in OKS and SF-12 PCS, increased PCO ratio, decreased ACO ratio, restoration of

joint line, and Triathlon TS implant were associated with a greater rate of patient satisfaction at one year on univariable analysis (Table IV). Entering these variables into the multivariable bivariate regression model confirmed that improvement in OKS and Triathlon TS implant were independent predictors of one-year satisfaction (Table V).

## Discussion

This study has demonstrated that PCO is an independent predictor of early functional outcome, for both the joint specific OKS and generic physical health SF-12 score, after aseptic revision TKA. Patient satisfaction was shown to be high (85%) overall and that a greater improvement in the OKS was associated with a greater rate of patient satisfaction. Hence, preservation of the PCO should be a major consideration in the pre-operative planning when performing a revision TKA.

Restoration of the native joint line during revision total knee surgery TKA is difficult, and failure to restore this

**Table V.** Predictors of satisfaction after revision total knee arthroplasty (TKA) on bivariate regression analysis. All variables significant at the 10% level (Table IV) were all entered into the model using forward conditional methodology (Nagelkerke  $R^2 = 0.50$ )

Predictors of model	B	Odds Ratio	95% confidence intervals	p-value
Change OKS	0.23	1.26	1.11 to 1.43	<b>0.002</b>
Triathlon TS TKA (Stryker)	2.42	1.24	1.09 to 1.43	<b>0.04</b>
Constant	-0.02	0.98	-	<b>0.97</b>

OKS, Oxford Knee Score

results in a poor functional outcome for the patient.<sup>5,6,12</sup> Porteous et al<sup>6</sup> demonstrated a diminished functional outcome in patients undergoing revision TKA with elevation of the joint line more than 5 mm. Partington et al<sup>5</sup> also showed that elevation of the joint line after revision TKA resulted in a poorer functional outcome, but they found a greater tolerance of up to 8 mm. We also identified joint line to be a factor in predicting functional outcome on univariable analysis. However, when adjusting for confounding variables, PCO ratio was the only radiographic predictor of outcome. Neither Porteous et al<sup>6</sup> nor Partington et al<sup>5</sup> analysed the effect of PCO on outcome, and it may be those patients who had their joint line restored also had a greater PCO to balance the knee in flexion. Those patients with an elevated joint line may have had downsizing of the femoral component with subsequent loss of PCO;<sup>12</sup> a compromise that some authors propose to balance the knee.<sup>23</sup> Hence, this would explain the results of Porteous et al<sup>6</sup> or Partington et al,<sup>5</sup> and how these relate to our findings.

It is acknowledged that restoration of an adequate PCO in revision TKA is important – providing stability in flexion and limiting posterior tibiofemoral impingement in deep flexion.<sup>9,12</sup> PCO can be increased with use of an oversized component, a flexed stemmed implant that displaces the condylar component posteriorly, or posterior offset stem coupler. However, use of an oversized component may cause soft-tissue impingement resulting in pain.<sup>24</sup> The use of intramedullary stems to provide implant stability has been shown to influence the anteroposterior position of the condylar portion of the femoral component.<sup>25</sup> Furthermore, straight femoral stems have been shown to result in a diminished PCO relative to offset stems.<sup>26</sup> Flexion of the stem may result in anterior bony impingement between the proximal uncemented stem tip and anterior femoral cortex, which may contribute to stem tip pain.<sup>27</sup> However, modern revision systems using short anterior translated cemented stems, allow the surgeon to maintain PCO and avoid the need to oversize without the risk of tip contact pain.

This study has identified PCO to be an independent predictor of outcome after revision TKA, with increasing PCO resulting in an improved outcome which has been

observed for primary TKA previously.<sup>9,10</sup> Malviya et al<sup>10</sup> demonstrated that after primary TKA, joint line was not a predictor of range of movement, but similar to our results, they found PCO to have a greater and more significant correlation. A recent study demonstrated that the normal PCO ratio is 0.80.<sup>28</sup> Interestingly, the mean PCO ratio for the Kinemax TS group was 0.86, which is greater than that predicted for the patients' native knee. Furthermore, the mean PCO ratio in the Triathlon group was 1.04, even greater than that predicted for their native knee. This increase in PCO with a balanced TKA is only possible if there has been soft-tissue disruption, which is likely at revision surgery.<sup>23</sup> The posterior cruciate ligament will have been excised and the popliteus tendon will probably have lost its insertion due to condylar bone loss. In addition, the posterior capsule will have probably been disrupted. Increasing the PCO beyond that expected in the native knee probably compensates for this soft-tissue disruption and allows for a non-linked semi constrained revision TKA to be used. Furthermore, there is evidence that increasing PCO tightens the extension gap in primary TKA,<sup>29</sup> and hence increasing this in revision TKA may help with ligamentous stability of the knee not only in flexion, but also in extension with increased soft-tissue tension as the posterior structures bow string over the condyles. However, we acknowledge that there is a point of diminishing return when the PCO increases to the extent the knee becomes tight, and flexion is reduced. We have shown that with a PCO ratio beyond 1.1, which is approximately 40% greater than the native knee, no further improvement in the OKS was observed and is likely the upper limit that should be accepted.

An interesting observation of this study was the finding that patients receiving a Triathlon TS TKA were more likely to have a significant improvement in their mental wellbeing. This is probably due to the superior outcome associated with the Triathlon group, with an improved outcome associated with an improvement in a patient's mental well-being. This may be due to the pain relief achieved by their implant, evident from their improved OKS, as chronic pain has been demonstrated to have a negative effect on mental health.<sup>30</sup>

There are several limitations to the current study, which included different implants, that were performed by a single surgeon in a relative small cohort of patients. The reason for including both implants was simply due to evolution of implant design over the study period, as the data were collected prospectively we continued with the original protocol after the change. Although the single surgeon series may be a limiting factor, the surgical technique did not change during the study period. However, with the change in the implant design this did facilitate maintenance of the PCO. The current study is a small cohort of patients, but there are relatively few published studies reporting larger cohorts

with radiographic measures. To minimise these limitations joint registries may be able to collect such data including implant size, radiographic measures, and functional outcome on a national scale to help affirm the influence of PCO.

The revision burden of TKA will likely continue to increase in the future, and the optimal outcome is essential to limit patient disability. Preservation of PCO should be a major consideration when undertaking revision TKA, and increasing PCO to balance the flexion gap while maintaining joint line should be assessed intra-operatively.

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## Author Contribution

- N. D. Clement: Study concept, data collection and/or analysis, editing and approval of the final manuscript.
- D. J. MacDonald: data collection and/or analysis, editing and approval of the final manuscript.
- D. F. Hamilton: data collection and/or analysis, editing and approval of the final manuscript.
- R. Burnett: Study concept, data collection and/or analysis, editing and approval of the final manuscript.

## ICMJE Conflicts of Interest

- None declared.

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