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Original research

Additional Distal Femoral Resection Minimally Improves Terminal Knee Extension: A Systematic Review and Meta-Regression Challenging the Dogma

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A B S T R A C T

Background: Additional distal femoral resection is a common technique to address a flexion contracture during primary total knee arthroplasty (TKA) but can lead to midflexion instability and patella baja. Prior reports regarding the magnitude of knee extension obtained with additional femoral resection have varied. This study sought to systematically review research describing the effect of femoral resection on knee extension and to perform meta-regression to estimate this relationship.

Methods: A systematic review was conducted using MEDLINE, PubMed, and Cochrane databases by combining the terms ("flexion contracture" OR "flexion deformity") AND ("knee arthroplasty" OR "knee replacement") to identify 481 abstracts. In total, 7 articles reporting change in knee extension after additional femoral resection or augmentation across 184 knees were included. The mean value for knee extension, its standard deviation, and the number of knees tested were recorded for each level. Meta-regression was performed using weighted mixed-effects linear regression.

Results: Meta-regression estimated that each 1mm resected from the joint line produced a 2.5° gain of extension (95% confidence interval, 1.7 to 3.2). Sensitivity analyses excluding outlying observations estimated each 1mm resected from the joint line produced a 2.0° gain of extension (95% confidence interval, 1.9 to 2.2).

Conclusions: Each millimeter of additional femoral resection is likely to produce only a 2° improvement in knee extension. Thus, an additional resection of 2 mm is likely to improve knee extension by less than 5°. Alternative techniques, including posterior capsular release and posterior osteophyte resection, should be considered in correcting a flexion contracture during TKA.

Introduction

Primary total knee arthroplasty (TKA) is successful in relieving pain and improving patient function, but up to 20% of patients remain unsatisfied with their surgical outcome [1]. Multiple factors of patient dissatisfaction have been described including improper correction of preoperative flexion contracture resulting in continued postoperative contracture and unfulfilled patient expectations [2–4]. Postoperative flexion contracture leads to restricted range of motion, diminished knee function, and fatigue during standing, walking, and stair climbing [5–9].

Several surgical methods to correct preoperative flexion contracture have been described including intraoperative manipulation, removal of posterior condylar osteophytes and loose bodies, posterior capsular release, posterior cruciate ligament release, decrease of posterior condylar offset, and additional resection of the distal femur [10–21]. No consensus has emerged on the optimal technique to restore full extension [22]. Historical studies have documented varying degrees of flexion contracture correction with incremental increases in distal femur resection. Bengs and Scott [10]

2-DePuy, EOS Imaging, Intellijoint Surgical, Smith & Nephew, OrthAlign, BoneSupport; 3B-DePuy, EOS Imaging, Intellijoint Surgical, Lima Corporate, Zimmer Smith & Nephew, OrthAlign, BoneSupport; 4-Intellijoint Surgical, MiCare, ROM-Tech, Parvizi Surgical Innovation; 5-Intellijoint Surgical, Smith & Nephew, Medtronic, BoneSupport, Stryker, Zimmer/Biomet; 8-JAAOS, JoA, The Knee, Journal of Hip Surgery, American Journal of Sports Medicine; 9-BOC.

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found that an average of 9° of contracture could be corrected with every 2 mm of additional distal femur resection when measuring this using a manual goniometer. This degree of expected correction has subsequently become ingrained in orthopedic teaching.

While preplanned additional femoral resection may be considered a simple method to perform intraoperatively, it has been shown to cause problems associated with joint line elevation- mid flexion instability and pseudopatella baja [23–28]. More recent studies have demonstrated less of a correction with additional distal femoral resection than those reported by Bengs and Scott [13,24,25,29–31]. There may also be variation associated with whether the posterior cruciate ligament is maintained though historically its release has been associated with increasing the flexion space [32,33]. This study sought to systematically review research describing the effect of femoral resection on knee extension and to perform meta-regression to estimate this relationship. We hypothesized that the increase in terminal extension associated with additional femoral resection would vary across studies but that meta-regression would estimate less than 4° of gained extension for a 1mm resection.

Material and methods

Literature search

A systematic review of the literature was conducted in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines [34]. Electronic searches were performed in the MEDLINE (EBSCO), PubMed, and Cochrane databases during February 2022. To achieve maximum sensitivity, the terms (“flexion contracture” OR “flexion deformity”) AND (“knee arthroplasty” OR “knee replacement”) were combined as keywords. The reference lists of retrieved articles were reviewed to identify any additional relevant studies as per the inclusion and exclusion criteria as listed below. This search identified 481 abstracts which were reviewed.

Selection criteria

Studies eligible for this systematic review included English-language studies published at any time that addressed or reported intraoperative factors in TKA for osteoarthritis that affect correction of fixed flexion deformity. Specifically, studies involving TKA with an assessment of flexion contracture correction by method of additional distal femoral resection or the creation of a flexion deformity (loss of passive extension) by way of augmentation to the distal femur were included. Studies that did not specifically measure the amount of distal femoral resection or augmentation or the degree of change in passive extension were excluded. Studies in which assessment of the change in extension was not from distal femoral resection in isolation or not in a reported step-wise fashion (if techniques of correction included other measures to increase the knee extension, such as a posterior capsule release) were excluded. Studies in which it was not possible to obtain data from the publication were also excluded. Studies investigating other conditions such as rheumatoid arthritis or hemophiliac arthropathy were excluded. Case reports, abstracts and conference proceedings were also excluded. Of the 481 abstracts reviewed, 14 articles were reviewed in full with 7 articles included, 2 of which were identified through the review of references (Fig. 1). Of these, 5 were level II studies of human patients and 2 were basic science studies, one using a computer model and the other cadavers. The Newcastle-Ottawa Quality Assessment Scale was also applied to each article to assess quality [35]. All studies were found to be of high quality though the cadaver and computer model studies lost a star for quality of selection and 1 article lost a star for quality of outcome assessment (Appendix B).

Data extraction

Data regarding the amount of distal femur resected or augmented as well as the change in degrees of passive knee extension were extracted from the text, figures, and tables of included references. The type of knee prosthesis and any additional methods of flexion deformity correction were recorded.

Statistical analysis

The mean value for knee extension, the standard deviation about this mean, and the number of samples tested were recorded for each joint line level tested in each study. As each study measured extension values across multiple joint line levels, all studies contributed multiple observations. Given the summary estimate, the mean knee extension, has intrinsic value, it was not standardized. Weights were created for these summary estimates as the inverse of the variance. These observations were then plotted with the size of the marker reflecting the weight so the association between changes to the joint line and knee extension could be visually assessed. Study-specific linear trend lines were added to aid in the visual assessment of the form of the association between joint line change and knee extension.

Meta-regression was then performed using a mixed-effects linear regression model to empirically assess the association between joint line change and knee extension. Prior to fitting the model, the results from all studies were transformed through addition so that the range of motion value measured at the joint line was set to neutral for each study. Additionally, other forms for the association were explored. These results were also plotted and visually inspected. Knee extension was used as the dependent variable. Joint line change was the independent variable and models as both a fixed and random effect. The fixed effect represents the estimate of the expected change in knee extension with a change to the joint line. The random effect allows this slope to vary within studies. As extension at the joint line was set to neutral, the intercept was set as fixed and not random. Weights were used. Given one study had an outlying form and another an outlying slope, a sensitivity analysis was performed with some observations excluded.

Results

Article methodology and designs of included studies employed a variety of surgical techniques, knee implant designs, and measurement techniques for extension range of motion. The literature search retrieved 7 intraoperative cohort studies with 2 of the studies on cadavers. Knee range of motion was assessed with different methods. Goniometers were used in 1 study; 1 study used intraoperative photographs and skin markers; 5 studies used computerized navigation. All passive extension measurements were assessed at the time of surgery (or in the cadaver studies at the time of modeling) without clinical follow-up (Table 1).

Mean knee extension measured at the joint line varied across studies (Fig. 2A). In most studies, the association between change to the joint line with knee extension appeared linear. In most studies, the linear association between change to the joint line with knee extension appeared to have a similar slope. After transforming the range of motion value measured at the joint line to neutral, the similarity in the linear form and slope of the association between change to the joint line with mean knee extension is more evident (Fig. 2B).

Meta-regression estimated that each 1mm added to the joint line is associated with a 2.5° loss of extension (95% confidence interval, 1.7 to 3.2) (Fig. 3A). Sensitivity analyses estimated that each 1mm added to the joint line is associated with a 2.0° loss of extension (95% confidence interval, 1.9 to 2.2) (Fig. 3B).

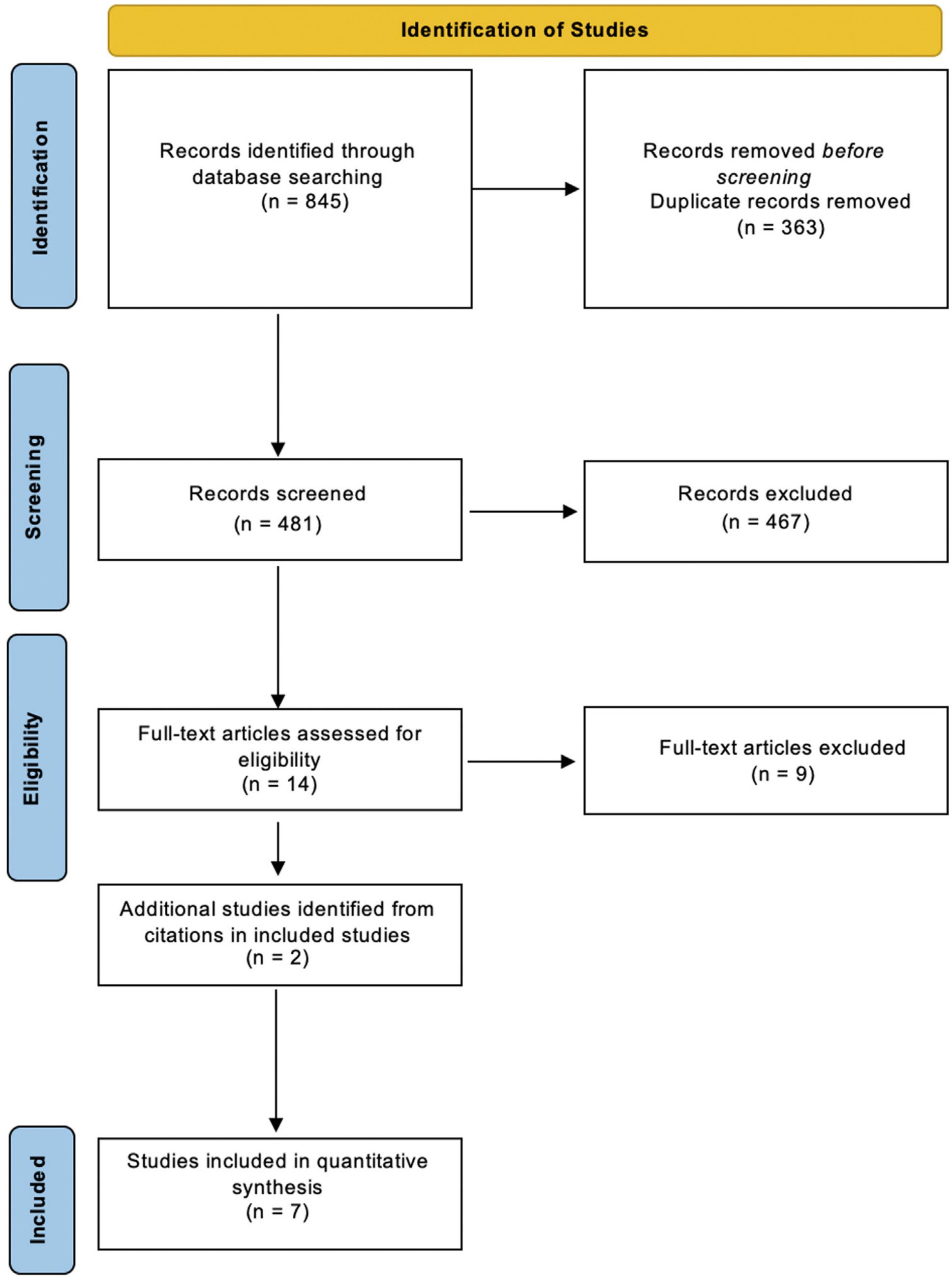

Figure 1. PRISMA selection process. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

Discussion

This systematic review estimated that the expected gain in passive knee extension associated with an additional 2 mm of distal femoral resection is less than 5° and is consistent with more recent evidence challenging the dogma of additional distal femoral resection being a first-line strategy for addressing flexion contracture in TKA.

While performing TKA, the orthopedic surgeon is often faced with a patient that has a preoperative flexion contracture. A common goal is to alleviate the contracture during surgery. Kim et al. [36] found that an extension angle between 0 and 5° in the passive extension position immediately after TKA can be considered ideal, whereas patients with flexion contracture greater than 5° should be followed to assess whether residual contracture will worsen. There are a few studies to support conservative management of residual flexion contracture. Quah et al. [37] found that gradual improvement in the flexion contracture can be expected up to 2 years and a small residual flexion contracture does not cause functional deficit. Tanzer and Miller [38] reported on 35 knees with fixed flexion contractures on average preoperatively 12.9°; immediately postoperatively, 14.8°; and at final follow-up, 2.9°. They suggested that knee flexion contractures can significantly improve after TKA and there is not an indication for excessive removal of bone to achieve intraoperative correction.

Multiple algorithms have been described for correcting fixed flexion deformity [11,18,21,39–41]. A common theme in all of them is the step of additional distal femoral resection. Our results call the utility of this step into question. Our meta-regression found that 2 mm of additional distal femoral resection is likely to produce only a

Table 1
Description of articles included in the systematic review.

First author	Year	Study design	Study population	Intervention	Method of measuring knee extension	Study results
Bengs	2006	Intraoperative Cohort	30 CR total knee replacements	Balanced intraoperative knee then added distal femoral augments 2 mm to 8 mm	Goniometer 1° markings recorded to nearest 5° increments	9° of passive extension per 2 mm of distal femoral resection
Smith	2010	Intraoperative Cohort	27 CR total knee replacements, 2 subsequently excluded	Balanced intraoperative knee then added distal femoral augments 1.5 mm and 3.0 mm	Digital image analysis based on intraoperative photographs of markers attached to the leg	1.8° of passive knee extension per 1 mm of distal femoral resection
Cross	2012	Cadaver Cohort	7 PS cadaver total knee replacements	Additional distal femur resection of 2 mm and 4 mm performed after creation of 10° flexion contracture by way of posterior capsular imbrication	Computer navigation	Maximum knee extension increased from 10° of flexion to 6.4° and to 1.4° of flexion with each 2mm recut of the distal femur
Liu	2016	Intraoperative Cohort	50 CR total knee replacements	Balanced intraoperative knee then added distal femoral augments 2 mm to 8 mm	Computer navigation	Correcting 10° of preoperative fixed flexion to full extension requires an extra 3.55 mm of distal femoral resection
Kim	2017	Intraoperative Cohort	59 PS total knee replacements – 43 managed with soft-tissue balancing only – 16 cases with additional 2 mm distal femoral resection	Additional 2 mm of distal femoral resection after soft tissue balancing	Computer navigation	Mean difference in flexion contracture angle of 4.8° after 2 mm of additional femoral bone resection
Matziolis	2020	Intraoperative Cohort	50 PS total knee replacements	Balanced intraoperative knee then added distal femoral augments 2.7 mm to 8.5 mm	Computer navigation	2.2° flexion deformity per mm distal femoral augmentation
Elmasry	2021	Cadaver Cohort	Computational modeling of 6 cadaver PS total knee replacements	Additional 2mm and 4 mm distal femur resection after simulation of 10° flexion contracture	Computer simulation	2 mm achieved a mean extension angle of 5.4° 4 mm achieved mean extension angles of 1.7°

4° improvement in knee extension. Bengs and Scott [10] estimated that for an additional 2 mm of resection, that 9° of passive knee extension could be attained. Subsequent authors found significantly less correction using the method of additional distal femoral resection. Smith et al. [31] estimated the achievable correction for 2 mm of additional resection at 3.6°; Cross et al. [24], 3.3°; Liu et al. [29], 3.4°; Kim et al. [13], 4.8°; Matziolis et al. [30], 4.4°; Elmasry et al. [25], 4.6°.

The potential negative kinematic implications of raising the joint line have received increased attention recently. Cross et al. [24] found joint line elevation in primary TKA to be associated with midflexion instability. This finding was substantiated further by Chalmers et al. in their computational knee models. They found with an additional 2 mm resection of the distal femur, at 30° and 45° of flexion, coronal laxity increased by a mean of 3.1° and 2.7°, respectively. With +4 mm resection at 30° and 45° of flexion, mean coronal laxity increased by 6.5° and 5.5°, respectively. Maximum increased coronal laxity for a +4 mm resection occurred at a mean 15.7° (11° to 33°) of flexion with a mean increase of 7.8° from baseline [23]. A follow-up study utilizing a midlevel constrained poly in place of a standard PS insert in this computational model reduced the coupled axial rotation but did not substantially change the coronal laxity caused by the joint line elevation. The authors concluded that efforts should be taken to avoid joint line elevation in primary total knee arthroplasty as even midlevel constrained inserts may not mitigate the coronal laxity created by joint line elevation [42].

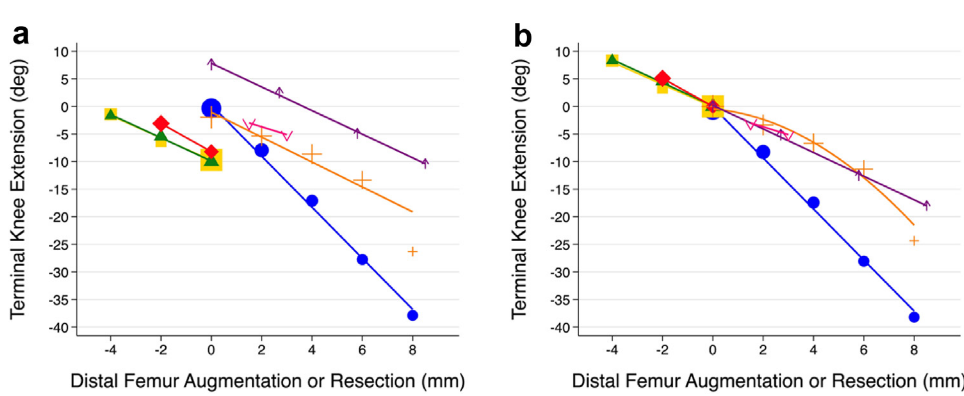

Figure 2. Scatter plot of mean terminal knee extension over distal femur augmentation or resection by study with markers representing the mean for each augmentation or resection level and a linear trend line placed for each study (A) and scatter plot of terminal knee extension over distal femur augmentation or resection by study with markers representing the mean for each augmentation or resection level studied with terminal knee extension corrected to 0 for the augmentation or resection value of 0 and a trend line that could be linear or polynomial placed for each study (B). Blue circle is Bengs et al., gold square is Cross et al., green triangle is Elmasry et al., red diamond is Kim et al., orange plus is Liu et al., purple arrow is Matziolis et al., and pink descending wedge is Smith et al.).

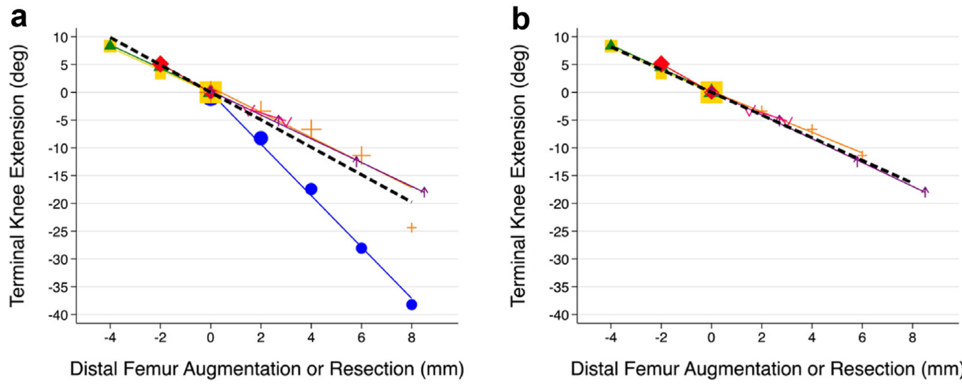

Figure 3. Scatter plot of terminal knee extension over distal femur augmentation by study with markers representing the mean for each augmentation or resection level studied with terminal knee extension corrected to 0 for the augmentation or resection value of 0 and linear trend line for each study. There is also an overall trend line for all studies produced by meta-regression, black dashed line (A) and Scatter plot of terminal knee extension over distal femur augmentation by study with markers representing the mean for each augmentation or resection level studied with terminal knee extension corrected to 0 for the augmentation or resection value of 0 and linear trend line for each study and outliers excluded. There is also an overall trend line for all studies produced by meta-regression with the outliers excluded, black dashed line (B). Blue circle is Bengs et al., gold square is Cross et al., green triangle is Elmasry et al., red diamond is Kim et al., orange plus is Liu et al., purple arrow is Matziolis et al., and pink descending wedge is Smith et al.).

More recently, alternative methods of correcting flexion contracture that do not alter the joint line have been studied. Chai et al. [12] described posterior capsulectomy in 32 knees with severe flexion contractures (>30°) at an average follow-up of 27 months. The flexion contracture improved from preoperative 37.69° ± 11.79° to postoperative 5.78° ± 4.44° ($P < .001$). They had no implant loosening, infection, hematomas, instability, neurovascular complications, or revision TKA for any reason. Okamoto et al. [19] also found capsular release around the intercondylar notch to increase the extension gap and prevent postoperative flexion contracture. Kinoshita et al. [14] performed a cadaveric study identifying attachment sites of the posterior capsule using computed tomography scan. They performed a stepwise release and found the gastrocnemius tendon and posterior capsule were integrally attached to the femoral cortex at the medial and lateral condyles, whereas the posterior capsule at the intercondylar fossa was independently attached directly to the femoral cortex. The posterior capsule at the intercondylar fossa was attached most distally among each femoral condyle. Posterior capsular release at the intercondylar fossa allowed 11.4° ± 2.8° improvement in knee extension. This angle was further increased by 5.5° ± 1.3°, after subsequent capsular release at the medial and lateral condyles.

Removal of posterior osteophytes, also termed posterior clearance, has been used for a long time but the degree of correction was recently quantified using navigation by Sasaki et al [43]. They estimated that posterior clearance/removal of posterior osteophytes resulted in an increased knee extension of 4.9° ± 1.6°. Leie et al. discovered similar amounts of correction with osteophyte removal using a classification system based on the size of the posterior osteophytes. Small osteophytes (grade 1) did not seem to affect the amount of extension, while removing grade 2 or grade 3 osteophytes led to a gain in extension of 2.7° and 4.5°, respectively [15]. A corollary to removal of tension on the posterior capsule by posterior osteophytes, Leie et al. [16] found that posterior femoral condyle offset as an independent variable affecting correction of flexion contracture. When patients had a combined posteromedial and posterolateral offset 2 mm thinner than the thickness of bone resected, there was an average correction of 3.5° of flexion contracture. Kim et al. [13] found significant differences in flexion contracture angle in all steps except between the posterior clearing step and final angle measurement. The mean difference in flexion contracture angle between after trial insertion and after posterior clearing procedure was 2.7° ± 1.9°. We did not find evidence that there was a significance difference in the expected change in terminal extension with additional distal femoral resection based on whether the components studied were cruciate retaining or posterior stabilized (Appendix A).

Limitations of this study include the relatively small number of studies included, varying study designs, varying knee implants, and the inherent limitations of each study included in the analysis. Bengs and Scott measured knee extension using a goniometer, which is less accurate compared to computer navigation. Smith et al. used skin markers and digital photography to measure the flexion angle, which may increase error due to differences in soft tissue mass between patients. A common technique in Beng and Scott [10], Smith et al. [31], Liu et al. [29], and Matziolis et al. [30] was to measure extension intraoperatively after blocks/augments of different thicknesses were added to the distal femur. The concept was this would be equivalent to the reverse (resecting more distal femur) but it may not be the same, due to saw blade thickness/cutting blocks not allowing perfect resections.

Conclusions

This study estimates that each millimeter of additional distal femoral resection is likely to produce only a 2° improvement in knee extension. Thus, an additional resection of 2 mm is likely to improve knee extension by less than 5°. This amount may be less than what is expected by practicing surgeons. Alternative techniques, including posterior capsular release and posterior osteophyte resection, may provide more meaningful correction without changing the joint line and should be considered in correcting a flexion contracture during TKA.

Source of funding

There was no source of external funding for this work.

Conflicts of interest

Stephen T. Duncan is a board member of BOC; is a member of JAAOS, JOA, The Knee, and Journal of Hip Surgery boards; received research support from Smith and Nephew, Medtronic, Bone-Support, Stryker, and Zimmer/Biomet; has stocks in MiCare and ROMTech; and is a paid consultant and a speaker for Smith and Nephew, OrthAlign and BoneSupport. David C. Landy is a member of Am J Sports Med. The other authors declare no potential conflicts of interests.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2022.101083.

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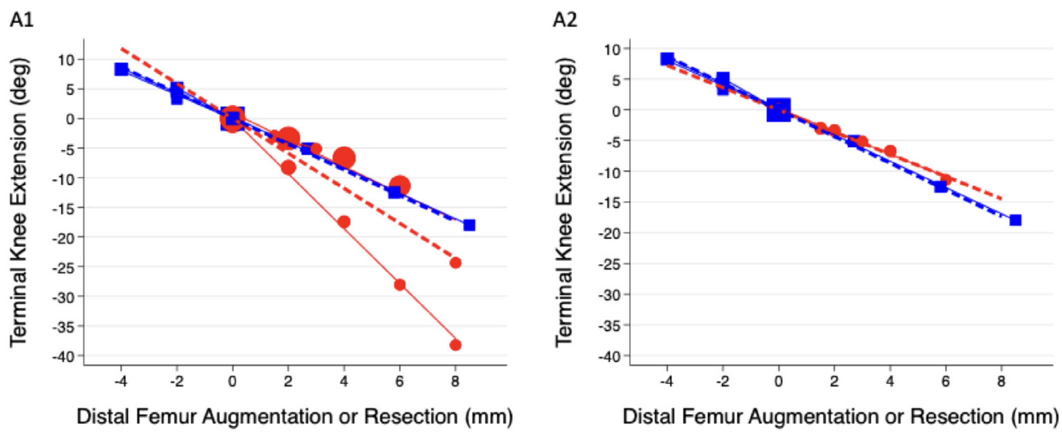
Appendix



Appendix A. Scatter plot of terminal knee extension over distal femur augmentation by CR or PS utilization. Red circles denote CR and blue squares PS.

Appendix B
Newcastle-Ottawa Quality Assessment Scale for Cohort Studies[a]

First author	Selection	Comparability	Outcome
Bengs	****	**	**
Smith	****	**	***
Cross	***	**	***
Liu	****	**	***
Kim	****	**	***
Matziolis	****	**	***
Elmasry	***	**	***

[a] The higher number of asterisk (*), the better quality of a given criterion. The maximum number of asterisks for the involved criteria are: 4 in selection, 2 in comparability, and 3 in outcome.