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ORIGINAL RESEARCH

Cadaveric comparison of two techniques for intraoperative placement of tibial plateau levelling osteotomies in dogs

Janusz Jaworski | **Matt Meek** | **Selena Malortie** | **Robert Dudley**

The Queen's Veterinary School Hospital, Cambridge University, Cambridge, UK

Correspondence
Robert Dudley, The Queen's Veterinary School Hospital, Cambridge University, Madingley Road, Cambridge CB3 0ES, UK.
Email: rjd78@cam.ac.uk

Abstract

Background: Both tibial tuberosity fractures and deviation from the planned postoperative tibial plateau angle have been associated with poor centring of tibial plateau levelling osteotomies (TPLOs). The aim of this cadaveric study was to compare two techniques for centring the osteotomy and preserving the tibial tuberosity width (TTW).

Methods: Stifle radiographs were obtained from 20 limbs of 10 dogs. TPLO was planned on each stifle, and a two-wire technique (TWT) and a technique using the medial collateral ligament (MCL) as an intraoperative landmark were planned. The techniques were executed and marked with radiopaque pins. Further radiographs were obtained and analysed.

Results: On average, TWT resulted in a 20.4% increase in TTW and medial collateral ligament technique (MCLT) resulted in a 13.4% decrease. Expressed as a percentage of the radial saw size, the average error in the centring of the osteotomy arising from the TWT was 13.4% and that from the MCLT was 14.2%.

Limitations: This study had a small sample size and involved a single surgeon.

Conclusion: Neither technique reliably identified the desired centre of the osteotomy, and both had a similar magnitude of error. MCLT resulted in reduced TTW, while TWT resulted in increased TTW. A reduced TTW has been associated with an increased risk of tibial tuberosity fracture, so MCLT is not recommended for clinical use.

INTRODUCTION

Cranial cruciate ligament (CCL) disease is the most common condition of the canine stifle[1] and one of the most common orthopaedic conditions in dogs.[2] The primary function of the CCL is to counteract the cranial tibial thrust that is generated by ground reactive forces acting on the sloped tibial plateau, resulting in cranially directed shear force; additionally, it limits internal rotation of the tibia and hyperextension of the stifle.[3] Rupture of the CCL arises from progressive pathological failure, often under conditions of normal loading.[4] Less commonly, rupture of the CCL can be traumatic in origin.[4] The consequences of a CCL-deficient stifle are lameness and instability, leading to progressive osteoarthritis[5] and an increased risk of meniscal tears.[6]

CCL rupture most commonly affects large and giant breed dogs, with Labradors, Rottweilers, Golden Retrievers and Boxers being overrepresented.[7] Other studies reported that West Highland White Terriers, Miniature Poodles and Yorkshire Terriers were overrepresented among small breeds.[8,9] The underlying etiopathology remains unclear and is considered complex and multifactorial.[4] Previous studies have reported that obesity,[10] sex,[8] neuter status[11] and age[8] are risk factors for developing a CCL rupture. Numerous treatment options have been advocated for the treatment of CCL insufficiency.[12–22] Tibial plateau levelling osteotomy (TPLO) is the most commonly performed surgical treatment.[23]

The aim of TPLO is to provide dynamic stifle stability during the stance phase of the gait by neutralising the cranial tibial thrust force.[12] A proximal tibial radial osteotomy is performed and the proximal fragment is rotated and fixed.[22] Accurate execution has been reported to be crucial as a tibial plateau angle (TPA) angle greater than 6.5° may not neutralise the cranial tibial thrust, and a TPA less than 6.5° may cause excessive stress on the caudal cruciate ligament.[24] Contrary to this, a study on Labrador Retrievers demonstrated that limb function and ground reaction forces were not significantly different between cases with a range of postoperative TPAs from 0° to 14°.[25] Nevertheless, CCL disease affects a large number of different breeds,[7–9] and similar studies demonstrating limb function in patients with higher and lower postoperative TPAs are lacking.

It has been shown in a geometric study that the positioning of the osteotomy in relation to the mechanical axis of the tibia and the articular surface has a significant effect on the resultant TPA given a set saw radius and degrees of rotation.[26] Accurate intraoperative establishment of the planned desired centre of rotation (DCR) is therefore necessary for obtaining a predictable postoperative TPA. Geier et al.[27] reported an increased risk of tibial tuberosity fracture in dogs with a lower postoperative TPA (median of 1.4° in patellar fracture group), and as Kowaleski and McCarthy[26] demonstrated, the centre of the osteotomy relative to the tibial eminences will impact the resultant TPA.

Furthermore, accurate placement of the osteotomy has an implication in preserving an appropriately sized tibial tuberosity width (TTW).[28] Tibial tuberosity avulsion fracture is a well-established, major complication associated with TPLO and is reported to occur in 4% of patients.[28] It has been shown that positioning of the osteotomy too far cranially or distally results in decreased cranio-caudal TTW, predisposing it to fracture.[28] A postoperative TTW of 7.2 mm ± 2.2 mm has been associated with an increased risk of fracture compared to a postoperative TTW of 10.8 mm ± 2.7 mm.[29] Recently, a novel preoperative method for selecting the osteotomy radius was described. In this study, the authors chose the size of the radial saw blade based on preserving a TTW of one-third of the distance between the tibial tuberosity and the caudal edge of the medial tibial plateau, and no tibial tuberosity fractures occurred.[30]

Although the precise planning of TPLO is now relatively straightforward, the authors' experience of TPLO surgery is that intraoperative execution of the plan can be challenging, largely because the utilised planning landmarks are obscured by soft tissues.

The use of a jig is described to assist with intraoperative positioning of the osteotomy.[31] Interestingly, it has been shown that there is no significant difference in postoperative TPA and TTW between TPLOs performed with or without a jig.[32]

Various other techniques have been investigated to attempt to improve the accuracy of the TPLO. A novel two-wire technique (TWT) for establishing the position of the osteotomy has been described.[33] In this technique (Figure 1), distance A was measured on preoperative radiographs from the most cranio-proximal point of the tibial tuberosity to the point where the intended tibial osteotomy transected the cranial tibial subchondral bone (point A). Distance B was measured perpendicular to the cranial straight edge of the tibial tuberosity originating from the most cranio-proximal point of the tibial tuberosity and finishing at the intended osteotomy (point B). Distance C was measured from the subchondral bone at the most caudal margin of the tibial plateau to the point where the intended tibial osteotomy transected the caudal tibial cortex (point C). Two Kirschner wires were then placed at points A and C and were used as a guide for the radial saw. Point B was used as an intraoperative check to ensure that this corresponded to preoperative point B. The authors found that there was variation from the planned osteotomy with errors of 13%, 5% and 7% in their A, B and C measurements, respectively, but concluded that due to the lack of tibial tuberosity fractures in the study population, the technique was acceptable.[33] Mossman et al.[34] investigated three methods of preoperative TPLO planning, which all used tibial landmarks that can be utilised intraoperatively to establish the centring of the radial saw blade. One of the techniques (B) was similar to the TWT.[33,34] Techniques A and B were deemed to be more accurate than technique C, with a mean absolute difference of 1.79 mm ± 1.01 mm for technique B compared to the planned osteotomy.[34]

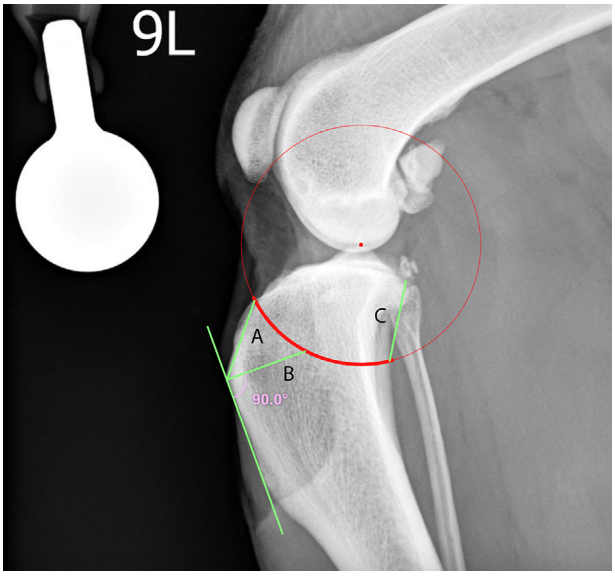

FIGURE 1 Mediolateral radiograph of a left stifle (specimen 9L) with a planned osteotomy (red circle) centred on the tibial eminences (red dot) and the A, B and C measurements (green lines). The B measurement was obtained at 90° to the cranial cortex of the tibial tuberosity

It is taught on some TPLO training courses that, intraoperatively, the position of the tibial intercondylar eminences, and therefore the DCR, can be identified by walking a needle from the tibia proximally along the medial collateral ligament (MCL) until it drops into the stifle joint.[35–37] The radius of the saw can then be measured from the needle at various points and marked onto the bone or the saw can simply be centred over the needle. To the authors' knowledge, there are no publications that have investigated whether, on a sagittal plane of the stifle, the MCL overlies the location of the tibial eminences or if the medial collateral ligament technique (MCLT) preserves the planned TTW. The first aim of this cadaveric study was to establish whether MCLT would result in a significant difference in TTW in comparison to the TWT. The second aim was to establish how accurate the MCLT and TWT are in identifying the DCR and to assess whether the MCLT results in a similar error in identifying the DCR compared with the TWT. It was hypothesised that the TWT would result in a significantly different TTW than the MCLT, as the nature of the TWT prevents placement of the osteotomy cranial to the A measurement. The second hypothesis was that the MCLT would result in a similar error in establishing the DCR compared with the TWT.

MATERIALS AND METHODS

The inclusion criteria were intact cadaveric stifle joints with no implants inserted proximally and distally to the stifle that could interfere with the surgical execution of both techniques and no evidence of previously performed stifle osteotomy techniques for the treatment of CCL insufficiency. Limbs that did not meet these criteria were excluded. Stifles with significant osteophytosis that prevented the reliable identification of bone landmarks were excluded.

Twenty pelvic limbs were obtained from 10 skeletally mature cadaveric dogs, weighing between 10 and 40 kg, that were euthanased for reasons unrelated to the study. Some of the cadaveric specimens had previously been utilised for undergraduate teaching and had undergone lateral stifle arthrotomy, lateral fabello-tibial suture and femoral head and neck ostectomy. Following the completion of these surgeries, all of the limbs were amputated via coxofemoral disarticulation and stored in a freezer at −10°C.

All cadaveric specimens were thawed for 24 hours prior to dissection. The cadaveric limbs were placed in lateral recumbency and a routine surgical approach to the medial aspect of the proximal tibia was performed, including the careful elevation of the pes anserinus with preservation of the MCL. This was executed by the authors J.J., S.M. and R.D. All cadaveric limbs were radiographed using a standard mediolateral projection of the stifle with the X-ray beam centred on the stifle joint and the stifle flexed to 90°. The 90° angle was chosen based on the authors' preference and standard convention for TPLO planning radiographs.[38] A 25 mm spherical magnification marker was included at the height of the stifle and close to the region of interest. The radiographs were only accepted for the study when the lateral and medial tibial condyles were superimposed, primarily assessed by alignment of their cranial and caudal margins and the proximal subchondral bone surface. If the radiographic criteria for inclusion were not met, the radiographs were repeated until the satisfactory requirements were met. The radiographs were performed by the three authors J.J., S.M. and R.D. and assessed for inclusion by R.D.

TPLO was then planned on each limb's radiograph as previously described[22] using orthopaedic planning software vPOP Pro (VETSOS Education), ensuring that the centre of the rotation of the osteotomy was placed on the central, most proximal aspect of the intercondylar eminences. In the circumstance when the intercondylar eminences were not superimposed onto each other, the centre of the rotation was placed midway between the intercondylar eminences. The radius of the planned osteotomy was selected by estimating a safe absolute TTW based on patient size for each specimen and ensuring that the shape of the remaining tibial tuberosity tapered from distal to proximal.[29,39] The osteotomy radius was noted for each specimen. To plan the TWT, distances A, B and C were measured as previously described[33] and noted (Figure 1). Each TPLO was planned by an experienced orthopaedic surgeon who has performed more than 200 TPLO preoperative plans and surgeries (R.D.).

On each cadaveric specimen, the stifle was flexed to approximately 90°, one of the authors (R.D.) established the centre of the MCL and a 21-gauge needle was walked from the tibia proximally along the centre of the ligament until it entered the stifle joint. The needle was then replaced with a tailor's pin with a small metal head, which was depressed until the head reached the level of the MCL. A spring calliper was then used to mark point A on the bone by measuring from the most cranial proximal point of the tibial tuberosity along the proximal cortical bone, as per the preoperative plan. A needle was used to identify the most caudal extent of the medial tibial condyle, and a spring calliper was used to mark point C by measuring distally from this needle along the caudomedial cortex of the tibia. The needle was then removed. A monocortical hole was drilled perpendicular to the long axis of the tibia at each of these points using a 1.1 mm drill bit to represent a Kirschner wire. A tailor's pin was then inserted into each of the tunnels so that the head was at the level of the medial cortex. The decision to utilise headed tailor's pins instead of needles or Kirschner wires was made to avoid ambiguity over which point along the length of the needle or wires should be measured on the later radiographs. The osteotomy was not performed in each case. The mediolateral stifle radiographs were then repeated using the original radiographs as a reference to ensure that the positions were identical. The radiographs were performed by the same authors who performed the first set of radiographs, and the same 25 mm magnification mark was included. The second set of radiographs was imported into vPOP and scaled to size using a magnification marker. A circle of the same radius as the planned osteotomy for each specimen was inserted on the image and centred on the head of the MCLT pin. A second circle was inserted such that the circle intersected the centre of the heads of the pins representing TWT points A and

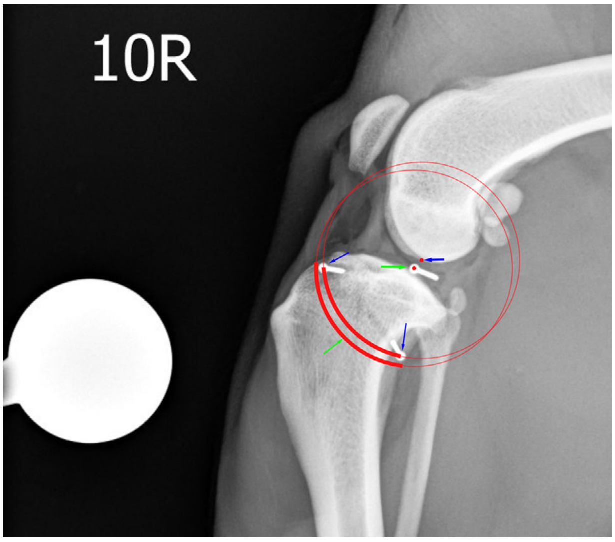

FIGURE 2 Mediolateral radiograph of a right stifle (specimen 10R) following execution of the medial collateral ligament technique (green arrows) and two-wire technique (blue arrows) and overlaying of two circles to represent the resultant osteotomy of each technique. The red dot at the centre of each circle represents the resultant centre of the osteotomy

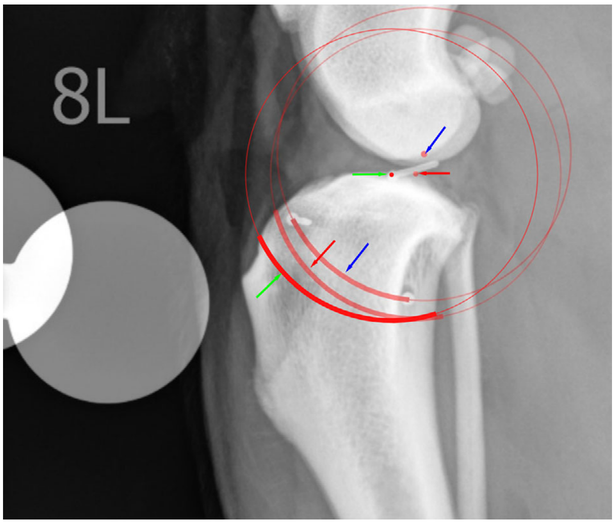

FIGURE 3 Two overlaid translucent mediolateral radiographs of a right stifle (case 8L). The radiographs were matched to the scale, and the tibia was perfectly superimposed. The planned osteotomy and its centre are shown with red arrows, the medial collateral ligament technique resultant osteotomy and its centre are shown with green arrows, and the two-wire technique resultant osteotomy and its centre are shown with blue arrows

C (Figure 2). The preoperative radiographs with their planned osteotomies were then overlaid onto their corresponding postoperative radiographs, which were made 50% translucent and scaled to the same size, using the magnification marker as a reference, with Adobe Photoshop software (Adobe). The tibias of the pre- and postoperative radiographs were then aligned to perfectly superimpose (Figure 3). The images were saved and transferred back into vPOP and the scale was calibrated to the magnification marker. The resultant TTW for each technique was established via an identical method to how the B measurements were obtained previously, measuring from the most cranial proximal extent of the tibial tuberosity at 90° to the cranial cortex of the tibial tuberosity to the intersecting point of each circle. The error in the centring of each resultant osteotomy location was established by measuring the distance from the centre of each of the circles, representing the MCLT and the TWT, to the centre of the planned osteotomy (the DCR).

Statistical analysis

For each sample, the percentage error in the B measurement was calculated by dividing the TTW derived from using the TWT or MCLT by the planned B and then multiplying the result by 100.

A Shapiro–Wilk test for normal distribution was performed, followed by a Levene's test for equal variances. A two-tailed Student's test was then performed to compare the results for the TWT and MCLT groups.

The DCR was used as the ground truth to calculate surgical error, which was calculated as the distance between the DCR and the resultant centre of rotation for each technique. The error was then expressed as a percentage of the radial saw size to make it relative to the size of each tibia.

A Shapiro–Wilk test was performed on the percentage error data for both techniques to assess for normal distribution. A Levene's test was performed to assess the datasets for equal variance.

The statistical equivalence between the MCL and Woodbridge techniques was assessed using the TOST procedure, with equivalence bounds set at −5% and +5%.

Ninety-five percent confidence intervals (95% CIs) were calculated for the mean percentage error for each technique and for the difference in means between the two techniques.

RESULTS

One of the 20 limbs was excluded from the study due to severe osteoarthritic changes that prevented the authors from identifying the MCL with certainty or performing repeatable radiographs. The breeds included Staffordshire Bull Terrier (n = 3), Whippet Cross (n = 1), Greyhound (n = 1), Jack Russell Terrier (n = 1), Golden Retriever (n = 1), Sharpei (n = 1), crossbreed (n = 1) and French Bulldog (n = 1).

The B measurement errors in the TWT and MCLT groups exhibited a normal distribution when measured using a Shapiro–Wilk test (p = 0.11 and 0.31, respectively). The Levene's test confirmed equal variance between the two groups (p = 0.11). The Student's t-test demonstrated that the two groups were significantly different (p = 9.2e–10) (Figure 4). The TWT group mean was 120.4% (95% CI: 115.2%–125.5%), indicating that the TWT resulted in a 20.4% increase in TTW. The MCLT mean was 86.6% (95% CI: 79.7%–93.6%), indicating that the MCLT resulted in a 13.4% decrease in TTW.

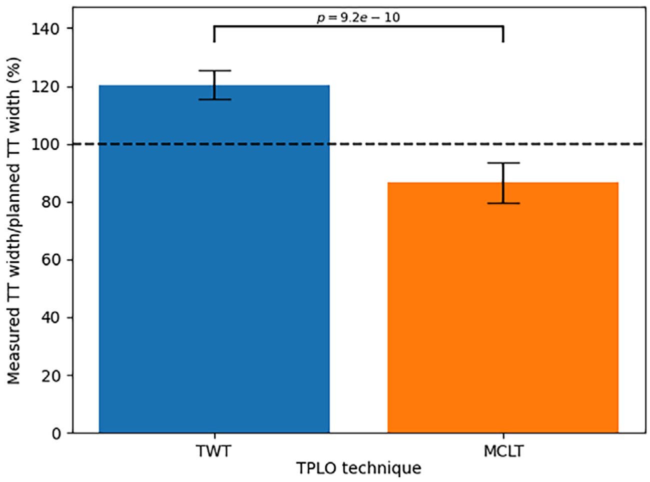

FIGURE 4 Mean postoperative tibial tuberosity (TT) width as a percentage of the planned TT width, arising from using the two-wire technique (TWT) and the medial collateral ligament technique (MCLT). A dotted horizontal line is shown at 100% to indicate the mean planned TT width. Error bars represent 95% confidence intervals. TPLO, tibial plateau levelling osteotomy

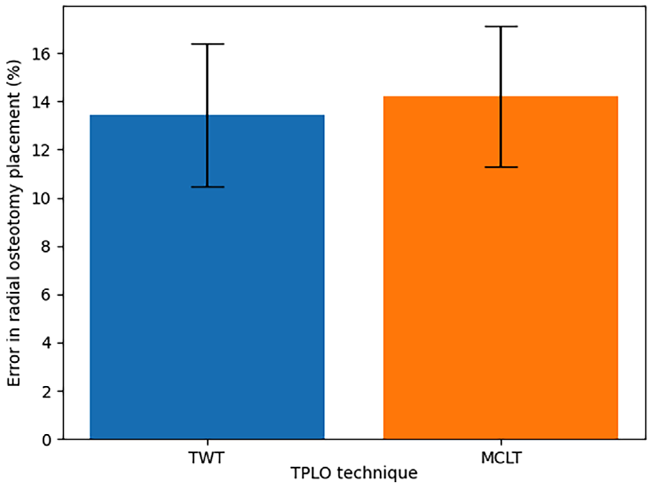

FIGURE 5 Mean percentage error in osteotomy placement arising from using the two-wire technique (TWT) and the medial collateral ligament technique (MCLT). Error was calculated as the difference between the preoperative planned desired centre of rotation and the resultant centre of rotation of the osteotomy, as a percentage of the saw radius. Error bars represent 95% confidence intervals. TPLO, tibial plateau levelling osteotomy

The mean percentage error in the centring of the osteotomy arising from using the TWT was 13.42% (95% CI: 10.45%-16.38%), and that for the MCLT was 14.20% (95% CI: 11.27%-17.12%) (Figure 5). Both samples were normally distributed according to the Shapiro–Wilk test (p = 0.49 for MCLT and p = 0.97 for TWT) and exhibited equal variance ($p = 0.73$). The equivalence testing procedure showed that the MCLT and TWT were statistically equivalent within a range of −5% to +5% for error ($p = 0.02$ for MCLT not more than 5% worse and $p = 0.003$ for MCLT not more than 5% better). The 95% CI for the difference in mean error was −2.57% to 4.13%, which fell within the predefined equivalence bounds.

DISCUSSION

We compared two intraoperative techniques in a cadaveric study with the aim of establishing which technique more reliably preserved the planned TTW and whether the technique accurately centred the osteotomy on the intercondylar eminences. In order to control for potential cumulative errors, the hypotheses were deliberately tested in isolation from the execution of the osteotomy and fragment rotation. The conclusions assume that the subsequently executed osteotomy will perfectly represent the osteotomy as marked onto the specimens, and although this is unlikely to be the case, it is reasonable to assume that this is the goal of a TPLO surgeon. By assessing the establishment of the osteotomy location in isolation, we avoided the potential accumulation of further surgical errors and radiographic positioning changes that can result from completing and rotating the osteotomy. The results showed that the MCLT does not preserve the planned TTW, whereas the TWT results in increased TTW. We also showed that both techniques result in a similar error in locating the DCR. The magnitude of the error was similar to that reported in previous work.[33,34]

In our study, MCLT resulted in poor preservation of the TTW, likely because the MCL was not consistently anatomically aligned with the tibial eminences. This inconsistency may be due in part to the mobility of the MCL and its underlying bursa relative to the bone structures of the stifle.[40] Contrary to MCLT, TWT resulted in a TTW greater than planned, which based on the known risk factors for tibial tuberosity fracture, is preferable, although this may result in an inadequately sized tibial plateau fragment and thus difficulty in placing a plate of adequate size. A recent study demonstrated an increased risk of MCL transection when using saws with a small radius or by placement of the osteotomy more proximally.[41] It is possible that the inadvertent caudo-proximal shift in the positioning of the saw resulting from TWT could pose similar risks. The TWT most commonly resulted in a DCR more caudal and proximal to the planned DCR, hence the increase in resultant TWT. The authors found it challenging to reliably identify the caudal extent of the medial tibial condyle, which, combined with the inability of radiographic planning to accommodate radiolucent articular cartilage, may have caused a proximal shift in the C measurement. Accurate placement of the A pin can also be challenging, as the radiographic plan does not account for the domed shape of the proximal tibia at this point or for the articular cartilage.

This study did not evaluate the effect of MCLT and TWT on postoperative TPA. The work of Kowaleski and McCarthy[26] has shown that centring the osteotomy away from the proximal tibial axis has an adverse effect on the postoperative TPA. Therefore, it can be inferred that the failure to accurately locate the DCR by either technique will result in an unpredictable resultant TPA. Under-rotation has been associated with insufficient neutralisation of the cranial tibial thrust, while excessive rotation has been associated with excessive strain on the caudal cruciate ligament[24] and patellar fracture.[27]

Our study did not evaluate the effect of radial saw placement against the Kirschner wire and its effect on DCR. Woodbridge et al.[33] concluded that some of the discrepancies between preoperative planning and postoperative results are caused by placing the radial saw against the Kirschner wires, which will lead to a shift in the measured dimensions of approximately half the diameter of the Kirchner wires. Woodbridge et al.[33] found that the A and C measurements were the most inaccurate, likely caused by difficulty in identifying and placing markers at the sites and by radiographic planning not accounting for articular cartilage; however, the radiographic measurements are taken at the margin of subchondral bone.

The first hypothesis, that the TWT would result in a significantly different TTW than the MCLT, was confirmed. The second hypothesis, that the two techniques would result in similar error in identifying DCR, was also confirmed. A logical progression from this study would be to explore how each technique affects the outcome following completion of the TPLO.

Woodbridge et al.[33] found that the B measurement was more reliable than the A and C measurements, and it is recognised that preservation of the B measurement is important for reducing the risk of tibial tuberosity fracture.[28] Future work could therefore investigate placement of a Kirschner wire at the B point instead of the A point to improve accuracy. A new and more reliable method of identifying the C point should also be explored.

A strength of this study is that both techniques were performed on the same stifle, as they controlled for individual variability between dogs. A single stifle was excluded from the study due to severe osteoarthritis affecting the stifle and the authors' inability to confidently identify the MCL and obtain repeatable radiographs. The contralateral stifle of the same specimen was included in the study as the degree of osteoarthritis affecting this stifle did not present the same problems and the results fell within the standard deviation.

A significant problem with studies of this nature is that there is no established acceptable error in the centring of the osteotomy. We are therefore reliant on using other established yet imperfect techniques as a benchmark. Woodbridge et al.[33] concluded that although their technique was inaccurate, it was acceptable because the incidence of tibial tuberosity fracture in their study population was zero. Future work could focus on establishing what equates to an acceptable error in large in vivo samples.

However, this study has limitations. The first limitation is the small sample size, which is associated with difficulties in obtaining cadavers with client consent for research. The second limitation was the decision not to check the B measurements during the TWT. Point B is an intraoperative check used to help avoid intraoperative errors.[33] Although this measurement was not performed intraoperatively, the authors double checked the intraoperative A and C measurements to minimise the error. It is possible that the use of the B measurement as an intraoperative check may have improved the accuracy of the technique, although our results from TWT were similar to what was reported by the original authors of the technique.[33] The third limitation was related to a single surgeon performing the preoperative planning and cadaveric execution of both techniques. Assessing multiple surgeons would increase the validity of our findings, although this would be challenging, as significantly more cadavers would be required. Finally, MCLT relies on the position of the MCL, which may change relative to the tibial eminences when the flexion/extension angle of the stifle is altered. MCLT was assessed only on a 90° flexed stifle in this study, which was chosen based on conventional radiographic positioning for TPLO planning[38] and the surgeon's (R.D.) preference for the position of the limb when performing TPLO surgery. It is possible that MCLT could be more accurate with the stifle positioned at a different angle; therefore, further work may be warranted to investigate this topic. The presence or absence of cranial tibial subluxation as a result of CCL insufficiency is also likely to affect the accuracy of MCLT through shifting of the soft tissues, although this variable is difficult for the surgeon to control; therefore, a technique reliant only on tibial landmarks, such as TWT, may ultimately be preferable.

CONCLUSION

MCLT results in loss of TTW compared to preoperative planning, whereas TWT results in increased TTW. For this reason, the authors do not recommend the use of the MCLT as it will likely increase the risk of tibial tuberosity fracture. MCLT and TWT were equally inexact at identifying DCR intraoperatively and are therefore both likely to result in unpredictable postoperative TPA and plateau fragment size. As is the case for the techniques described by Mossman et al.[34] and Woodbridge et al.,[33] who had similar errors in centring on the osteotomy, the inability of MCLT or TWT to accurately identify the DCR is problematic and further refinement of intraoperative techniques for placing the osteotomy may be warranted. Both of these papers concluded that their techniques were adequate for clinical use, but research evaluating the level of acceptable intraoperative error is required to provide further clinical context.

AUTHOR CONTRIBUTIONS

Janusz Jaworski participated in the study design and execution and drafted the manuscript. Matt Meek analysed the data and contributed to the manuscript. Selena Malortie participated in the execution of the study. Robert Dudley initiated the study, coordinated the project, participated in its design and execution

and drafted the manuscript. All the authors approved the final manuscript.

CONFLICT OF INTEREST STATEMENT

The authors declare they have no conflicts of interest.

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The authors received no specific funding for this research.

DATA AVAILABILITY STATEMENT

The data that support this research project are available from the corresponding author upon request.

ETHICS STATEMENT

Ethical approval for the study was granted by the University of Cambridge Department of Veterinary Medicine's Ethics & Welfare Committee.

ORCID

Janusz Jaworski https://orcid.org/0000-0002-3520-907X
Robert Dudley https://orcid.org/0009-0001-0606-3200

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