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Increased valgus laxity in flexion with greater tibial resection depth following total knee arthroplasty.

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Abstract

Purpose

Soft tissue balancing is of central importance to outcome following total knee arthroplasty (TKA). However, there is a lack of data analysing the effect of tibial bone cut thickness on valgus laxity. A cadaveric study was undertaken to assess the biomechanical consequences of tibial resection depth on through range knee joint valgus stability. We aimed to establish a maximum tibial resection depth, beyond which medial collateral ligament balancing becomes challenging, and a constrained implant should be considered.

Methods

Eleven cadaveric specimens were included for analysis. The biomechanical effects of increasing tibial resection were studied, with bone cuts made at 6mm, 10mm, 14mm, 18mm and 24mm from the lateral tibial articular surface. A computer navigation system was used to perform the tibial resection and to measure the valgus laxity resulting from a torque of 10 Nm. Measurements were taken in four knee positions: 0° or extension, 30°, 60° and 90° of flexion. Intra-observer reliability was assessed. A minimum sample size of 8 cadavers was necessary. Statistical analysis was performed using a nonparametric Spearman's ranking correlation matrix at the different stages: in extension, at 30°, 60° and 90° of knee flexion. Significance was set at $p < 0.05$.

Results

There was no macroscopic injury to the dMCL or sMCL in any of the specimens during tibial resection. There was no significant correlation found between the degree of valgus laxity and the thickness of the tibial cut with the knee in extension. There was a statistically significant correlation between valgus laxity and the thickness of the tibial cut in all other knee flexion positions: 30° ($p < 0.0001$), 60° ($p < 0.001$) and 90° ($p < 0.0001$). We identified greater than 5° of valgus laxity, at 90° of knee flexion, after a tibial resection of 14mm.

Conclusion

Increased tibial resection depth is associated with significantly greater valgus laxity when tested in positions from 30° to 90° of flexion, despite stability in extension. Greater than five degrees of laxity was identified with a

29 tibial resection of 14mm. When a tibial bone cut of 14mm or greater is necessary, as may occur with severe
30 preoperative coronal plane deformity, it is recommended to consider the use of a constrained knee prosthesis.

31
32 **Keywords** Tibial bone cut - Total knee arthroplasty - Medial collateral ligament - Knee stability - Total knee
33 replacement - Resection depth

34 35 **Introduction**

36
37 Total knee arthroplasty (TKA) is one of the most commonly performed orthopaedic procedures. The thickness of
38 the tibial cut depends on many factors, including implant design, limb alignment, previous surgery, and range of
39 motion. As the tibial bone cut influences both the flexion and extension gaps, any effect of tibial resection depth
40 on valgus laxity may occur throughout range of movement.

41 Several publications highlight the importance of the MCL in ligament balancing for TKA [1, 7, 11, 19].

42 However, there is a lack of data analysing the relationship between tibial bone cut thickness and coronal plane
43 laxity. This is surprising, as with severe deformity or TKA revision procedures, significant tibial resection may
44 be required, which may impact on the degree of prosthetic constraint required. Logically, no universal resection
45 depth exists beyond which a constrained TKA should be implanted. However, a threshold beyond which a
46 constrained prosthesis may be required, or at least available, would seem useful.

47 To analyse the biomechanical effect of tibial resection depth on valgus knee laxity throughout range, a cadaveric
48 study was undertaken. It was hypothesised that increasing the depth of tibial resection would be associated with
49 increasing valgus laxity throughout range of movement. We aimed to establish a tibial resection threshold,
50 beyond which the ability to achieve good, through range medial ligament balancing was impaired.

51 52 **Materials and methods**

53 A cadaveric biomechanical study was performed. Thirteen cadavers were available for this study. Exclusion
54 criteria were previous surgery or dissection of the knee, inability to achieve full extension, severe valgus or varus
55 deformity, coronal plane laxity on examination or full thickness chondral loss at incision. Deformity was
56 assessed clinically. For varus deformity, the gap between the medial aspect of the knee and the approximated
57 normal mechanical axis of the limb was measured in fingerbreadths. For valgus deformity, the gap was measured

between the medial malleolus and the approximated normal mechanical axis of the limb. Severe deformity was defined as being more than three fingerbreadths. Two knees were excluded; one for inability to achieve full extension and another for severe varus deformity. Eleven cadaveric (8 female and 3 male) specimens of mean age 86 (range 68-95) and mean BMI 22.1 (range 20.3-25.2) were included (six right-sided and five left-sided). Full cadaveric specimens were used and preserved by the Thiel method of soft embalming, [12] which has been shown to maintain the biomechanical properties of soft tissues at ambient temperature [18].

The effect of tibial resection on valgus angulation under load was studied for tibial cuts made sequentially on each specimen at 6mm, 10mm, 14mm, 18mm and 24mm. Computer navigation (Amplitude® navigation system with a Polaris® infrared camera « Amplivision® » [3]) was used to position the tibial cutting guide at the selected depth, and to result in a cut with a posterior slope of 0° and a frontal tibial angulation at 90° to the tibial mechanical axis. Trackers for the navigation system were applied to the femoral and tibial diaphysis. Resection level was measured from the highest point on the lateral tibial articular surface. After each cut, and prior to laxity testing, a spacer matching the thickness of the cut was inserted.

Valgus angulation resulting from an applied torque of 10Nm was then assessed, in four positions: 0° or full extension, 30°, 60° and 90° of flexion (figure 1, C). This was repeated for each resection level. For the purpose of this study, an unstable knee was defined as having greater than five degrees of valgus angulation when tested. Dissection and testing was performed by a single author (ESM). The specimens were placed in a supine position on a dissection table. A strap was used to secure the pelvis, to allow accurate determination of the hip centre. A leg-holding device was used to control and stabilise knee flexion [13]. We performed a medial para-patellar approach followed by a standardized triangular shaped soft tissue release of part of the deep medial collateral ligament including the first three centimetres, superior to inferior from the joint line of the medial tibial plateau. Anterior and posterior cruciate ligaments were resected during the preparation of the notch. The tibial resection guide was positioned in order to perform the first tibial bone cut, 6mm from the highest point of the lateral tibial plateau. The tibial resection guide was moved down by 4mm for each tibial bone cut. The accuracy of each cut was verified using the navigation system, and adjustments were made if required. Valgus force was applied through a traction hook fixed to the lateral border of the tibia (to avoid rotation bias), 25cm distal to the joint line, using one 4.5mm bicortical screw. The distal part of the femur was maintained by the leg-holding device (figure 1, A). The accuracy of the system is <1 mm for length measurement and <1° for angle measurement. For each specimen, the system was recalibrated. A KERN CH50 K50® dynamometer was used for dynamic

measures and recalibrated for each specimen. Each dynamic measurement was captured by a single acquisition of the navigation system, totalling 20 acquisitions per specimen and 220 acquisitions in total (figure 1, B) [13]. To assess intra-observer reliability, measurements were performed twice by the same operator. This was shown to be good, with a pearson correlation coefficient of $\rho=0.93$ ($p<0.00001$). Dissection was performed according to the ethics guidelines of the Rockefeller Anatomy Laboratory, Lyon Est university, with prior approval being obtained from the laboratory director.

Statistical analysis

The same method of analysis was applied to all data. Nonparametric Spearman's ranking correlation matrix was performed at the different positions through range: in extension, 30°, 60° and 90° of knee flexion. Statistical analysis was performed using XLSTAT software. Significance was set at $p < 0.05$. Sample size calculation was performed for a Spearman coefficient correlation at 0.2, a confidence interval 0.95 at 1.47 and an alpha risk of 0.05. A minimum sample size of 8 cadavers was necessary for this study.

Results

Following each tibial bone cut, the status of the dMCL and sMCL was noted. While the dMCL was released from the tibia during the approach as described, its macroscopic status did not change following tibial resection in any specimen. Similarly, the sMCL was not macroscopically injured in any specimen.

In all positions of knee flexion, valgus laxity was observed to increase with increasing thickness of tibial resection. A trend was also observed for more pronounced laxity as flexion increased. This is shown in table 1.

At 0° of knee flexion, there was no significant influence of the thickness of the tibial cut on valgus laxity. At 30°, 60°, and 90° of knee flexion, there was a significant correlation between the thickness of the tibial cut and valgus laxity. The Spearman coefficients correlation are shown in figure 2.

For all specimens, following a tibial resection of 14mm, the mean valgus laxity was greater than to 5° when tested at 90° of knee flexion, as shown in figure 2.

Discussion

The major finding of this study is the significant correlation between the thickness of the tibial bone cut and valgus laxity at different knee flexion positions. To our knowledge, this is the first study to present a variable contribution of the medial ligament complex to valgus laxity, both through range and according to the thickness of tibial bone resection.

Adequate ligament balancing is essential for successful TKA. Instability may result in severely disabling symptoms requiring revision to a more constrained prosthesis, or MCL reconstruction [19]. This study highlights the major role of the three components of the medial ligament complex, the medial collateral ligament with its superficial (sMCL) and deep (dMCL) layers [7, 8, 14] and the posteromedial capsule [15]. The posteromedial capsule controls valgus in extension, the sMCL has a major action in knee stability at all angles especially from 30 to 90 degrees of flexion, whereas the dMCL acts mainly in flexion [15].

In extension, no significant correlation was found between the thickness of the tibial cut and valgus laxity. The mean range of valgus laxity varied from 1.5° to 2.1°, which is considered to be stable [16]. In this study, a valgus torque of 10Nm was used, which might be insufficient to produce a valgus laxity in extension. However, multiple previous studies have demonstrated valgus laxity using a valgus torque of 10Nm or less [2, 5, 7, 13]. This stability in extension implies that the posteromedial capsule and distal tibial attachment of the sMCL are functionally preserved in extension following even considerable tibial resection, of up to 24mm. Again, this is in keeping with the described anatomy of the tibial attachment of the sMCL, which is below the level of resection [8, 15].

In flexion, a significant correlation was found between the thickness of the tibial bone cut and valgus laxity. As the dMCL and the proximal tibial attachment of the sMCL act mainly in flexion, this study seems to confirm that during tibial resection a selective defunctioning of the deep layer and one part of the sMCL occur, leading to valgus laxity in flexion. This is in keeping with the described anatomy of the dMCL and sMCL, as being intimately related to the resected portion of the tibia [8].

No data was found in the literature to quantify the amount of valgus laxity which would result in clinically relevant knee instability. For the purpose of this study, valgus laxity of greater than 5 degrees was considered clinically unstable. As a tibial bone cut of 14mm resulted in 5 degrees of laxity at 90 degrees of flexion, this was considered an unstable knee. This finding may be useful intraoperatively, or when planning complex cases such as primary TKA with severe valgus or varus deformity, medial unicompartmental knee arthroplasty revision to TKA, and revision TKA. In severe valgus deformity, for example, there is no literature consensus on when a standard prosthesis [4] or a constrained prosthesis [6] is required. In the absence of such definitive data, this

basic science study indicates that if a tibial resection of 14mm or more below the lateral compartment is required, consideration should be given to the use of a constrained implant to avoid flexion instability. This study also highlights the importance of assessing balance through full range of movement. Both intraoperatively and following TKA, stability should be tested in flexion and extension, as laxity may be present in flexion, despite stability in extension. This study has several limitations. As this was a cadaveric study, the results may differ from those found *in vivo*. Although the embalming method used has been demonstrated to result in comparable stiffness of the MCL complex to fresh tissue, these results should be carefully considered [18]. The sample size of eleven knees is relatively small, however it remains in accordance with our sample size calculation. Inter-observer reliability testing was not performed. All specimens had a varus clinical deformity, and care should be taken in applying these findings to other deformity patterns. However, as valgus deformity is commonly associated with attenuation of the MCL, valgus laxity following tibial resection could possibly be worse than found in this study. A medial parapatellar approach was performed in all cases, releasing the dMCL. While this approach may be confounding in a study focused on the medial compartment, a portion of the dMCL would need to be released to remove the resected tibia even had a lateral approach been used. We also believe this approach better replicates common practice. Furthermore, the dMCL was released during the standardised medial approach, before any tibial cut. If this release was a bias, a medial laxity would be expected for each cut, and not just from a tibial bone cut of 14mm. As the PCL was resected in this study, the results are valid for posterior-stabilized total knee arthroplasties (PS-TKA). Tsubosaka et al. [17] showed a comparable medial stability with either PS-TKA and cruciate retaining TKA (CR-TKA). However, Matsumato et al. [9, 10] showed better medial gap balancing with CR-TKA. These reports suggest using only our results for PS-TKA. The influence of bone resection depth on soft tissue balance, which is of primary importance to outcome in knee arthroplasty, is complex. In primary arthroplasty, large tibial resection occurs most commonly in cases of severe coronal plane deformity or following high tibial osteotomy. This study demonstrates that increasing tibial resection depth may introduce valgus laxity in flexion which is challenging to balance, or result in clinical instability when an unconstrained prosthesis is used.

Conclusion

Increasing tibial resection depth is associated with increased valgus laxity in flexion, despite preserved stability in extension. A 14mm resection depth was associated with 5° of valgus laxity at 90 degrees of flexion. Careful consideration should be given to adequate prosthesis constraint in such cases.

Conflict of interest

The authors declare that they have no conflict of interest.

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Figure 1 : Different aspects of the experimentations

Figure 2: Valgus laxity according to the thickness of the tibial bone cut at four positions

Legend: Different knee flexion positions 0°(purple), 30° (green), 60° (red), 90° (blue)

Table 1:**Analysis of valgus laxity under a torque of 10Nm**

Degree of flexion (°)	Thickness tibial cut (mm)	Mean valgus laxity (°)	Minimum-Maximum (°)	Standard Error
0	6	1.5	0-3	0.4
	10	1.6	0-4	0.4
	14	1.9	0-5	0.5
	18	2.1	0-5	0.5
	24	2.1	0-7	0.6
30	6	1.7	1-3	0.2
	10	2.2	1-4	0.3
	14	2.6	1-5	0.4
	18	3.1	1-5	0.4
	24	3.3	2-6	0.4
60	6	3.0	1-4	0.4
	10	3.3	1-6	0.4
	14	3.8	1-6	0.5
	18	4.5	3-7	0.4
	24	5.0	3-7	0.3
90	6	4.1	2-6	0.3
	10	4.5	2-8	0.5
	14	4.9	2-10	0.6
	18	6.1	4-10	0.6
	24	6.5	4-10	0.5

Table 1: Mean range of values of valgus laxity according to the thickness of the tibial cut at the four knee flexion positions