Planned wedge size compared to achieved advancement in dogs undergoing the modified Maquet procedure

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Keywords

Cranial cruciate ligament, MMP, stifle, Maquet procedure

Summary

Objectives: To evaluate the patellar ligament to tibial plateau angle (PL-TPA) and amount of achieved advancement in dogs that underwent the modified Maquet procedure; compare wedge sizes recommended using two different planning techniques (Orthomed and modified tibial tuberosity advancement); and evaluate anatomical factors that predict the wedge size required to obtain a 90° PL-TPA.

Methods: Pre- and postoperative radiographs of dogs that had a modified Maquet procedure performed were evaluated for the following: calculated wedge size using two different planning techniques, the actual wedge size used, the achieved tibial tuberosity advancement, and the changes in PL-TPA. Anatomical measurements of the tibia were evaluated and correlated with the actual wedge size.

Results: Of the 38 modified Maquet procedures identified, 53% (n = 20) had a PL-TPA of 90° ± 5°. Actual achieved advancement of the tibial tuberosity was 30% less than the wedge size used. Changes in PL-TPA and tibial width persisted at eight weeks postoperatively without loss of advancement. The two planning techniques did not result in a significantly different selection of wedge size.

Clinical relevance: Current planning techniques for the modified Maquet procedure result in under-advancement of the tibial tuberosity. Both measurement techniques evaluated do not result in appropriate advancement.

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Introduction

Several surgical procedures have been developed with the aim of neutralizing the cranial tibial shear forces present in cranial cruciate deficient stifles (1-3). A common school of thought exists supporting the alteration of proximal tibial geometry in an effort to establish a 'patellar ligament to tibial plateau angle' (PL-TPA) of 90° thereby neutralizing cranial tibial shear forces (1, 2). Surgical techniques that apply this concept include the tibial tuberosity advancement and the modified Maquet procedure (1, 2, 4, 5).

The modified Maquet procedure differs from the tibial tuberosity advancement in that the osteotomy is not completed distally, leaving a bone bridge typically protected with a figure-of-eight tension band or staple (4-6). The advancement is maintained with an appropriately-sized titanium foam wedge or titanium cage placed in the osteotomy gap (4). To the authors' knowledge, no previous studies have confirmed that the modified Maquet procedure performed using the originally proposed planning and surgical technique will result in a PL-TPA of 90° (7).

The method originally described by Orthomed[a] for calculating the modified Maquet procedure wedge size is based on measurements that were solely reliant on tibial anatomy, without the need for 135° stifle positioning (7). However, after using this method on a series of clinical patients, it was noticed that, as the tibial plateau angle (TPA) increased, the calculated wedge size decreased. An alternative planning method, modified from the tibial tuberosity advancement measurement method, was used in conjunction with the Orthomed method to direct wedge size selection (8, 9). The primary modification was that the amount of advancement needed was measured in a cranial direction, not along the line of the tibial plateau slope, since tibial tuberosity advancement displaces the tuberosity cranially and perpendicularly to the long axis of the tibial crest rather than along a craniocaudal line parallel to tibial plateau.

The purpose of the current study was to retrospectively evaluate postoperative

a Orthomed (UK) Ltd., Huddersfield, West Yorkshire, UK

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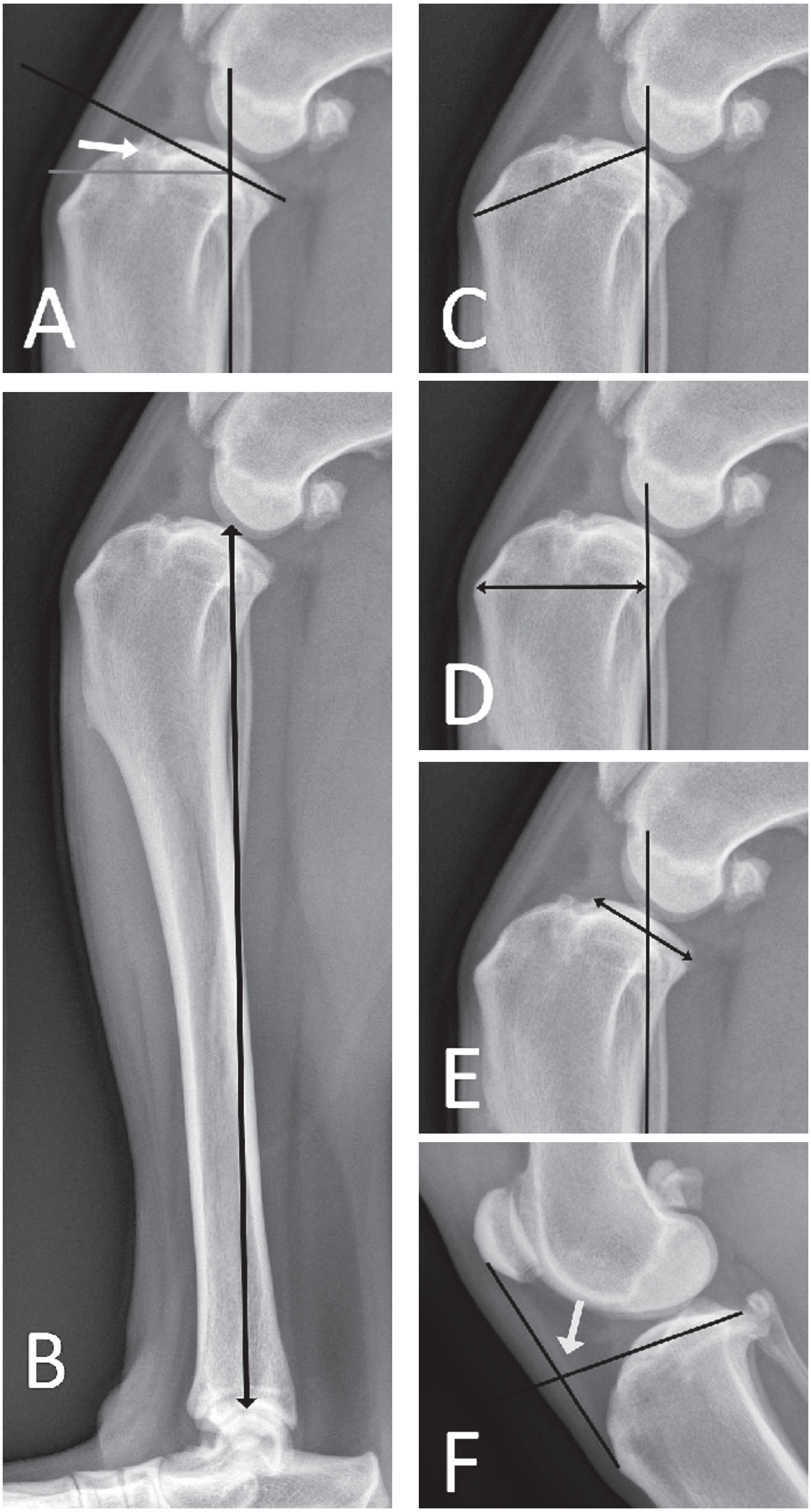

radiographs of dogs that underwent the modified Maquet procedure to determine whether a PL-TPA of 90° was obtained. Because there were concerns that the wedge may not maintain the advanced position of the crest if it was only supported by softer metaphyseal bone, radiographs were also assessed to determine if the achieved advancement was maintained eight weeks postoperatively (10). In addition, this study aimed to evaluate preoperative radiographs of the same patient population and compare the size of the wedge recommended when planning a modified Maquet procedure by use of two different planning methods (Orthomed and modified tibial tuberosity advancement). Using these same planning radiographs, it was intended to identify anatomical factors that could help predict the wedge size required to obtain a 90° PL-TPA angle. Evaluating the success of the modified Maquet procedure as it is currently performed would allow better

Figure 1 **A)** The tibial plateau angle (TPA) was measured by comparing the orientation of a line joining the small, discreet cranial margin of the tibial plateau and the point of insertion of the caudal cruciate ligament to a line joining the intercondylar eminence and a point equidistant to the cranial and caudal aspects of the trochlea of the talus (functional axis). **B)** The length of the functional tibial axis was measured from the articulation of the distal tibia and tarsus (a point equidistant to the cranial and caudal aspect of the trochlea of the talus) to the most proximal aspect of the intercondylar eminence. **C)** The Z angle was measured using a line drawn from the most cranial aspect of the tibial crest to the midpoint between the two tibial intercondylar tubercles. The angle formed between this line and the functional axis of the tibia was defined as the Z angle. **D)** The tibial width from the functional axis was measured along a line perpendicular to the functional axis and level with the cranial-most point of the tibial crest. **E)** The tibial plateau length was measured from the most cranial point of the tibial plateau to the most caudal point of the tibial plateau. **F)** The patellar ligament to TPA (PL-TPA) was measured as the intersection of the TPA with a line joining the craniodistal point of the patella, at the level of the origin of the patellar ligament, to the cranial aspect of the tibial crest, at the insertion of the patellar ligament.

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understanding and utilization of an optimized planning method.

Our hypotheses were as follows: 1) the PL-TPA will be 85°-95° after the modified Maquet procedure, 2) the differences in PL-TPA and the achieved advancement measured immediately after surgery, compared to eight weeks later, would not be significant, and 3) the wedge sizes resulting from the modified Maquet procedure planning measurements made using the Orthomed method and the modified tibial tuberosity advancement method would be significantly different.

Materials and methods

This retrospective study was based on archived radiographic images at the North Carolina State University Veterinary Hospital. The medical records of all patients that underwent a modified Maquet procedure to manage cranial cruciate ligament disease between March 2012 and November 2013 were reviewed. Cases were included if surgery was performed on one or both limbs and the medio-lateral radiographs of the stifle at 90° and 135° of flexion at the following time points were available for review: preoperative, immediate postoperative, and between seven and nine weeks postoperatively ('eight-week' postoperative radiographs). Each limb was considered as an individual data point or procedure. Procedures were excluded if they had any previous orthopaedic surgery on that stifle, or if any complications occurred before the eight week postoperative time period resulting in the need for additional surgery on that limb. Data collected from the medical records included patient weight, date of surgery, size of wedge placed, and date of final radiographic re-evaluation.

Radiographic assessment

Standardized radiographic views available included mediolateral views of the stifle joint with the hock and stifle flexed to 90° and the radiographic beam centred over the proximal portion of the tibia, and mediolateral radiographs with the stifle placed at a 135° angle with the beam centred over the stifle. The radiology technicians were expected to confirm the 135° stifle angle using a transparent overlay. A 100 mm magnification marker[b] positioned at the level of the stifle joint was included in each image. The length of this marker and the stifle angle were measured on all images and recorded (11).

The following measurements were made on the radiographs with the stifle flexed at 90°:

1. TPA measured using the Slocum method (▶Figure 1A)(12).
2. Tibial length along the functional axis (▶Figure 1B).
3. Level of the tibial crest in a proximodistal orientation (Z angle) (13) (▶Figure 1C).
4. The proximal tibial width from the functional axis (▶Figure 1D).
5. Tibial plateau length (▶Figure 1E).

The width of the tibial tuberosity was then calculated as the difference between the total tibial width, measured by a line connecting the most caudal point of the tibial plateau to the most cranial point of the tibial crest, and the tibial plateau length (13). For radiographs obtained after surgery, the amount of tibial crest advancement in the cranial direction was calculated by subtracting the preoperative measurement of proximal tibial width from the postoperative measurement. The PL-TPA (▶Figure 1F) was measured on radiographs with the stifle at 135°. To evaluate for possible distal displacement of the patella after the modified Maquet procedure, the distance from the proximal aspect of the trochlear groove to the base of the patella was measured on pre- and postoperative radiographs with the stifle flexed to 90°.

All images for a patient were opened and viewed side-by-side. The three lines that defined the functional axis, the patellar ligament, and TPA were positioned on each radiograph for each time point. In doing this, similar placement of the functional axis and the line defining the tibial plateau was achieved for each time point despite minor differences in tibial positioning.

b X-ray magnification indicator #6–013: BioMedtrix, Boonton, NJ, USA

For all cases, both wedge size calculation methods were performed. The Orthomed measurement method was performed using the 90° stifle radiographs. This method began with creating a line that is 135° to the function axis which was then positioned so that it extended proximally from the insertion of the patellar ligament to intersect with a line depicting the tibial plateau slope. A line was drawn from this intersection, perpendicular to the tibial plateau slope line, to intersect with a line drawn perpendicular to the functional axis of the tibia and aligned with the most cranial point of the tibial tuberosity. The distance between this intersection and the most cranial point of the tibial tuberosity was the planned amount of cranial advancement (▶Figure 2A). The modified tibial tuberosity advancement measurement method was performed using the 135° stifle radiographs. Similar to the tibial tuberosity advancement planning method, lines oriented with the patellar ligament and tibial plateau were drawn. A line drawn perpendicular to the tibial slope was located approximately 3 mm distal to the distal pole of the patella (to account for anticipated distal translation of the patella after advancement), and was extended distally beyond the cranial-most point of the tibial tuberosity. The distance, in the cranial direction, between the point of the tibial tuberosity and this line was the planned amount of cranial advancement (▶Figure 2B).

Statistical analysis

A successful PL-TPA was defined as a postoperative PL-TPA of 90° ± 5°. The success rate was determined by the frequency distribution of postoperative PL-TPA. The planned advancement, as measured by the Orthomed and modified tibial tuberosity advancement methods, were compared using a Student's paired t-test. The difference between the tibial width pre- and postoperatively was defined as the actual achieved advancement at the level of the patellar ligament insertion as this represented the achieved cranial advancement accomplished by wedge insertion. This actual advancement was compared to the wedge size using Pearson's correlation coefficient.

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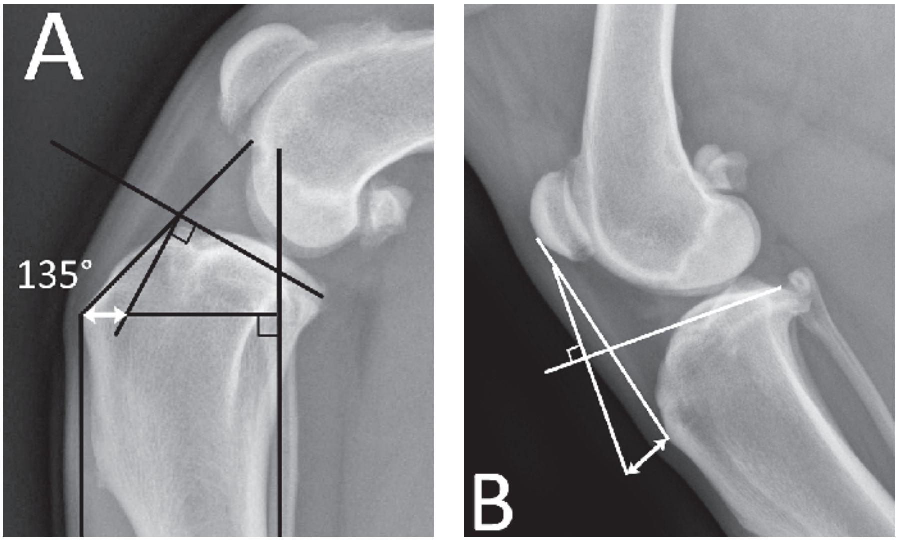

Figure 2 **A) Orthomed modified Maquet procedure measurement method:** A line drawn 135° to the function axis was located on the tibial tuberosity at the insertion of the patellar ligament. This line intersected the tibial plateau angle (TPA) line that was previously drawn. A second line 90° to the TPA was drawn and placed on the intersection described above. The distance between this line and the most cranial point of the tibial tuberosity, measured along a line perpendicular to the function axis, was recorded as the Orthomed measurement. **B) Modified tibial tuberosity advancement measurement method:** The line defining the tibial plateau was drawn in the same manner as its placement on 90° stifle radiographs and the patellar ligament was defined by a line from the distal pole of the patella to its insertion on the tibial tuberosity. A line 90° to the TPA and equal in length to the patellar ligament was created with its proximal extent placed 3–4 mm distal to the distal aspect of the patella, such that its distal end was positioned directly cranial to the most cranial point of the tibial tuberosity. The distance from the most cranial point of the tibial tuberosity to the 90° line, in the cranial direction, was recorded as the modified tibial tuberosity advancement measurement.

The preoperative and postoperative tibial width from the functional axis, distance from the proximal trochlea to the base of the patella, and the PL-TPA were compared using paired Student's t-tests. Tibial width from the functional axis measured on immediate postoperative radiographs and eight-week radiographs were compared using paired Student's t-tests.

Anatomical tibial landmarks (Z angle, tibial width from the functional axis, tibial crest width, and preoperative TPA) and body weight were evaluated as possible predictive factors for determining actual wedge size in the entire group as well as for cases defined as successful using multiple regression. P-values less than 0.05 were considered significant. All statistical analyses were performed using statistical software[c].

c SAS 9.3: SAS, Cary, NC, USA

Results

Forty-eight modified Maquet procedures were performed during the study period. Ten procedures were excluded: three procedures had postoperative complications that necessitated additional surgery prior to the eight week re-examination time period (crest fracture, tibial fracture, implant motion, and eventual wedge explanation due to infection) and seven procedures had incomplete radiographic evaluation. Thirty-eight procedures met the inclusion criteria. Mean (± SD) patient weight was 33.4 ± 7.4 kg (median: 32.2 kg; range: 19.6 to 47.1 kg). Four dogs had bilateral surgery, with one dog undergoing simultaneous bilateral procedures.

The success rate, based on a postoperative PL-TPA of 90° ± 5°, was 53% (20/38 procedures). Immediate postoperative PL-TPA angles ranged from 86.7° to 108.2°. No angle was less than 85° and 18 procedures had angles greater than 95°. The difference between postoperative tibial width and preoperative tibial width (actual advancement, mean ± SD: 7.24 ± 1.57 mm) was significantly smaller than the actual wedge size used (mean ± SD: 10.5 ± 1.54 mm) ($p < 0.001$).

Mean (± SD) postoperative tibial width from the functional axis (39.8 ± 4.1 mm) was larger than the preoperative measurement (32.5 ± 3.4 mm) ($p < 0.001$). Postoperative distance from the proximal trochlea to the base of the patella (19.9 ± 4.9 mm) was larger than the preoperative measurement (15.9 ± 4.5 mm) ($p < 0.001$). The postoperative PL-TPA (95.9° ± 7) was smaller than the preoperative PL-TPA (103.1° ± 4.7) ($p < 0.001$). No significant differences were found for the above measurements between the postoperative and eight-week follow-up radiographs.

The measurements calculated using the Orthomed and modified tibial tuberosity advancement measurement methods did not differ significantly ($p = 0.09$). In evaluating the tibial anatomical measures and body weight as predictive factors for actual wedge size, the overall model for all of the procedures (n = 38) was significant ($r^2 = 0.61$, $p < 0.001$), meaning that 61% of the variation in the wedge size was accounted for by all of the predictor variables with the exception of the tibial tuberosity width and body weight, which were not significant. The Z angle and TPA had negative regression coefficients (–0.13 and -0.16, respectively) meaning a one degree increase in the Z angle resulted in a decrease in the mean actual wedge size by 0.13 mm, and similarly, a one degree increase in the preoperative TPA resulted in a decrease in the mean actual wedge size by 0.16 mm. When a multiple regression model was performed using only the cases defined as successful (PL-TPA <95°; n = 20) with the same predictor variables, the model was once again significant ($r^2 = 0.75$, $p < 0.001$). However, only the Z angle (coefficient –0.17) and the tibial width from the functional axis (coefficient 0.29) were significant.

Discussion

In this study, we found that only 20/38 modified Maquet procedures achieved a

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PL-TPA of 85 to 95°. The 95° angle is five degrees greater than the optimal 90° (less correction than planned) that is the goal of tibial tuberosity advancement procedures. However, in one other study the mean postoperative PL-TPA was 95° following tibial tuberosity advancement and most patients had a clinically acceptable outcome (14). Additionally, in another study investigating the postoperative outcomes of 458 cases following tibial tuberosity advancement, the reported mean postoperative PL-TPA was 92° ± 2° with high overall owner satisfaction in clinical outcome (15). Since the success rate in our study was only 53%, with all unacceptable procedures having a PL-TPA greater than 95°, we rejected our hypothesis that the modified Maquet procedure, as currently planned and performed, reliably results in a PL-TPA angle of 90°. There are several potential explanations for not achieving the planned advancement. Both the Orthomed and modified tibial tuberosity advancement measurement methods appear to underestimate the size of wedge needed to provide appropriate advancement. In addition, the widest portion of the wedge (the dimension by which they are named) is at the top, and this is not located at the level of the patellar ligament insertion, though this is where the proposed advancement is measured in both measurement methods. In our study, the amount of advancement achieved was measured at the level of the tibial tuberosity in a direction perpendicular to the functional axis. Although this is not the standard way in which tibial tuberosity advancement is measured for the tibial tuberosity advancement procedure, this method was used by the authors to illustrate the advancement that was achieved at the insertion of the patellar ligament in a cranial direction only (9). The modified Maquet procedure does not result in proximal advancement of the tibial crest fragment as the distal bone bridge is left intact. The proximal tibial width is, thus, more representative of the actual achieved advancement.

According to these results, advancement achieved at the level of the patellar ligament was significantly less than the wedge size used to achieve advancement. The average advancement was 30% less at the patellar ligament insertion than the calculated wedge size. A similar finding was reported by Etchepareborde and colleagues regarding achieved tibial tuberosity advancement and cage size discrepancy in tibial tuberosity advancement cases (14). The underestimation of cage size was more disparate in dogs with a greater TPA, leading to the recommendation that tibial tuberosity advancement procedures are not ideal for cases with slopes in excess of 30° (14, 16).

There were significant changes to tibial width and PL-TPA postoperatively compared to the preoperative measurements. We accept our hypothesis that there would be no difference between the postoperative and eight-week measurements as these changes persisted at the eight-week follow-up radiographs indicating that the implants remained stable with no detectable loss of advancement. In addition to this, the patella was displaced distally on postoperative radiographs. This distal displacement is expected with the modified Maquet procedure because the tibial tuberosity is not advanced in a proximal direction, effectively pulling the patella distally. The clinical relevance of this slight patella baja is unknown and further investigation is beyond the scope of this current study.

Wedge sizes determined by the two surgical planning methods did not differ. We therefore reject the hypothesis that these methods would result in significantly different wedge sizes. This indicates that the modified tibial tuberosity advancement measurement method is no less likely to lead to an underestimation of wedge size than the Orthomed measurement method. A factor that may influence this finding is that the wedge sizes are in 1.5 mm increments, requiring a large difference between the two measurement methods to cause a change in the size of the wedge used. Another factor may be that none of the stifle joints had a TPA greater than 30°. It may be that a difference is apparent when planning advancement in patients with steeper slopes. Additionally, when the limb is positioned at 135° there is the possibility for cranial tibial subluxation. If subluxation is present, it will affect the result of the modified tibial tuberosity advancement method, possibility resulting in an artificially smaller than expected measurement for wedge size.

One of the ultimate goals of this study was to develop an improved, more accurate measurement method. Measurements of tibial anatomical parameters were evaluated and correlated with the actual wedge size used to identify parameters that could be used to predict the appropriate wedge size. The comparisons were made for all cases as well as cases only identified as successful (PL-TPA <95°). Ultimately, significant correlations were found for Z angle and tibial width from the functional axis in cases defined as successful. The Z angle is a means by which the proximodistal location of the insertion of the patellar ligament can be quantified (13, 17). A negative correlation was found between the Z angle and wedge size, which indicates that with each decrease in Z angle by 0.17°, the wedge size increases by one millimetre. A smaller Z angle represents a more distal patellar ligament insertion. The Z angle relationship can potentially be explained by the discrepancy between the actual achieved advancement and the actual wedge size used. The more distal on the tibia the measurements are made, as in the case with a smaller Z angle, the more likely that the wedge size will be underestimated. Patellar ligament insertion site has been implicated as a factor effecting surgical planning for osteotomy procedures for stabilization of the cranial cruciate ligament deficient stifle (17, 18). This finding with the Z angle continues to support the need for further trigonometric evaluation of this crucial anatomic feature to offer the best individual radiographic plan. The correlation was positive for the tibial width from the functional axis; with each 0.29 mm increase in tibial width, wedge size increased by one millimetre. Body weight was found not to be significantly correlated with wedge size, which was an unexpected finding. It is possible that our patient weight range was not wide enough to reflect a correlation with wedge size. Additionally, body condition score was not known. The current Orthomed brochure has a table outlining that wedge size be chosen based on dog breed and, by implication, size, without making further radiographic measurements (10). Clinical data on the success of this more

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generalized sizing method have not been published. The goal of this study was to evaluate geometrically, a more optimal measurement method that could be applied to all radiographs, independent of breed or size.

Underestimation of wedge size must be addressed and both measurement methods investigated in this study did not achieve the goal of accurate planning. Because patients with smaller Z angles were identified as needing larger wedges, further investigation should be sought into the trigonometric influence of the Z angle as a possible anatomic feature that could be useful in determining appropriate wedge size; unfortunately that was beyond the scope of this study. Currently, these authors consider increasing measured wedge size by 30% to adjust for the amount of underestimation that we identified. This correction has not been evaluated to determine its influence on radiographic or clinical outcome.

This study has several limitations. The surgical procedures were performed prior to this study being conceived and during a period where confidence in the Orthomed method was changing. The actual method used to plan each case, and the intra-operative decisions that influenced the final wedge size selection, are not known. Patients were not randomized to the different measurement methods as this was a retrospective study. The patient population was selected at the surgeon's discretion, and thus, patients with an excessively steep TPA were not included. No patient had a TPA >30°. Clinical outcomes were not evaluated as part of this study. Additionally, the current Orthomed brochure no longer recommends the measurement methods that prompted the undertaking of this study (10).

In conclusion, further investigation is needed to determine the ideal planning method for the modified Maquet procedure. With the current planning methods, the wedge size calculated often leads to insufficient advancement of the tibial tuberosity. In addition, a prospective study with objective clinical outcome assessment should be performed to determine the clinical success of this procedure and the amount of advancement necessary to achieve success in an individual.

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Conflicts of interest

S. C. Roe and D. J. Marcellin-Little are a paid consultants of BioMedtrix, LLC. There are no further conflicts of interest to declare.

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