Double-Cut Tibial Plateau Leveling Osteotomy for the Management of Cranial Cruciate Ligament Insufficiency in Dogs with an Excessive Plateau Angle: Early Clinical Results in 16 Dogs

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Abstract

Objective To describe a modification of the tibial plateau leveling osteotomy technique wherein a double cut is made in the same plane to level the tibial plateau (double-cut tibial plateau leveling osteotomy [DCTPLO]) for treating dogs with cranial cruciate ligament (CrCL) and excessive tibial plateau angle (eTPA) diseases.

Study Design The DCTPLO technique was performed on 18 stifles in dogs with CrCL and an eTPA (>34°). This study evaluated the accuracy of preoperative planning, feasibility of the technique, postoperative clinical outcomes, radiographic examinations at the postoperative follow-up for the first 120 days, evolution of the tibial plateau angle (TPA), time of union of the osteotomy, apposition of the implants, and possible complications.

Results The described technique proved to be feasible for clinical application, with reproducibility from preoperative planning. An effective reduction in the eTPA levels was observed. The mean preoperative and postoperative TPA values were 39.4° (36°–43.5°) and 6.3° (3°–13°), respectively. Radiographic healing time was 60 days in 17/18 of stifles. Minor complications (not requiring surgical review or clinical treatment) were observed in 4/18 of stifles.

Conclusion The DCTPLO technique was effective for treating CrCL disease with TPA of up to 43.5° in dogs.

Keywords
- tibial plateau leveling osteotomy
- double cut
- osteotomy
- cranial cruciate ligament
- TPLO

Introduction

Cranial cruciate ligament (CrCL) disease, the most prevalent type of tibiofemoral-patellar joint disorder in dogs,[1] has garnered significant interest in the fields of veterinary medicine and orthopaedic implant manufacturing in recent decades.[2,3] Tibial plateau leveling osteotomy (TPLO) has been studied extensively, and most previous studies have indicated that it achieves the best overall results in patients with CrCL insufficiency.[4,5] TPLO has exhibited a higher efficacy in correcting the tibial plateau angle (TPA). Moreover, it has wide applicability in dogs of different sizes.[6] Consequently, TPLO has become the treatment of choice for CrCL insufficiency in dogs.[4,5]

Nevertheless, TPLO is associated with a few limitations.[7–9] For instance, the technique of leveling the tibial plateau is

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challenging in patients with a TPA of >34°.[5] This can potentially lead to a decrease in the efficacy of TPLO. Furthermore, rotation of the fragment beyond safe limits, increased risk of tibial tuberosity fractures, and excessive internal rotation of the proximal tibial fragment compromise the fixation of the implants in patients undergoing TPLO.[3,7,10,11] Thus, TPLO may not be the choice of treatment in such cases.[9,12]

The use of additional techniques and combinations,[5,13] such as cranial closing wedge ostectomy (CCWO),[14] modified CCWO,[15] a combination of TPLO and CCWO,[7] and coplanar CORA-based tibial plateau leveling osteotomy (coCBLO),[16] has been proposed to address this limitation. However, these techniques are associated with higher complication rates and a longer healing time in patients with excessive TPA (eTPA).[7,12,16–20] A consensus on the optimal treatment choice for dogs with eTPA remains to be established despite the availability of a wide range of options.[5,7,13,15,21]

Therefore, this study aimed to evaluate the clinical effectiveness of a modified version of TPLO, wherein a double cut was made in the same plane to level the tibial plateau (double-cut TPLO [DCTPLO]). It was proposed that adequate leveling of the tibial plateau can be achieved using DCTPLO via the closure of a semicircular wedge in the sagittal plane of the tibia and that the incidence of intra- and postoperative complications would be lower following DCTPLO compared with alternative procedures.

Materials and Methods

Inclusion Criteria

Consecutive dogs that presented to "Ortopedia Vet" institute with CrCL disease and eTPA were included in this study. CrCL disease was diagnosed based on the laxity observed during cranial drawer and tibial compression tests and the presence of clinical signs suggestive of this condition, such as pain and lameness. Only dogs with complete rupture of the CrCL were included in this study. Dogs with meniscal injuries were included.

Surgical Planning

Radiographic examinations were performed in accordance with the acceptable radiographic positioning criteria[22,23] using craniocaudal and mediolateral projections of the tibia, including the proximal and distal joints. Surgical planning was performed on magnified digital radiographic images using commercially available vPOP Pro software (VetSOS Education Ltd; ►**Supplementary Figs. S1–S4**, available in the online version). The positioning and radius of the osteotomy were determined according to a technique for planning conventional TPLO described in a previous study.[24] However, the tibial anatomy varies among cases. A second osteotomy was positioned adjacent and cranial to the first with the exit points in the caudal cortex aligned, forming a curved wedge. Due to individual variation in tibial anatomy, the geometry of the remaining tibial tuberosity must be taken into account, as narrow tuberosities may fracture[5] and certain patients may be unable to accommodate larger wedges.

The anatomical landmarks D1, D2, D3, and D4 were recorded. D1 was defined as the distance from the insertion of the patellar ligament into the tibial tuberosity to the osteotomy line perpendicular to the cranial edge of the tibia. D2 was defined as the distance from the insertion of the patellar ligament to the osteotomy line along the cranioproximal edge of the tibia. D1 and D2 were further subdivided. D1a was defined as the distance between the most cranial point of the tuberosity at the insertion of the patellar ligament on the tibial tuberosity and the first line of the osteotomy. D1b was defined as the distance between the first and second osteotomy line at the most caudal point. D2a was defined as the distance from the insertion of the patellar ligament to the first osteotomy line. D2b was defined as the distance between the first and second osteotomy line, being the size of the wedge in the cranial region. D3 was defined as the distance from the center of the intercondylar eminence of the tibia to the final point of the apex of the two osteotomy lines. D4 was defined as the midpoint of the osteotomy, which was evaluated to avoid losing the wedge in this region (►**Fig. 1**).

The cutting and closing of the wedge simulated using vPOP Pro resulted in a partial reduction in TPA. The required residual rotation was calculated as follows. TPA was measured by tracing the line of the mechanical axis of the tibia at the center of the talus and another line at the intersection of the intercondylar eminence at 85° to obtain a final plateau angle of 5°. The TPLO rotation in millimeters was obtained using vPOP Pro after performing the rotation.

Surgical Technique

The dogs were positioned in dorsal recumbency after inducing general anesthesia, and the affected limb was aseptically prepared for surgery in a hanging position. A standard medial surgical approach was used for the stifle and proximal tibia. The cruciate ligament, medial and lateral menisci, and the visible area of the femoral cartilage were inspected via a medial parapatellar mini-arthrotomy. Partial meniscectomy of the damaged meniscal segment was performed after identifying the meniscal lesions. The pes anserinus (insertion of the tendons of the sartorius, gracilis, and semitendinosus muscles) was subsequently reflected, and the medial collateral ligament was identified. The approximate location of the intercondylar eminence was determined using a 20×0.55 mm (24G) needle cranial to the medial collateral ligament at the level of the joint as a reference. This point served as a reference for measurement D3 and the caudal exit point of the tibial osteotomies. Measurements D1a, D1b, D2a, and D2b were marked on the tibia.

Both osteotomies were performed through the cis-cortex, before placement of a jig guide (►**Fig. 2**). The TPLO rotation was marked in the most caudal region of the osteotomies where the small wedge width would minimize errors in the measured rotation. The osteotomies were continued through the trans-cortex and the wedge removed, partially correcting the TPA (►**Fig. 3**).

The osteotomized fragment of the TPLO was rotated using a rotation pin inserted medially into the proximal segment of

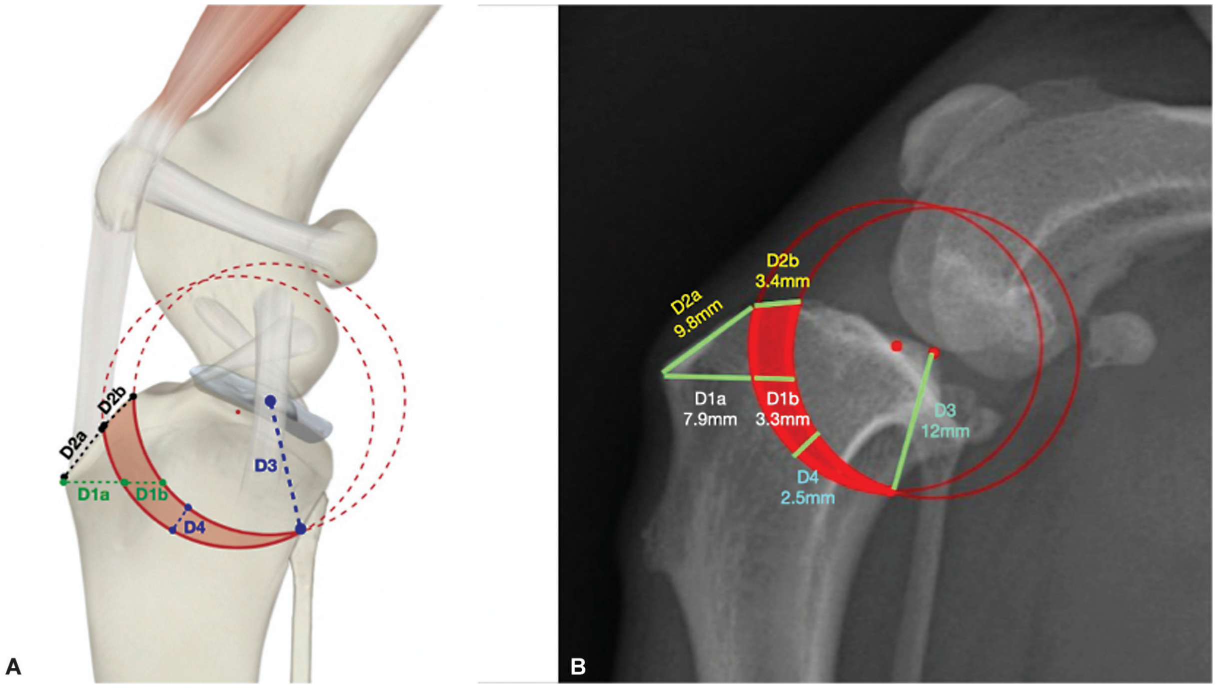

Fig. 1 (A) Illustrative image of the technique of double-cut tibial plateau leveling osteotomy in a dog showing D1a, D1b, D2a. D2b, D3, and D4. D1a is defined as the distance between the most cranial point of the tuberosity at the insertion of the patellar ligament on the tibial tuberosity and the first line of the osteotomy. D1b is defined as the distance between the first and second osteotomy line at the most caudal point. D2a is defined as the distance from the insertion of the patellar ligament to the first osteotomy line. D2b is defined as the distance between the first and second osteotomy line, being the size of the wedge in the cranial region. D3 is defined as the distance from the center of the intercondylar eminences of the tibia to the final point of the apex of the two osteotomy lines. D4 is defined as the midpoint of the osteotomy, which was evaluated to avoid losing the wedge in this region.
(B) Radiographic planning for eDCTPLO in a Yorkshire Terrier dog in mediolateral projection.

the tibia to correct the remaining TPA. The osteotomy was stabilized temporarily using a pin introduced proximal to the insertion of the patellar ligament and through the tibial tuberosity with a slightly distal orientation. The fragments were compressed and stabilized by placing a locking TPLO plate (Fixin System, Intrauma, Rivoli – TO, 10098; Focus, Indaiatuba, SP, 13.346–610; Aldrivet, Campinas, SP, 13030–150) over the proximal regions of the tibia (►**Fig. 4**). The jig was then removed, and the surgical site was closed.

A modified Robert Jones bandage was applied for 24 to 48 hours, and physical activity was restricted for 4 weeks. The sutures were removed 2 weeks postoperatively.

Postoperative Evaluation

Radiographic examinations were performed immediately and at 30, 60, 90, and 120 days after the surgery to evaluate the postoperative TPA, osteotomy union time, apposition of the implants, and complications (►**Fig. 5**). Major complications were defined as those requiring surgical treatment or medical treatment according to the current standard. Minor complications were defined as those that did not require additional surgical or medical treatment.[25]

D1, D2, and TPA were measured during the immediate postoperative period using digital imaging and vPOP Pro to evaluate the accuracy of tibial plateau reduction. Complete bone union was defined as the remodeling of the callus in all cortices. Incomplete bone union was defined as the presence of some cortex without a bridge, or gap in the osteotomy line. The thickness of the patellar ligament was also evaluated during the immediate postoperative period and 30 and 60 days postoperatively using radiographs and vPOP Pro in accordance with the guidelines proposed by Barnes et al.[26]

Results

Male and female dogs of various breeds that presented with CrCL and eTPA were included in this study (►**Appendix Table 1**). Sixteen dogs underwent a total of 18 surgical procedures (two dogs underwent bilateral surgery performed as different procedures at an interval of 18 months in first case and 45 days in the second case). The mean age and body weight of the participants were 73.2 months (range: 12–156 months) and 9.1 kg (range: 5.0–20.4 kg), respectively. Only three dogs (18.7%) weighed >10 kg. The mean preoperative and postoperative TPAs were 39.4° (36–43.5°) and 6.3° (3–13°), respectively. Radial saw blades (D3) of 10 to 18 mm were used, and a 12-mm blade was used in 10 of the 18 cases. The mean wedge size and TPLO rotation were 3.3 mm (2.0–4.9 mm) and 4.6 mm (2.2–7.0 mm), respectively.

Evaluation of the gait during the postoperative period revealed no signs of lameness after 60 days in any of the dogs in the subjective evaluation of the gait. Bone union was achieved at 60 days in 17/18 stifles and at 90 days in the remaining case (►**Appendix Table 1**).

Patellar ligament thickening was observed in 16/18 of stifles during the immediate postoperative period. An increase in thickness was observed at 30 and 60 days after the surgery in 13/18 and 11/18 of stifles, respectively. Minor

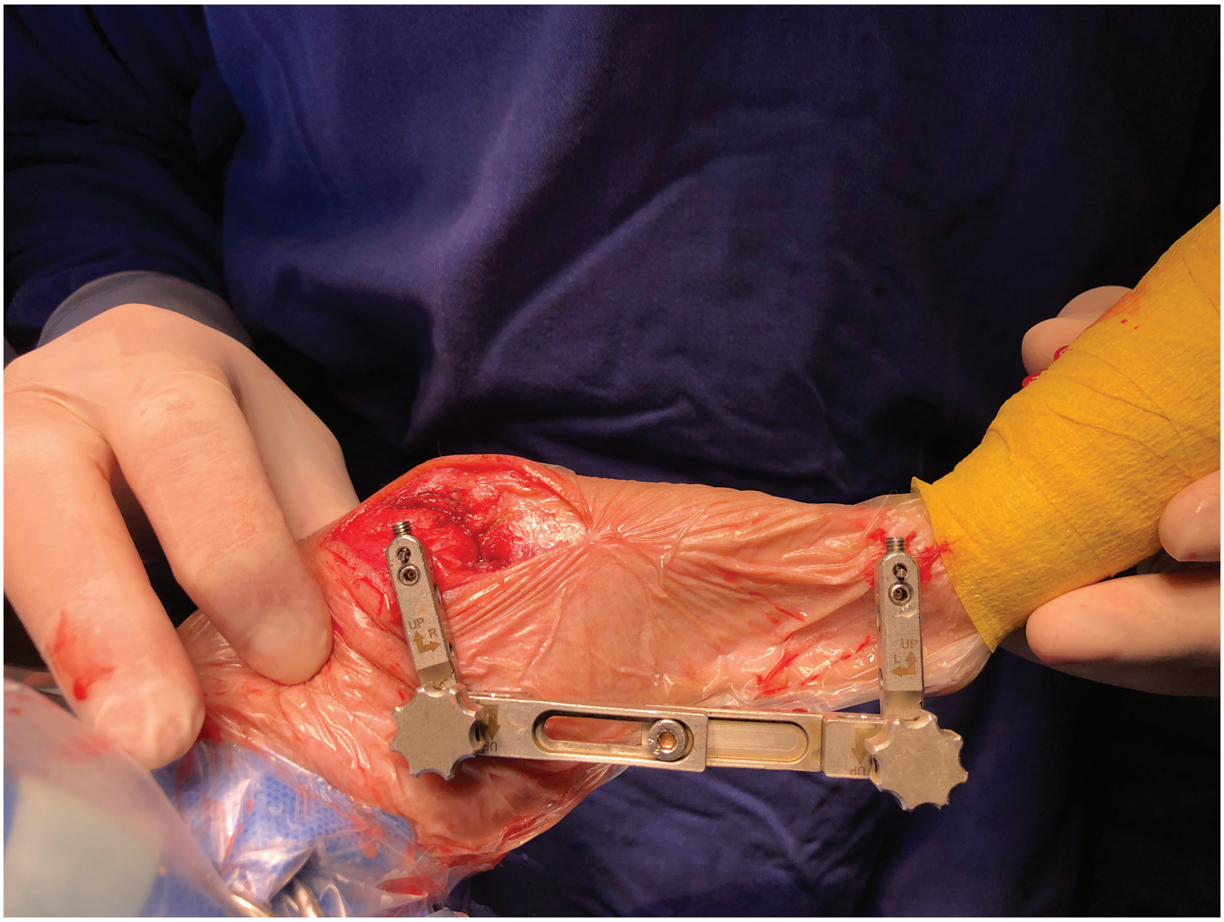

Fig. 2 Intraoperative image of double-cut tibial plateau leveling osteotomy using the craniomedial approach on the left knee of a Yorkshire Terrier dog. Note the use of a jig guide to maintain the stability of the two bone segments during the execution and stabilization of the osteotomy.

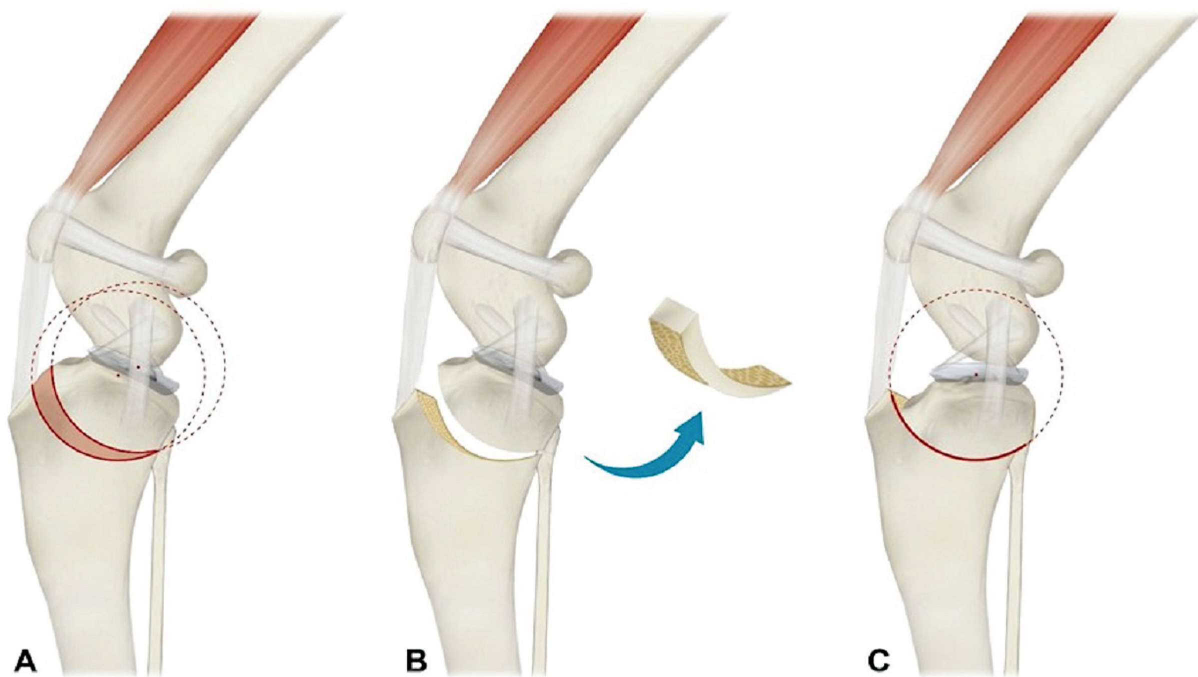

Fig. 3 Illustrative image of the technique of double-cut tibial plateau leveling osteotomy for correction of eTPA in dogs. (**A**) Positioning of the angle of the blades to form the wedge. (**B**) Wedge removal and reduction of the tibial plateau. (**C**) Final appearance of the tibial plateau after wedge removal and remaining TPLO rotation. eTPA, excessive tibial plateau angle; TPLO, tibial plateau-leveling osteotomy.

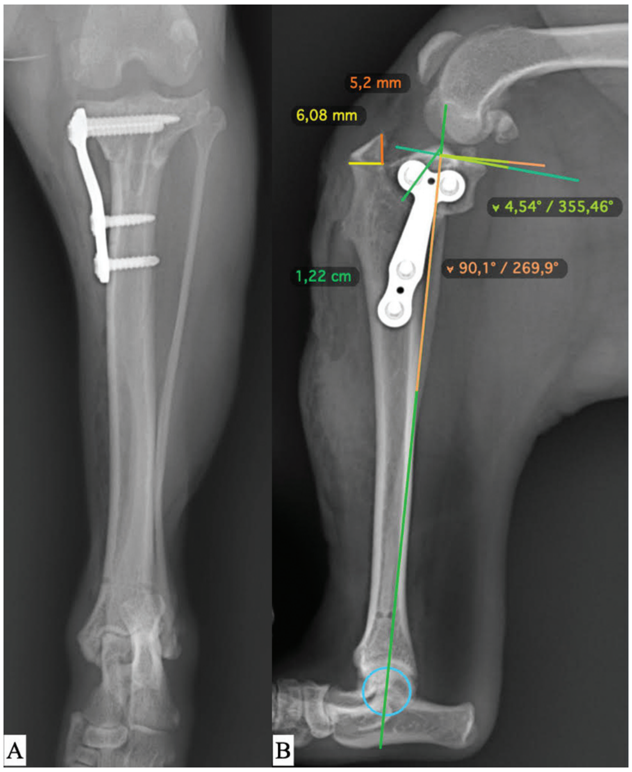

Fig. 4 Radiographic image of a Yorkshire Terrier dog acquired during the immediate postoperative period of double-cut tibial plateau leveling osteotomy in craniocaudal (**A**) and mediolateral (**B**) projections. Note the correction of the angle of the tibial plateau to 4.5° after the technique, trapezoid-shaped tibial crest, and good positioning of the implants.

Fig. 5 Radiographic image of a Yorkshire Terrier dog acquired after 90 days of double-cut tibial plateau leveling osteotomy in craniocaudal (**A**) and mediolateral (**B**) projections. Total union of the osteotomy and good positioning of the implants are observed.

complications were observed in 2/18 of stifles, including a gap in the cranial region of the wedge in stifles 4 and 8, which hindered intraoperative interfragmentary compression. Small bone fragments were observed within the wedge in the lateral region of the tibial tuberosity until 60 days after the surgery. These fragments were removed using a small osteotome. The final TPA was measured using an immediate postoperative radiograph. Immediate postoperative TPA deviated from the target of 5 to 6.5 in 5/18 of stifles. In stifles 4 and 8, postoperative TPA of 13 and 8, respectively, was considered due to the presence of small bone fragments hindering reduction of the osteotomy. No healing complications were noted in these two cases.

Discussion

The innovative technique described in this study is promising in that it resulted in a significant reduction in the tibial plateau in dogs with eTPA with minimal increase in complexity. Furthermore, the preliminary rates of intra- and postoperative complications were low, and safety was high.

TPLO achieves the goal of dynamically stabilizing the stifle joint, and excellent results have been reported.[11,20,25] However, excessively high TPAs are observed in a significant proportion of patients; this makes treatment more challenging and limits the use of conventional TPLO.[5] Many patients with eTPA cannot undergo TPLO as a single correction technique owing to the increase in the complication rate.[5,26,27]

The risk of tibial crest fracture might be increased when the proximal fragment is excessively rotated as the safe limit of rotation marked by the patellar ligament insertion into the tibial tuberosity may be exceeded in these cases.[7,11] The contact between the proximal and distal fragments of the tibia becomes narrow, which impairs bone healing and decreases the area of implant application. The removal of the semicircular wedge of the cranial closure used in the technique described herein facilitated smaller rotation of the proximal fragment to level the tibial plateau.

Limited options have been available for patients with eTPA and they typically require complex and somewhat inaccurate preoperative calculations, advanced surgical skills, multiple implants, and increased surgical time.[7,26] Among them, the CCWO technique[14] remains the most widely used; however, it can potentially change the patellar position, leading to hyperextension of the hamstring muscles.[18–20] The coCBLO modifies the TPA by reducing plateau translation and has demonstrated better outcomes and lower complication rates when combined with CCWO, which requires advanced surgical skill and ends up in a multiple number of implants.[6,21] Finally, the combination of TPLO with CCWO involves two adjacent osteotomies, an association of metal implants, advanced surgical skill, and increased surgical time. Patellar ligament thickening, loosening or breakage of implants, and changes in the final TPA have also been reported.[7,11,19,20]

Healing of the osteotomy line occurred within the expected period, with total union being observed in 17/18 of stifles within 60 days, and bone remodeling being observed within 120 days. These time periods are similar to those achieved using other techniques used for eTPA.[11,16] Performing osteotomies in the metaphyseal region of the tibia contributes significantly to the quality of the bone union process, as this region exhibits better healing than the diaphyseal region.[17,28,29] The metaphyseal bone union is less dependent on periosteal cells, as numerous active osteogenic cells, in addition to osteoblasts with great differentiation capacity and abundant blood supply, are available in the existing trabeculae.[30]

The safety of the remaining tuberosity should be carefully evaluated when planning DCTPLO to prevent tibial crest fractures.[5] In the present study, patellar ligament thickening was noted in 16/18 stifles during the immediate postoperative period. An increase in thickness was observed in 13/18 stifles at 30 days and in 11/18 stifles at 60 days postoperatively. It has been documented that postoperative thickening of the patellar tendon occurs in 80-100 % of cases following tibial plateau leveling osteotomy (TPLO) and may be be associated with pain and lameness.[31] It has been hypothesized that manipulation or even minimal retraction of the patellar ligament thickening during surgery, placement of the antirotational pin through the distal fibers of the patella, contact with the blade during osteotomy, and increased tension due to the changes in biomechanics after TPLO can cause this complication.[32] The patellar ligament thickening was not manipulated during the proposed surgical technique; thus, the change in the biomechanics of the knee may have led to this finding. Nevertheless, no clinical changes were observed.

Internal pivot-shift of the tibia, which can occur during the stance phase of gait after TPLO, is a complication of this technique, especially in cases where rotation is excessive and tibial torsion is noted intraoperatively.[33] This phenomenon was not observed on the radiographs of any of the cases that underwent the proposed technique. However, it is imperative that osteotomies be performed in a coplanar manner to avoid internal or external torsion of the fragment.

A change in the final TPA was observed in 5/18 of stifles in the present study, considering a targeted TPA ranging between 5° and 6.5°.[24,34] Limited space for implant fixation and limited contact between fragments may predispose to rock-back postoperatively.[5,35] Factors such as intra- and inter-observer variations can lead to differences in the final TPA.[36] No statistically significant differences in clinical outcome were observed between cases with postoperative TPA ranging from 0° to 14°.[37] TPAs of all cases were within this range in the present study, indicating joint stabilization and functional return of the limb.

The correction mechanism of the DCTPLO technique involves the removal of the bone wedge near the joint; consequently, the reduction of the plateau tilt becomes more effective (►**Supplementary Figs. S1–S4**, available in the online version). This is in contrast to that observed in techniques wherein the wedge is placed farther from the stifle joint, which increases the likelihood of loss in the angle of rotation during the postoperative period.[7,11,16,17,20,38] No complications requiring surgical revision or additional treatment were observed in the present study.

The present study has some limitations. First, the small sample size may have reduced the power of interpretation of the results. Second, an objective evaluation of gait that facilitates the comparison of the proposed technique with those already described for cases with eTPA, which could provide more reliable results, was lacking. Third, certain geometric characteristics of the proximal tibia of dogs hinder DCTPLO as the remaining tuberosity or bone stock for the application of the implant can reduce the safety of the technique, especially in miniature breeds that are overrepresented in the case of eTPA.

Thus, the present study demonstrated that the DCTPLO technique can be an efficient alternative for treating dogs with CrCL disease with a TPA of up to 43.5°. This technique is associated with lower morbidity. Moreover, it is relatively less complex than the other techniques and is applicable to most cases of eTPA. Furthermore, it provides satisfactory results in the short and medium term and has low preliminary complication rates.

Authors' Contribution
E.C., B.W.M., T.V.M., L.P.B., and L.G.G.G.D. contributed to the conception, study design, acquisition of data, data analysis and interpretation. All authors drafted, revised, and approved the submitted manuscript and are publicly responsible for the relevant content.

Conflict of Interest
None declared.

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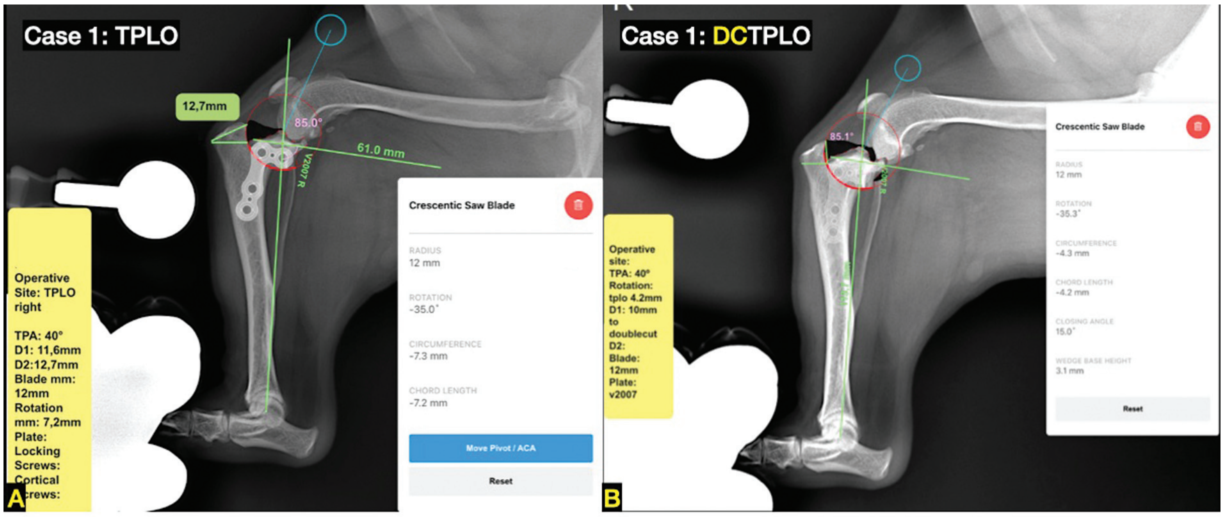
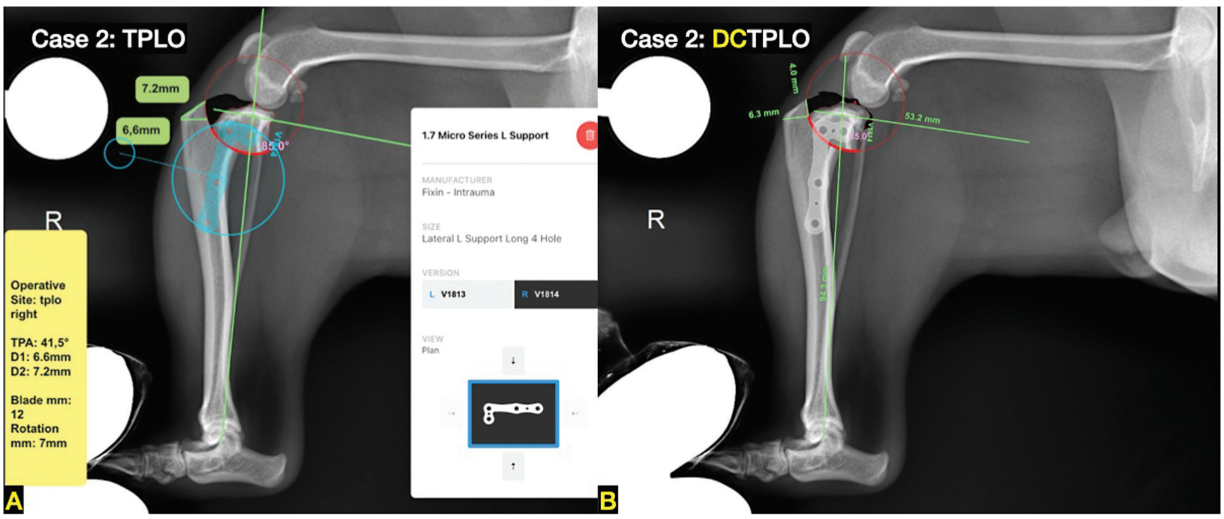
Appendix Table 1 Summary of the 18 stifle joints in dogs with cranial cruciate ligament disease that underwent double-cut tibial plateau leveling osteotomy

CASE	Breed	Age (y)	Weight (kg)	TPA pre-op	Saw radius (mm)	Wedge angle	TPLO rotation (mm)	TPLO rotation (°)	TPA post-op	Intraoperative complications	Final TPA (at healing)	Complications after 30 and 60 days	Bone union (days)
1	Maltese	6	5	40°	12	15°	5.1	24.2°	6°	–	7°	–	60
2	Shih-tzu	6	6.8	41.5°	12	15°	3.9	21.7°	9°	Very thin tibial tuberosity	12°	No complications; increase in the thickness of the tibial tuberosity observed	90
3	Shih-tzu	6	6.8	39°	10	15°	3.1	25°	6°	–	6°	–	60
4	Bichon Frisé	5	10.3	40°	12	15°	4.2	33.5°	13°	Gap in the wedge	12°	No complications; bone union of the gap observed	60
5	Bichon Frisé	6	10	43°	12	15°	5.0	17.9°	4.7°	Very thin tibial tuberosity	4.5°	No complications; increase in the thickness of the tibial tuberosity observed	60
6	Mixed	7	10.6	39°	15	10°	6.5	22°	9°	–	9°	–	60
7	Yorkshire	4	8.5	43.5°	12	15°	5.0	20.3°	4°	–	4°	–	60
8	American Bully	1	20.4	37°	18	10°	7.0	24°	8°	Remnant of a small bone fragment of the wedge in the tibial tuberosity	8°	Reduction in the size of the frag-ment; absence of pain	60
9	French Bulldog	6	13	37°	15	10°	6.1	24°	6°	Gap in the wedge	6°	Remnant of a small bone fragment of the wedge in the tibial tuberosity	60
10	Mixed	10	10	36°	12	10°	4.5	23.3°	10°	–	10°	–	60
11	Chihuahua	8	4.8	40°	12	10°	4.8	19.1°	5°	–	5°	–	60
12	Mixed	7	22	38°	18	15°	6	12.8°	4°	–	4°	–	60
13	Mixed	7	5.1	37°	10	15°	2.2	22.8°	6°	–	6°	–	60
14	Yorkshire	6	4.5	36°	10	10°	3.8	24.1°	3°	–	3°	–	60
15	Shih-tzu	7	5.1	36°	12	15°	3.3	15°	5°	–	5°	–	60
16	Jack Russel	5	8.6	40°	12	20°	3.2	20°	4.6°	–	4.6°	–	60
17	Shih-tzu	13	6.5	45°	12	15°	5.4	15°	5.6°	–	5.6°	–	60
18	Mixed	6	6.5	42°	10	10°	3.7	10.6°	6.2°	–	6.2°	–	60

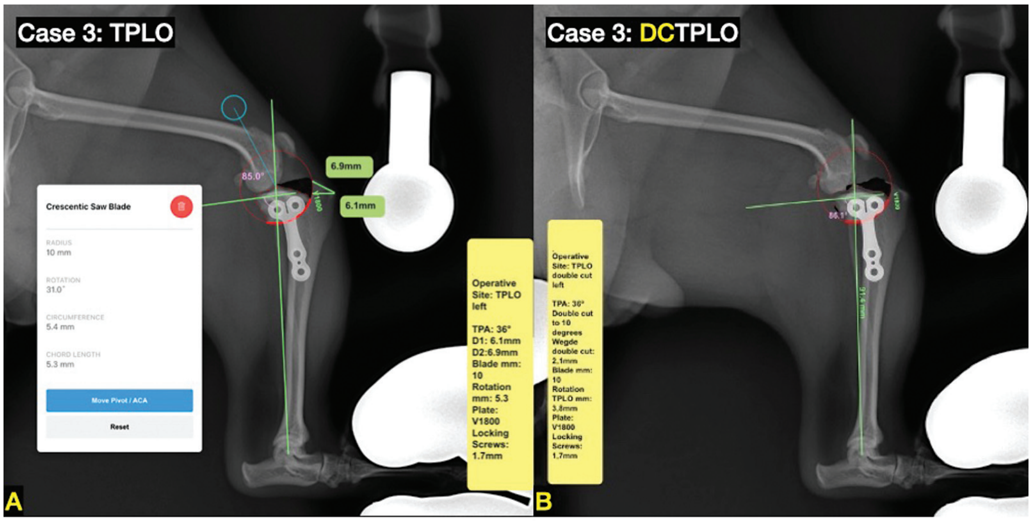
Abbreviations: TPA, tibial plateau angle; TPLO, tibial plateau-leveling osteotomy.



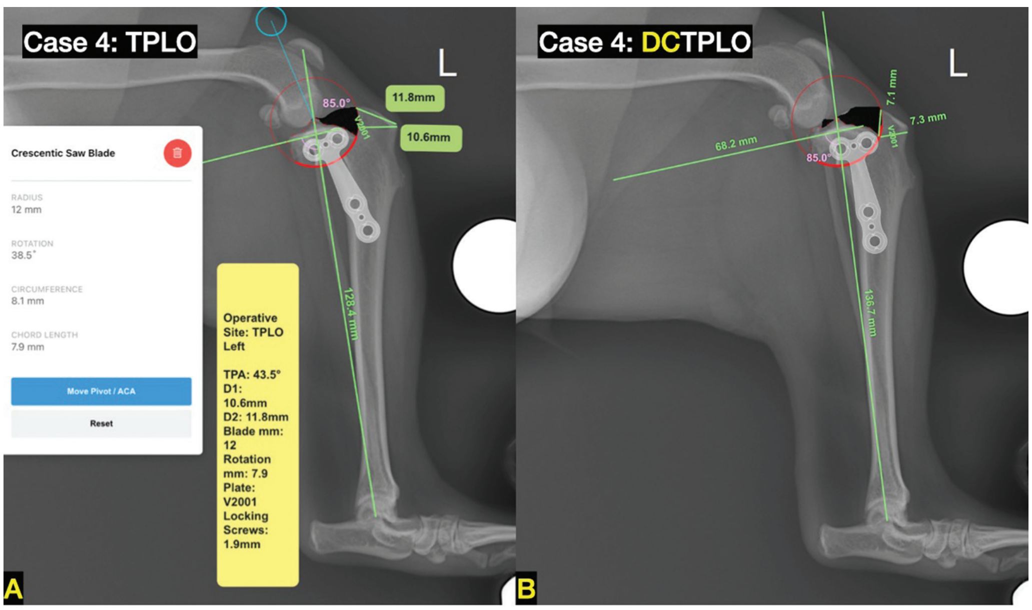
Supplementary Fig. S1 (**A**) Maui, Bichon Frisee: The use of the conventional TPLO alone (TPA = 40 °/rotation = 7.3 mm) would lead to considerable loss of bone contact between the fragments and significant translation of the mechanical axis of the tibia. Furthermore, it requires the placement of the plate at an excessive caudal direction; (**B**) Maui, Bichon Frisee: DCTPLO allows the tibial plateau to be leveled without significant modification of the mechanical axis of the tibia. The plate remains more aligned with the longitudinal axis of the tibia, potentially promoting a more robust and reliable fixation. Additionally, bone contact between the fragments is improved. The rotation of the bone fragment is reduced to 4.2 mm.



Supplementary Fig. S2 (**A**) Lili, Shih Tzu: Considering the TPA (41.5 °), 7 mm of rotation is required to level the tibial plateau. This will lead to a significant loss of bone contact between fragments and significant alteration of the mechanical axis of the tibia. Furthermore, the plate should be positioned tilted towards the caudal direction, making it potentially more challenging from a mechanical point of view. (**B**) Lili, Shih Tzu: With DCTPLO, the mechanical axis undergoes less change (in comparison) and the plate can be positioned in a more anatomical direction. The bone contact between the fragments is increased and the rotation of the bone fragment decreases to 3.9 mm.



Supplementary Fig. S3 (**A**) Lola, Yorkshire Terrier: Considering an TPA of 36 °, the rotation required to level the plateau with the conventional TPLO would be 5.3 mm. This would result in considerable loss of bone contact between fragments, leading to undesirable translation of the mechanical axis. The plate should be positioned at a more caudal angle. (**B**) Lola, Yorkshire Terrier: With DCTPLO, the mechanical axis is less modified. It facilitates better alignment of the plate with the longitudinal axis of the tibia. Furthermore, excellent bone contact is seen. The rotation of the bone fragment is 3.8 mm in this case.



Supplementary Fig. S4 (**A**) Melissa, Yorkshire Terrier: Conventional TPLO (TPA = 43.5 °) will require 7.9 mm of rotation, leading to significant loss of bone contact between fragments and translation of the mechanical axis. The plate should be positioned with an excessive caudal angle. (**B**) Melissa, Yorkshire Terrier: With DCTPLO, the mechanical axis undergoes less change and the plate can be better accommodated. Bone contact becomes more adequate. The rotation of the fragment falls to 5 mm.

