Modification of the cranial closing wedge ostectomy technique for the treatment of canine cruciate disease

Description and comparison with standard technique

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Introduction
Cruciate disease is the most common orthopaedic conditions to affect the canine stifle joint (1). This condition causes pain and lameness secondary to instability, and the development of secondary osteoarthritis. In addition to this, cranial cruciate ligament (CCL) rupture predisposes to medial meniscal tears (2).

Traditional surgical techniques for the treatment of this condition aim to restore stability to the joint by mimicking the anatomical location and function of the normal CCL. Various intra-articular and extra-articular techniques have been described (3–8).

In 1984, Slocum and Devine proposed a new treatment for cruciate disease, the cranial closing wedge ostectomy (CCWO). They described an internal force generated in the stifle and dubbed this force the ’cranial tibial thrust’. This force was generated during weight-bearing. In the normal stifle, the CCL opposes this force, however when the CCL is ruptured there is spontaneous cranial tibial subluxation during weight-bearing. The aim of the CCWO was to eliminate cranial tibial thrust by levelling the tibial plateau, thus providing functional stability during the stance phase of the gait (9).

Tibial plateau levelling osteotomy (TPLO), also described originally by Slocum, functions on the same biomechanical principles (10). This technique has largely replaced the CCWO as the most commonly performed plateau levelling procedure (11). However the CCWO is still a useful procedure and might have advantages over conventional TPLO for the treatment of dogs with an excessive tibial plateau angle (TPA). This problem (excessive TPA) is often associated with a deformity of the proximal tibia which results in tibial ante-curvatum (12, 13). The cranial tibial long axis shift that occurs with CCWO addresses this deformity of the plateau directly. In addition to this, performing TPLO in cases with excessive TPA may necessitate a large...
rotation, leading to loss of a caudal buttress for the tibial crest, which may predispose to tibial crest fracture (14).

The desired postoperative TPA of five to 6.5 degrees is difficult to achieve with surgical treatment of excessive TPA, and under-correction was reported as a problem in a clinical case series (15–17). Various surgical techniques have been investigated in order to address this problem (18). One technique that allows complete correction in excessive TPA cases is a combination of the TPLO and the CCWO, however the complication rate for this procedure is significantly higher than with either the TPLO or CCWO alone (14, 18).

The aim of this study was to describe a modification of the cranial closing wedge osteotomy (Modified CCWO) and to compare this technique to the standard CCWO technique using cadavers. The hypothetical advantages of the modified CCWO are a reduction in the size of the bone wedge removed by the osteotomy, as well as reduced tibial shortening and a greater preservation of proximal bone stock for implant placement.

Materials and methods
Cadaveric specimen collection

Eight pairs of cadaveric tibias from various breeds of dogs, free from orthopaedic disease, were used in this investigation. The animals were all skeletally mature and had been euthanatized for reasons unrelated to this study. The tibias were harvested by stifle and talocrural disarticulation. All soft tissue, except for the insertion points of the CCL and the caudal cruciate ligament, was removed. The tibias were double wrapped in saline soaked gauze sponges and stored in a freezer at −20 °C. Bones were thawed at room temperature at least 12 hours prior to testing.

Determination of pre-osteotomy tibial plateau angle

Anatomical TPA was measured by the method described by Reif et al. (19). Briefly, two 1.1 mm Kirschner wires were inserted into the subchondral bone at the cranial and caudal extent of the medial tibial plateau (Fig. 1). The functional axis of the tibia was defined as the midpoint between the intercondylar tubercles and the middle of the distal intermediate ridge of the tibia. The cranial Kirschner wire was placed immediately cranial and medial to the insertion of the CCL and the caudal Kirschner wire was placed at the caudal edge of the tibial condyle immediately medial to the caudal cruciate ligament (Fig. 2).

The specimens were then mounted in a frame constructed from external fixation clamps and connecting bars (Fig. 1). Two half pins were used to stabilise the tibia within the frame. To ensure that the functional axis of the tibia was parallel to the connecting bar, the proximal pin was placed into the midpoint between the intercondylar tubercles, and the distal pin was placed into the midpoint of the distal intermediate ridge. The connecting bar and the Kirschner wires in the tibial condyle were aligned such that both were parallel to the surface of the table (Fig. 1). A digital camera was used to photograph the specimen. The photograph was centred over the intercondylar tubercles, and the focal distance was measured as 100 cm. The anatomical TPA was measured on the photograph as the angle between the line perpendicular to the connecting bar and the line joining the Kirschner wire insertion points. The angle was measured using angle measurement software.

Determination of pre-osteotomy anatomical tibial plateau angle

Tibial length was measured from the photograph as the distance between the midpoint between the intercondylar tubercles and the middle of the distal intermediate ridge of the tibia. The measurements were made using image measurement software. A ruler was included in all photographs at the same elevation as the

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3 IMEX Veterinary Inc., Longview, Texas, USA
4 Fuji Film Co. Ltd., Minato-Ku, Tokyo, Japan
5 Screen Protractor Software Version 4.0: Iconico Inc. Software Stores, New York, NY, USA
6 AVPSoft - available online at http://avpsoft.com/
midpoint of the tibia to allow accurate calibration of measurement for magnification (Fig. 1).

Osteotomy techniques

Standard cranial closing wedge ostectomy

An osteotomy was performed with an oscillating saw perpendicular to the long axis of the tibia at the level of the most distal point on the tibial crest. A second osteotomy was performed at a fixed angle of 25° relative to the first osteotomy (Fig. 3: A and B). A fibular osteotomy was performed at the level of the distal tibial osteotomy. A wedge of bone was removed. The ostectomy site was reduced and the fragments were stabilised using a cranial hemicerclage wire and two crossed 1.6 mm Kirschner wires placed across the osteotomy (Fig. 4). The area of the proximal segment of the tibia and the area of the wedge removed were both measured from digital photographs of the proximal segment of the tibia and the area of the wedge removed were measured as described for standard CCWO (Fig. 5). The area of the proximal fragment and the wedge removed were measured as described for standard CCWO. The area of the distal osteotomy surface with bone-to-bone contact with the proximal fragment osteotomy was measured from a digital photograph of the cut surface of the distal fragment using the image measurement software. The margin of contact, between the proximal and distal fragments was marked with pieces of adhesive tape on the proximal and distal fragments after the fixation of the osteotomy was removed to allow determination of the area of contact (Fig. 6). The percentage of the total cross sectional area of the distal fragment osteotomy in contact with the proximal fragment (area cranial to adhesive tape) was calculated.

Post-ostectomy measurements

The post-ostectomy anatomical TPA was measured using the same method as described for the pre-ostectomy anatomical TPA. From this measurement, the degree of reduction in TPA was determined (pre-ostoperative TPA minus postoperative TPA).

Statistical analysis

The data were analysed with descriptive statistics using statistical software. Due to the small sample size, a normal distribution could not be assumed; thus the data were analysed using the Mann-Whitney U test. A p-value of <0.05 was considered as significant. Different breeds with tibias of varying

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dimensions were used in this study. For this reason, the data were normalised according to the cranial to caudal width of the tibia, at the level of the most distal part of the tibial crest (where the distal osteotomy was made) perpendicular to the long axis of the tibia. The following parameters were compared: reduction in TPA achieved (degrees), tibial long axis shift (degrees), reduction in tibial length (mm), area of bone wedge removed (cm²), area of proximal fragment post-ostectomy (cm²).

Results
All of the results for the measurements obtained for the standard and Modified CCWO are summarized in Table 1.

The reduction in tibial length for the standard CCWO (mean = 2.5 mm, CI = 1.2–3.9) was greater than for the Modified CCWO (mean = 1.5 mm, CI = 0.9–2.1) (p < 0.015). Also, the area of bone removed with the standard CCWO (mean = 0.73 cm², CI = 0.64–0.82) was greater than that for the Modified CCWO (mean = 0.35 cm², CI = 0.30–0.40 [p < 0.0001]).

Table 1 Comparison of measurements expressed as mean and 95% confidence intervals of cadaveric tibiae after Standard and Modified cranial closing wedge ostectomy.

<table>
<thead>
<tr>
<th></th>
<th>Standard CCWO mean (95% CI)</th>
<th>Modified CCWO mean (95% CI)</th>
<th>p-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction in TPA (°)</td>
<td>19.30 (17.59 - 21)</td>
<td>20.84 (18.17 - 23.51)</td>
<td>NS</td>
</tr>
<tr>
<td>Tibial long axis shift (°)</td>
<td>1.60 (0.78 - 2.42)</td>
<td>1.28 (0.57 - 1.98)</td>
<td>NS</td>
</tr>
<tr>
<td>Difference in tibial length (mm)</td>
<td>2.5 (1.22 - 3.9)</td>
<td>1.5 (0.9 - 2.1)</td>
<td>&lt;0.015</td>
</tr>
<tr>
<td>Bone wedge area (cm²)</td>
<td>0.73 (0.64 - 0.82)</td>
<td>0.35 (0.3 - 0.4)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Proximal fragment area (cm²)</td>
<td>4.18 (3.48 - 4.88)</td>
<td>4.63 (3.89 - 5.37)</td>
<td>NS</td>
</tr>
<tr>
<td>Mean cross-sectional area of distal fragment in contact with proximal fragment (%)</td>
<td>100</td>
<td>74</td>
<td>NA</td>
</tr>
</tbody>
</table>

Key: Standard and Modified CCWO values are expressed as mean and the 95% confidence interval (CI). CCWO = cranial closing wedge ostectomy. * indicates comparison between groups made using Mann Whitney U tests. NS = not significant; NA = not applicable.

For the Modified CCWO group, the mean percentage of cross sectional area of the distal fragment osteotomy in contact with the proximal fragment was 74%. For the standard CCWO group, 100% of the distal fragment osteotomy was in contact with the proximal fragment.

Fig. 5 Modified cranial closing wedge osteotomy stabilised with cranial hemicerclage wire and crossed Kirschner wires.

Fig. 6 Adhesive tape marking area of bone-on-bone contact between the proximal (left) and distal (right) osteotomy fragments.

Discussion
The results of this study confirms that the Modified CCWO is equally effective at plateau levelling as there was no significant difference in the reduction in TPA between the two techniques. Although a 25° wedge was removed in all tibiae, the reduction in TPA was only approximately 20° for both groups. It is well recognised that, in order to correct TPA to a target of five to six degrees, a wedge angle larger than the TPA is required. Apelt et al. identified that cranial tibia subluxation is neutralised when a wedge angle of TPA plus five degrees is taken (21, 22). This wedge angle resulted in a postoperative TPA of approximately six degrees. In the current study, similar results were obtained: the TPA was reduced by an amount that was significantly less than the wedge angle. When tibial long axis shift was compared, again, there was no significant difference between the two groups.

The major difference between the two techniques is that a significantly smaller amount of bone is removed with the modified technique. Although the area of the proximal fragment was larger for the modified technique. Although the area of the proximal fragment was larger for the modified technique, this difference was not statistically significant. Because the area of the proximal fragment is much greater than the area of the wedge, the difference between the two techniques is accentuated when wedge area is compared. The failure to find a significant difference for the area of the proximal fragment is likely to represent a type 2 error. Evaluating the technique logically, it makes sense that if the distal osteotomy is performed at the same location and approximately twice as much bone is removed with a standard wedge it follows that there will be less bone remaining in the proximal fragment if a standard wedge is performed. The smaller wedge of bone removed with the modified technique allows greater preservation of bone stock proxim-
ally, particularly caudally, which may facilitate implant placement. This advantage becomes particularly important when there is an excessive TPA, defined as a TPA of \( \geq 34^\circ \), a problem which is often diagnosed in small terrier breeds such as West Highland Terriers (17). When a patient with excessive TPA is treated with standard CCWO, a large wedge of bone must be removed in order to fully correct the TPA to the target angle of five to 6.5 degrees. Removal of a relatively larger wedge leaves less room in the proximal fragment, making implant placement more difficult. The use of TPLO plates is described for CCWO, and triple tibial osteotomy (23, 24). These plates facilitate the placement of implants in a small proximal fragments, however even if these plates are employed the surgeon may still encounter limitations regarding proximal fragment size.

In clinical cases where a standard CCWO is performed, one way of circumventing this problem is to perform an under-correction: removing a wedge with a more acute angle and aiming for a postoperative TPA of approximately 15 to 20 degrees. This approach allows greater bone preservation proximally. The disadvantage of this approach is inadequate plateau levelling. Under-correction and inadequate plateau levelling may lead to residual cranio-caudal instability predisposing to lameness, osteoarthritis and secondary meniscal tears. Under-correction is a well-recognised problem when the Standard CCWO is used to correct patients with excessive TPA. Macias et al. reported the use of Standard CCWO in seven terriers with excessive TPA, and six out of seven of these dogs had a postoperative TPA of 15 to 21 degrees (17). Under-correction has also been identified where standard CCWO was applied to cases without excessive TPA – a postoperative TPA as high as 18° was reported in another case series (25). In cases not undergoing meniscal release in that study, the rate of subsequent meniscal tears was 17%, with all these cases requiring revision arthroscopy and partial meniscectomy. One study that evaluated under-correction of excessive TPA following standard Slocum TPLO found a superior owner-perceived outcome with a postoperative TPA of \( \leq 14^\circ \) (18). In another study on standard Slocum TPLO performed on Labrador retrievers, there was no correlation between postoperative TPA and ground reaction forces \( \geq 4 \) months after surgery (26).

However, the mean postoperative TPA in this study was 7.8 ± 3.7 degrees with a range of zero to 14 degrees. Thus no cases of marked under-correction were present in this study. The Modified CCWO provides a major advantage to the surgeon in that a smaller wedge can achieve the same degree of plateau levelling, which may allow full correction of the TPA.

An alternative approach to the problem of large angular corrections using the Standard CCWO technique is to aim to perform a full correction, but to instead perform the osteotomy more distally to allow more room for implant placement. However, Bailey et al. demonstrated that the more distal this osteotomy is performed, the greater the tibial long axis shift, and the greater the postoperative TPA. Thus, this approach may result in inadequate plateau levelling (21).

A second advantage of the Modified CCWO is significantly reduced tibial shortening. Tibial shortening can be problematic for a number of reasons. Firstly, craniodistal displacement of the tibial crest will lead to patella alta and increased strain on the straight patella ligament, increasing the likelihood of patellar desmitis (14). Secondly, tibial shortening creates increased load and bending of the fibula, increasing the risk of fibular fracture either intra-operatively or during the recovery period. Fibular fracture can lead to morbidity and lameness (27). Fibular fracture also leads to loss of lateral splitting, theoretically increasing the risk of implant failure. Finally, removal of a wedge with a larger cranial dimension might result in relatively greater recurvatum of the tibia. As well as being aesthetically suboptimal, this alters the load bearing through the stifle and crurotarsal joints. This abnormal load bearing may alter contact mechanics, and thus result in cartilage wear and functional lameness.

The major disadvantage with the Modified CCWO technique is that the entire cross sectional area of the distal fragment might not contribute to load sharing. In our study, the mean percentage of distal fragment in contact with the proximal fragment was 74%, whereas 100% of the distal fragment was in contact with the proximal fragment for the Standard CCWO. For both techniques, as the cross sectional area of the proximal fragment is far larger than the distal fragment, a significant percentage of its area does not contribute to load sharing, with a large amount of ‘caudal overhang’ present (Fig. 4 and 5). Assuming that adequate stabilisation is employed, the authors believe that this factor would be unlikely to contribute to higher rates of implant failure for the modified technique. Furthermore, the option to perform the Modified CCWO more proximally may have a mitigating effect on this problem. The cross sectional area of the proximal tibial metaphysis increases markedly from distal to proximal. Thus, a more proximal osteotomy takes full advantage of tibial morphology, with a greater area of bone available to contribute to load sharing. A more proximal osteotomy also affords improved access to cancellous bone. It is well recognised that bone healing occurs more rapidly in cancellous bone compared with cortical bone, thus a more proximal osteotomy is biologically as well as biomechanically advantageous (28). A recent study comparing CCWO with standard Slocum TPLO identified a higher rate of implant failure for CCWO despite the fact that 3.5 mm TPLO plates were used for both groups (23). One of the obvious differences between the two techniques is that the osteotomy for TPLO is performed more proximally, affording improved access to cancellous bone. Due to this biological advantage, patients treated with TPLO may heal more rapidly, reducing the risk of implant failure. This may be the reason why this important difference was identified in this study.

Taking into consideration these mitigating factors, the reduced bone on bone contact that occurs with the modified CCWO technique may not actually translate to an increased rate of implant failure in clinical cases. This question could only be effectively addressed by biomechanical and prospective clinical studies. The problem might be less of a concern with the advent of locking TPLO plates which offer enhanced biomechanical security in comparison with conventional plates (29).
This study had several limitations. The study employed cadaveric tibiae of varying dimensions. In order to address this, the results were normalised to the cranial to caudal width of the most distal point of the tibial crest. This is the point where the distal osteotomy was made. This point was chosen as the authors felt that it was the location most closely related to the area of bone removed, the reduction in tibial length, and the area of the proximal fragment post-osteotomy. The use of normalised data can potentially lead to increased variability and a degree of inaccuracy. Using tibiae from the same breed, or bone models, could have circumvented this problem. However, the methodology applied more closely approximates a clinical situation where the surgeon has to apply their technique to tibiae of differing size and morphology.

While the results obtained using cadaveric specimens suggest that the modified CCWO has some theoretical advantages over the standard CCWO, whether this translates to improved results in a clinical setting is a question that cannot be answered by this study.

Conflict of interest
None declared.

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