Accuracy of three pre- and intra-operative measurement techniques for osteotomy positioning in the tibial plateau levelling procedure

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Keywords
Cranial cruciate ligament, tibial plateau levelling osteotomy, accuracy, dog, stifle

Summary
Objectives: To prospectively compare the accuracy of three preoperative measurement techniques in tibial plateau levelling osteotomy (TPLO) planning.

Methods: Fifty-nine dogs were randomly assigned to one of three measurement techniques; A, B or C. Surgeons measured the intended osteotomy location on preoperative radiographs according to the assigned technique. Measurements were used intra-operatively during osteotomy placement. Postoperative measurements were made by a single blinded observer and compared to preoperative measurements.

Results: Fifty-one dogs were included for final statistical analysis. The mean absolute differences between pre- and postoperative measurements was 1.72 mm ± 0.958, 1.79 mm ± 1.010, and 3.56 mm ± 1.839, for techniques A, B and C, respectively. No significant differences were identified for patient age, gender, limb or surgeon. Techniques A and B were not significantly different (p = 0.8799). Techniques A and B were significantly more accurate than C (p = 0.0001 and p = 0.0003, respectively). Weight was significantly different among the groups (p = 0.047) but the statistical results did not change when an adjustment was made for bodyweight (p = 0.4971, p <0.001 and p = 0.0007, respectively).

Clinical significance: Preoperative measuring for planning a TPLO osteotomy is recommended. Techniques A and B in the current study were clinically practical and significantly more accurate compared to technique C.

Introduction
Cranial cruciate ligament disease is the most common cause of pelvic limb lameness in dogs (1, 2). Among the many surgical procedures developed to achieve stifle stabilization, the retinacular imbrication technique, tibial tuberosity advancement and tibial plateau levelling osteotomy (TPLO) are frequently used (3-6). Tibial plateau levelling osteotomy has become one of the most popular procedures to stabilize cranial cruciate ligament-deficient stifle joints, particularly for active large and giant breed dogs (7). The surgical technique and variations, biomechanics and clinical outcome have been thoroughly described (8-15).

Correct placement of the TPLO radial osteotomy is essential to achieve optimal outcome (10, 16). Incorrect placement can lead to complications, including tibial crest fracture and inadequate or improper rotation of the proximal segment. If the osteotomy is not centred at the intersection of the tibial plateau and the mechanical axis of the tibia, then shifting of the long axis of the tibia occurs, potentially altering biomechanics and resulting in a gait abnormality (10, 17, 18).

A technique to improve the accuracy of osteotomy placement may improve optimal postoperative radiographic and clinical outcome. Talaat and colleagues suggested the use of a preoperative measurement technique which was later described in a book chapter, but scientific evaluation of this technique, or comparisons with other
techniques are scarce (1, 19). One retrospective study compared the effectiveness of pre-planned and non-pre-planned techniques in achieving a centred osteotomy and found that pre-planning resulted in a more centred osteotomy and reduced the risk for tibial tuberosity fracture (20). A second retrospective study analysed the accuracy of other preoperative measurements and found a small variation between the actual and intended position of the osteotomy, and none of the pre-planned cases suffered a tibial tuberosity fracture (21). Both studies illustrate the need for a practical, accurate preoperative measurement technique resulting in correctly placed TPLO osteotomies.

Yet, to our knowledge, no study has prospectively compared different preoperative measurement techniques. The purpose of this prospective study was therefore to compare the accuracy of three preoperative measurement techniques in planning a TPLO osteotomy. Our hypothesis was that there would be no significant difference between the three techniques.

Materials and methods

Pilot study

A pilot study of the three measurement techniques, designated as A, B, and C, was conducted to evaluate feasibility and predict appropriate sample size (19, 20, 21). Over 10 weeks, 38 patients were enrolled. At the pilot study conclusion, measurement techniques were clarified, surgeons were encouraged to add comments about each procedure, and technique C was modified.

Initially, technique C was used as previously described (20). However, the authors found it difficult to measure intra-operatively. Also, the feasibility of comparing pre- and postoperative measurements in this technique proved problematic. The technique is based on the mechanical axis of the tibia as described (6). However, when the radial osteotomy is not centred exactly on the intercondylar tubercles, the mechanical axis of the tibia is altered. If this change is minimal, the result probably does not affect clinical outcome, but it inherently changes the postoperative measurements, making it impossible to accurately compare them with preoperative measurements. Therefore, a modified version of technique C, as described in the following section, was developed based on previous descriptions (19–22).

To achieve a power of 80%, power analysis indicated a sample size of 42 for the main study appropriate. However, additional cases were collected in the main study to account for any exclusions.

Main study

Dogs that had a TPLO performed at the Veterinary Surgical Centers and the Veterinary Surgical Referral Practice between June 2014–August 2014 were eligible for enrolment. Dogs, weighing more than 18.2 kg with complete medical records and radiographic study were included. Dogs were excluded if their radiographs were not adequately aligned, if they had a concurrent surgery such as patellar luxation correction on the same stifle, or if the planned osteotomy was intentionally changed during the TPLO procedure, for example due to anatomical challenges. Written owner consent was obtained.

Information recorded included age, gender, breed, weight, and affected limb of the patient and the name of the surgeon. Dogs were randomly assigned, using Microsoft Excel®, to one of three preoperative measurement techniques: A, B or C, as described below. Surgeons (S1–7), each of whom had performed at least 500 TPLO surgical procedures prior to main study initiation, measured according to the technique assigned, using these measurements intra-operatively during osteotomy placement. A single, blinded observer (HM) compared pre- and postoperative measurements.

Radiography, pre- and postoperative measurements

Digital pre- and immediate postoperative orthogonal radiographic projections of the affected limb were obtained as previously described while the patient was under anaesthesia (6). Proper alignment was confirmed by summation of intercondylar tubercles. Measurements were standardized by using a 100 mm calibration deviceb to adjust for magnification.

Preoperatively, each surgeon measured the tibial plateau angle (TPA) as previously described and applied the assigned measurement technique using TPLO templating software,c,d (6). The osteotomy template was centred on the tibial intercondylar tubercles as described (10). Surgeons did not perform any postoperative measurements, other than TPA, to ensure they were blinded to their osteotomy accuracy and to avoid bias that could have improved their technique during the study period.

Measurement techniques

Technique A

Two distances, A1 and A2 were measured from the point at which the patellar ligament inserts on the tibial tuberosity. A1 was measured along the craniodistal border of the tibia, and equalised the distance from the patellar ligament insertion to the point at which the intended osteotomy exited the tibia. A2 was measured along a line perpendicular to the cranial border of the tibial crest and equalled the distance from the patellar ligament insertion to the intended osteotomy (19). See Figure 1.

Technique B

The first two measurements were obtained as described in technique A, referred to here as B1 and B2. A third measurement, B3, was used to determine the point at which the osteotomy exited the caudal tibial cortex. B3 equalled the distance from the subchondral bone of the most caudal aspect of the tibial plateau to the point at which the intended osteotomy exited the caudal aspect of the tibia (21). See Figure 2.

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a Microsoft Excel 2013: Microsoft Inc., Redmond, WA, USA
b Biomedtrix, Boonton, NJ, USA
c Sound-Eklin, Carlsbad, CA, USA
d Medstrat, Downers Grove, IL, USA
polar electrocautery was used to mark the location of these measurements. To identify the most caudal aspect of the tibial plateau in technique B, a 25 gauge needle was “walked” carefully off the plateau to avoid placement of the needle into the joint space, thus avoiding meniscal damage (23). The use of a caudomedial arthrotomy negated the need for this technique, as the caudal aspect of the tibial plateau was directly identified in these cases.

Surgery was performed as described, using standard equipment with standard multilayer closure (6). Immediate postoperative radiographs were obtained and measured as described in the previous section.

Pre- and postoperative care

Anaesthetic protocol was based on patient needs and clinician preference. Patients were premedicated with an intravenously or intramuscularly administered opioid (morphine [0.4 mg/kg], hydromorphone [0.1–0.3 mg/kg], fentanyl [4 mcg/kg] or methadone [0.25–0.5 mg/kg]) and either midazolam (0.2–0.4 mg/kg), dexmedetomidine (3 mcg/kg) or acepromazine (0.02–0.05 mg/kg), either with or without atropine (0.02–0.04 mg/kg) or glycopyrrolate (0.01 mg/kg). Some patients were given an epidural of 0.5% bupivacaine (1.1 mg/kg) and morphine (0.11 mg/kg), and some had intra-articular blocks using 0.5% bupivacaine (0.2 mg/kg). The induction agent was propofol to effect (2–6 mg/kg IV); maintenance gas was isoflurane or sevoflurane. Some patients were given an intraoperative constant rate infusion of morphine (0.18 mg/kg/hr), hydromorphone (0.03 mg/kg/hr), fentanyl (4–15 mcg/kg/hr), or methadone (0.04 mg/kg/hr). Intra- venous administration of crystalloids was maintained at 3–10 ml/kg/hr. Cefazolin (22 mg/kg IV) was administered at induction and q90min throughout the procedures.

Postoperatively, patients were prescribed tramadol (2–5 mg/kg POq6–12h) with or without gabapentin (10 mg/kg POq8h), and meloxicam (0.1 mg/kg POq24h), carprofen (2.2 mg/kg POq12h), or firocoxib (5 mg/kg POq24h) if not contraindicated.

Technique C

C1 was the same measurement as A1 and B1 in techniques A and B, respectively. C2 was the distance from the point at which the patellar ligament inserted on the tibial tuberosity to the point of perpendicular intersection with C3. C3 was measured along a line perpendicular to the cranial border of the tibial crest and equaled the distance from this border to the point at which the intended osteotomy exited the caudal tibial cortex.

Surgical technique

A standard surgical approach to the cranio-proximal region of the tibia was performed in all cases. Arthroscopy, caudomedial arthrotomy or medial parapatellar arthrotomy, as well as meniscectomy or meniscal release, were performed based on surgeon preference. Castroviejo callipers, graduated from 0–20 mm, were used to make intra-operative measurements and mono-
Statistics

For each case, the absolute difference in millimetres between each set of pre- and postoperative measurements was calculated (e.g.: postoperative A1 – preoperative A1), as was the mean absolute difference (MAD) in millimetres (e.g.: [(postoperative A1 - preoperative A1) + (postoperative A2 - preoperative A2)]/2). A MAD equal to zero corresponded to a completely accurate osteotomy (i.e. one that was placed in the exact location it was intended). Similarity amongst the three techniques (A, B, C) for the factors age, gender, weight, limb and surgeon was presented with and without correction for weight. All data were analysed with a commercial software program. Values of p less than 0.05 were considered significant.

Results

Fifty-nine dogs were enrolled; however eight were excluded for following reasons: placement of intended osteotomy was changed at surgery (n = 4), radiographic technique was poor (n = 2), blade size was changed at surgery (n = 1), and an additional procedure performed on the stifle (n = 1). Thus, 51 dogs were included for final statistical analysis (Table 1).

Breeds included mixed (n = 19), Labrador Retriever (n = 7), Golden Retriever (n = 4), Bulldog (n = 4), Pit Bull (n = 3), Rottweiler (n = 2), and one dog of each of the following: American Staffordshire Terrier, Australian Cattle dog, Beagle, Boxer, Coonhound, Doberman Pinscher, German Shorthaired Pointer, Labradoodle, Newfoundland, Siberian Husky, Springer Spaniel, Vizsla and Weimaraner.

The mean age was 6.1 ± 3.1 years (median = 7.0 years). There were 27 neutered males, 22 neutered females, and two males. Mean weight was 34.0 ± 8.5 kg (median = 32.7 kg). The factors that might have affected the mean absolute differences (MAD; response variable) were technique (A, B, C) and weight (continuous variable). Analysis was by means of analysis of covariance with the fixed factor of technique and weight as the covariate. Assumptions were tested and data analysed using an equal slopes model with unequal intercepts.

The MAD for each technique (MAD_A, MAD_B, MAD_C) ± standard deviation (SD) was presented with and without correction for weight. All data were analysed with a statistical software program (Table 1).

Table 1

<table>
<thead>
<tr>
<th>Technique</th>
<th>Number of patients</th>
<th>Mean age (years)</th>
<th>Gender</th>
<th>Weight (kg)</th>
<th>Limb</th>
<th>Surgeon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Neutered male</td>
<td>Neutered female</td>
<td>Entire male</td>
<td>Left</td>
</tr>
<tr>
<td>A</td>
<td>18</td>
<td>5.9 ± 3.1</td>
<td>9</td>
<td>8</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>B</td>
<td>16</td>
<td>5.8 ± 3.9</td>
<td>10</td>
<td>6</td>
<td>0</td>
<td>30.5 ± 6.66</td>
</tr>
<tr>
<td>C</td>
<td>17</td>
<td>6.0 ± 2.3</td>
<td>8</td>
<td>8</td>
<td>1</td>
<td>33.5 ± 9.96</td>
</tr>
<tr>
<td>Total</td>
<td>51</td>
<td>6.1 ± 3.1</td>
<td>27</td>
<td>22</td>
<td>2</td>
<td>34.0 ± 8.5</td>
</tr>
</tbody>
</table>

Table 2

Comparison of mean absolute differences between pre- and postoperative measurements.

<table>
<thead>
<tr>
<th>Technique</th>
<th>n</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Standard error of the mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>18</td>
<td>1.72</td>
<td>0.958</td>
<td>0.226</td>
</tr>
<tr>
<td>B</td>
<td>16</td>
<td>1.79</td>
<td>1.010</td>
<td>0.253</td>
</tr>
<tr>
<td>C</td>
<td>17</td>
<td>3.56</td>
<td>1.839</td>
<td>0.446</td>
</tr>
<tr>
<td>Total</td>
<td>51</td>
<td>2.37</td>
<td>1.57</td>
<td>0.220</td>
</tr>
</tbody>
</table>

n = number.

Table 3

Mean absolute differences (mm) between pre- and postoperative measurements when adjusted for weight.

<table>
<thead>
<tr>
<th>Technique</th>
<th>n</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Standard error of the mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>18</td>
<td>1.59</td>
<td>0.958</td>
<td>0.226</td>
</tr>
<tr>
<td>B</td>
<td>16</td>
<td>1.92</td>
<td>1.01</td>
<td>0.253</td>
</tr>
<tr>
<td>C</td>
<td>17</td>
<td>3.61</td>
<td>1.839</td>
<td>0.446</td>
</tr>
</tbody>
</table>

n = number.

Table 4

Comparison of mean absolute difference (mm) between pre- and postoperative measurements when adjusted for weight.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Technique</th>
<th>Technique</th>
<th>Difference</th>
<th>Standard error of the difference</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technique</td>
<td>A</td>
<td>B</td>
<td>-0.33</td>
<td>0.48</td>
<td>0.4971</td>
</tr>
<tr>
<td>Technique</td>
<td>A</td>
<td>C</td>
<td>-2.01</td>
<td>0.45</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>
34.4 kg). There were 20 left and 31 right limbs. Numbers of TPLO procedures per surgeon were: S1 (n = 7), S2 (n = 5), S3 (n = 7), S4 (n = 5), S5 (n = 4), S6 (n = 5), and S7 (n = 18).

No significant differences were identified in the distribution of age, gender, limb or surgeon (p = 0.980, p = 0.849, p = 0.065, and p = 0.393, respectively). The MAD between pre- and postoperative measurements was 1.72 mm ± 0.958, 1.79 mm ± 1.010, and 3.56 mm ± 1.839, for technique A, B and C, respectively (Table 2). Weight was significantly different among the groups (ANOVA; p = 0.047), but did not significantly affect the accuracy of the technique (ANCOVA; p = 0.122).

Techniques A and B were not significantly different (p = 0.8799). Techniques A and B were significantly more accurate than C (ANOVA post hoc; p = 0.0001 and p = 0.0003, respectively). These results did not change when an adjustment was made for weight (ANCOVA post hoc; p = 0.4971, p < 0.001 and p = 0.0007, respectively) (Table 3, Table 4). While long-term follow-up was not an aim of this study, it is worth noting that none of the cases suffered a tuberosity fracture. Three cases were lost to follow-up, leaving 48 cases available for review. No tibial tuberosity fractures were identified on follow-up radiographs. Mean follow-up time was 8.4 ± 2.53 weeks (median = 8.1, range = 2.1–18.7).

Discussion

The goal of this study was to prospectively compare three preoperative measurement techniques (A, B, C) for TPLO osteotomy placement, the accuracy of which has not yet been established or compared with each other. Techniques A and B were similarly accurate, but technique C was significantly less accurate than both A and B. Age, gender, weight, limb and surgeon did not significantly affect accuracy of any technique.

It was deliberately decided to not include the freehand technique as described previously (6, 20). By nature, the freehand technique does not use preoperative measurements, so there are not any measurements with which to compare. Also, a previous study has shown it to be inferior to a preoperative measurement technique because it resulted in less centred osteotomies and a higher risk for tibial tuberosity fracture (20). While that other study was retrospective, the large number of cases (406 dogs) supports the idea that preoperative planning is safer than free handing.

The current study was designed prospectively and in vivo so that the results could be clinically relevant and applicable. A perfectly accurate osteotomy was defined as one in which the postoperative measurements equal the preoperative measurements. It was decided to measure absolute differences, as opposed to actual differences, to ensure that differences within each case were weighted equally. As an example, consider a case which the preoperative measurements were A1 = 17 mm and A2 = 16 mm and postoperative measurements were A1 = 20 mm and A2 = 15 mm. The mean actual difference is \[(20–17) + (15–16)/2 = [(+3) + (-1)]/2 = 1\] mm, but the mean absolute difference \[(20–17) + (15–16)/2 = [(+3) + (+1)]/2 = 2\] mm. The former makes this case appear falsely more accurate than it was, whereas the latter better reflects the total difference of all measurements.

To the authors’ knowledge, technique A has not been validated in published studies (1, 19). In the current study, technique A was equally as accurate as technique B, which has been evaluated and deemed clinically valuable in a retrospective study of 72 cases (21). In that study, it was concluded that the position of the actual osteotomy varied significantly from the proposed osteotomy, but the difference in the width of the tibial tuberosity was small (5%). None of the cases suffered fracture of the tibial tuberosity.

When using technique B in the current study, 25 gauge needles were used to identify the level of the tibial plateau. As a high incidence of iatrogenic meniscal damage when inserting a needle into the stifle joint for this purpose is described, surgeons used the needles to identify the tibial plateau very carefully, taking care to avoid penetration of the stifle joint, and thus avoid such damage (23). Two surgeons routinely performed caudomedial meniscal releases through a caudomedial arthrotomy (S1, S2). Therefore it was possible to identify the most caudal aspect of the tibial plateau, avoiding the use of needles.

Placement of intended osteotomy was changed at surgery in four of the eight excluded dogs. In these cases, intra-operative assessment determined that the proximal tibial segment that would be created based on preoperative measurements would be too small to accommodate an appropriately-sized plate. Therefore, pre-planning measurements were disregarded, and the surgeons placed the osteotomy based on intra-operative observation of the proximal tibia. It is important to note that while these preoperative planning measurements are intended to aid in placement of the osteotomy at surgery, they should not override surgeon expertise and clinical experience. Interestingly, three of four dogs excluded for this reason were Bulldogs. It is possible that the conformation of the tibia in this breed may make it more difficult to accurately assess preoperative planning. Additional research to determine if there is a difference between radiographic and intra-operative evaluation of the proximal tibia in Bulldogs may reveal additional information.

The surgical approach to the stifle was not standardized in this study. Each surgeon had their preferred method of approaching the stifle, which involved varying degrees of dissection. One could argue that opening the proximocranial and caudal tibial muscle envelope could offer improved visibility of the cranial and caudal border of the tibia and thus improve measurement accuracy (13). In fact, surgeons who did not elevate the cranial tibial and popliteal muscles did not feel this limited approach was disadvantageous in performing intra-operative measurements. However, the approach could be standardized and compared.

It is interesting to note that osteotomies, regardless of technique used, were more often placed more cranially than intended. In addition, osteotomies using techniques A and C were more often placed more distally than intended, while osteotomies using technique B were more often placed more proximally than intended. Full analy-
sis of these differences was impossible as absolute rather than actual differences in measurements were determined. The reason to calculate absolute differences was that if the values go in one direction or the other, they cancel themselves out if one just considers the actual difference. Further research would also be needed to establish if the side of TPLO (left or right) or surgeon handedness are variables. In our study only one surgeon was left-handed and this was another factor precluding calculation of actual differences.

This study had limitations. A single, blinded observer obtained all postoperative measurements to standardize any variability, but further study to evaluate intra- and interobserver variability, as has been done for TPA and patellar ligament angle measurements, may be warranted (24, 25). One could criticize the high number of surgeries, but the fact that surgeon did not affect the accuracy of any technique verifies that accuracy was independent of surgeon. There is partial confounding due to the numbers of measurements performed by different surgeons. However, there was no significant difference in accuracy of these measurements between surgeons so this proved not to be a significant factor in this study. Methods to negate this concern could include increasing the total number of TPLO procedures and limiting the number of surgeons to only one. Additional alternatives could be ensuring an equal number of patients in each method for each surgeon. A larger prospective study controlling these variables and allowing for intra- and interobserver variability would be necessary.

In summary, techniques A and B were clinically practical measurement techniques for planning a TPLO osteotomy. Technique C was significantly less accurate than both A and B. Age, gender, weight, limb and surgeon did not significantly affect accuracy of any technique. Refinement of these techniques may be an area of future study.

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Conflict of interest
The authors have no conflicts of interest in relation to this study to declare.

References