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Combination of closing-wedge distal femoral osteotomy and modified tibial plateau levelling osteotomy for the treatment of medial patellar luxation and concomitant cranial cruciate ligament disease in dogs

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ABSTRACT

Considering the prevalence of cranial cruciate ligament disease (CCLD) and concurrent medial patellar luxation (MPL) among dogs, and the concomitant bone deviations routinely identified, the aim of this study is to evaluate the efficacy of the combination between distal femoral osteotomy (DFO) and modified tibial plateau levelling osteotomy (mTPLO) for the treatment of MPL with distal femoral varus, tibial torsion, and CCLD. Dogs with concurrent MPL and CCLD that underwent DFO and mTPLO procedures were included. Subjective clinical evaluations of gait and pre-operative and immediate post-operative radiographic examinations were performed. Surgical data were documented. The anatomical lateral distal femoral angle (aLDFA), femoral varus angle, mechanical medial proximal tibial angle, and tibial plateau angle (TPA) were compared between the pre- and post-operative periods. A total of 12 dogs were included in this study. Closing-wedge DFO and mTPLO procedures were performed on 14 limbs. The mean pre-operative and post-operative aLDFA values were 104.8 $\pm$ 3.9° and 95.4 $\pm$ 2.4°, respectively. TPA values were 26.2 $\pm$ 3.7° pre-operatively and 6.3 $\pm$ 3.2° post-operatively. Bone healing was observed in 7.1 %, 71.3 %, and 85.5 % of patients at the first, second, and third follow-up, respectively. Lameness was resolved in 28.5 %, 78.5 %, and 100 % at 30, 60, and 90 days, respectively. No major peri- or post-operative complications were reported. The combination of mTPLO and DFO aligns the stifle extensor mechanism, promoting dynamic stabilization. It can be considered for the treatment of concurrent MPL and CCLD in dogs, performed as a single procedure, and is associated with favorable short-term outcomes.

1. Introduction

Cranial cruciate ligament disease (CCLD) is one of the most important conditions in veterinary orthopedics owing to the large number of cases and the strong involvement with marketing issues in the pet industry (Wilke et al., 2005). Similarly, patellar luxation has been attracting significant attention in journals and scientific events worldwide, with emphasis on the study and development of more effective techniques for the alignment of the stifle extensor mechanism (Perry and Déjardin, 2021).

The association between medial patellar luxation (MPL) and CCLD has been investigated (Campbell et al., 2010; Garces et al., 2021; Redolfi and Grand, 2024). Although the concomitant incidence of these conditions is not completely defined, it is believed that dogs with higher degrees of patellar luxation are more prone to CCLD (Campbell et al., 2010). This puts together two complex pathophysiological mechanisms that culminate in a critical impact on stifle biomechanics. The primary craniocaudal instability in the transverse plane caused by CCLD is added

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to the potentially harmful angular deviations from patellar luxation in the frontal plane, which makes surgical correction too challenging (Flesher et al., 2019; Livet et al., 2019; Redolfi and Grand, 2024). Invariably, a combination of techniques is necessary to obtain simultaneous stability in the transverse plane of the stifle and the frontal plane of the femur, tibia and patella (Langenbach and Marcellin-Little, 2010; Flesher et al., 2019; Redolfi and Grand, 2024). Several techniques have been described for the simultaneous treatment of both conditions at the same surgical moment: tibial tuberosity transposition and advancement, modified tibial plateau levelling osteotomy (mTPLO), over-the-top fascial technique associated with tibial tuberosity transposition (TTT) and extracapsular stabilization + TTT. However, the results are inconsistent because of the complication rates (Langenbach and Marcellin-Little, 2010; Fauron et al., 2017; Flesher et al., 2019; Candela-Andrade et al., 2020; Redolfi and Grand, 2024).

The mTPLO was described to level the tibial plateau and align the tibial tuberosity simultaneously (Langenbach and Marcellin-Little, 2010). The medial transposition of the proximal fragment of the tibia after the osteotomy allows lateral displacement of the patellar insertion, aligning the stifle extensor mechanism and indirectly correcting the external torsion of the tibia (Langenbach and Marcellin-Little, 2010). However, this modification does not completely resolve the misalignment of the extensor mechanism, especially in patients that show an increase in the anatomical lateral distal femoral angle (aLDFA). Several studies have been conducted to correlate the distal femoral varus with MPL and to subsequently correct this deviation using distal femoral osteotomy (DFO) (Swiderski and Palmer, 2007; Roch and Gemmill, 2008; Brower et al., 2017; Žilinčík et al., 2018; Aghapour et al., 2019).

Several studies have individually evaluated the efficacy of DFO for treating femoral varus and that of mTPLO for treating CCLD and tibial tuberosity deviation (Swiderski and Palmer, 2007; Roch and Gemmill, 2008; Perry et al., 2017; Flesher et al., 2019). However, there are no studies correlating these two techniques when both conditions are present. This study aimed to evaluate the efficacy of the association of DFO and mTPLO techniques for treating MPL with distal femoral varus, tibial torsion and CCLD. It is hypothetically believed that patients treated simultaneously with both surgical techniques can achieve tibial plateau levelling and at the same time an adequate alignment of the stifle extensor mechanism, with lower complication rates and quick functional return.

2. Materials and methods

This retrospective study was approved and received the favorable concern from Ethics Committee for Animal Use of the School of Agricultural and Veterinary Sciences (FCAV), "Júlio de Mesquita Filho" São Paulo State University, under the protocol number 1731/23. Owners were advertised about the inclusion of the animals in the clinical study and were asked to sign a consent form allowing the data collection from the patients. Data collection was conducted from 2020 to 2023 at a single referral hospital.

2.1. Patient inclusion criteria

The study included both male and female dogs diagnosed with CCLD concomitantly with MPL. Cases were included when DFO was required for correcting distal femoral varus (distal femoral varus >8°, considering the aLDFA as 94°) (Petazzoni and Jaeger, 2008), and a mTPLO (Flesher et al., 2019) was adopted for stifle dynamic stabilization and realignment considering tibial torsion >5° and < 20° (Petazzoni and Jaeger, 2008). The age range was standardized from 1 to 7 years old. The body weight and presence of concomitant contralateral MPL were not exclusion criteria; however, contralateral CCLD was. Additionally, previous orthopedic surgeries or amputation, endocrinopathies, and other concurrent systemic disorders were considered exclusion criteria. Data from the surgical reports were recorded, and pre- and post-operative radiographs were acquired. Computed tomography (CT) was performed whenever possible, and clinical evaluation was done at 30, 60 and 90 days after the surgery.

2.2. Pre-operative evaluation

The MPL grading was performed on a scale from I to IV (Perry and Déjardin, 2021). Three evaluators measured the tibial and femoral angles twice. Radiographic examinations of the craniocaudal and mediolateral projections of the femur and tibia were included. Measurements of the anatomical axis, aLDFA and distal femoral varus angle (FVA) were based on previous studies (Tomlinson et al., 2007) (Fig. 1). The femoral osteotomy site was based on the center of rotation of angulation (CORA) point, which was identified after positioning the FVA. Whenever available, CT was used to evaluate femoral torsion (Dudley et al., 2006) and a subjective analysis of femoral torsion was performed using the radiographic craniocaudal view, using a 5° steps (Petazzoni and Jaeger, 2008).

Radiographs in the mediolateral projection of the tibia included the stifle and tarsal joints, both flexed at 90°. To avoid rotation artefacts or internal torsion of the tibia, craniocaudal radiographs were assumed to be appropriate when the medial surface of the calcaneus was aligned to the distal center of the tibia (Apelt et al., 2005). The mechanical axis and mechanical medial proximal tibial angle (mMPTA) in the frontal plane were determined according to a previous study (Dismukes et al., 2007) (Fig. 1). The same was done to measure the mechanical axis as well as the mechanical proximal caudal angle of the tibia and TPA (Dismukes et al., 2008). Tibial torsion was subjectively measured when the tibial crest was located either medially or laterally in relation to the mechanical axis. Radiographic torsional deviations were considered in 5° steps (Petazzoni and Jaeger, 2008) (Fig. 1).

2.3. Surgical technique

All surgical procedures in this study were performed by the same surgeon. Lateral surgical access to the femur was obtained from the femoral shaft to condyles. The distal fragment of the femur was planned to be able to accommodate the bone plate and at least two screws in the distal fragment regarding the DFO. The femoral osteotomy was performed based on a previously described technique (Brower et al., 2017).

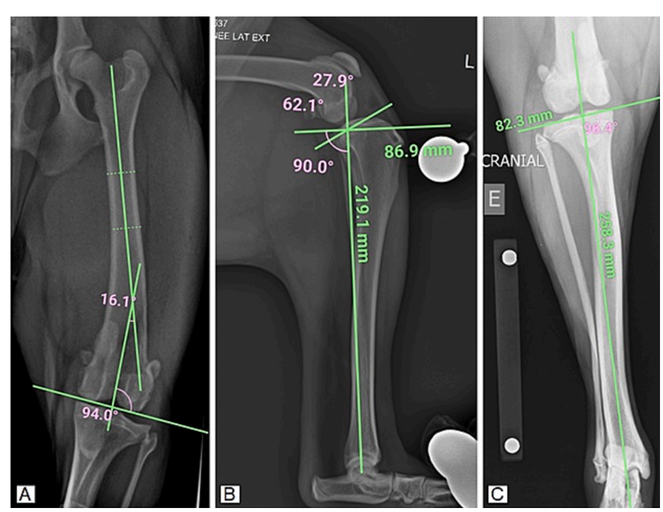

Fig. 1. Radiographic image of the femur in the craniocaudal projection, showing 16.1° of distal femoral varus and no subjective torsion (A); radiographic image of the tibia in the mediolateral projection, evidencing the pre-operative measurement of the tibial plateau angle (B); radiographic image of the tibia in the craniocaudal projection after the measurement of the mechanical medial proximal tibial angle (mMPTA) (C).

Care was taken to prevent the distal screws placed in the bone plate from entering the stifle or the trochleoplasty region. When necessary, a second bone plate was introduced medially to the femur.

In all cases, the pre-operative planning for mTPLO was conducted based on the craniocaudal and mediolateral radiographs of the affected tibia (Flesher et al., 2019). All planning was done using the Vpop software® (VETSOS Education Ltd., UK).

Craniomedial access to the tibia was achieved. The mTPLO was performed as previously described (Flesher et al., 2019). The jig was not removed after the osteotomy. The rotation of the fragment was done simultaneously with a medial transposition of tibial plateau until the patellar ligament was aligned, which was subjectively evaluated by the surgeon. This result was achieved when the tibial crest, patellar ligament and femoral trochlea were aligned. The distal portion of the jig was released to allow the lateral displacement of the distal tibial fragment in relation to the proximal fragment, resulting in the lateral transposition of the tibial tuberosity. After complete rotation and transposition, a Kirschner wire was inserted, transfixing the most proximal portion of the tibial crest and the proximal fragment of the tibia, preventing it from returning to its initial position. Immediately in sequence, the bone plate was contorted to cover the proximal displacement of the tibia, aiming at the best contact between the distal tibia and the proximal fragment, and the Kirschner wires were fixed until all the screws were distributed.

In addition, the depth of the femoral trochlea was subjectively evaluated using a Castroviejo caliper and compared with the height of the patella. This measurement was taken after the surgical medial displacement of the patella, directly measuring its height. The trochleoplasty was necessary when the depth of the trochlea was <50 % of the patellar height, and then it was wedge-shaped. Additionally, an intra-articular inspection was conducted to assess meniscal integrity. In cases where a meniscal tear was identified, a partial meniscectomy was performed (Thieman et al., 2010) using an 11-blade scalpel. At the conclusion of the surgery, lateral imbrication and release of the medial retinaculum were performed in all cases.

2.4. Post-operative evaluation

The surgery was also reassessed radiographically in the immediate postoperative period and every 30 days until bone healing was observed. This was defined by the absence of a fracture line or the presence of a complete and homogeneous bridging callus along the osteotomy line (Kowaleski et al., 2013). Patients were re-evaluated every 30 days during the follow-up period and encouraged to walk and trot during these evaluations. The lameness score was recorded according to Fauron et al. (2017) (Table 1).

All measurements obtained previously in the pre-operative period for surgical planning were repeated, using the same methodology, and compared by three evaluators, twice each, blindly.

2.5. Statistical analysis

All statistical analyses were performed using the R software, version 4.2.2, considering a 5 % significance level. To evaluate the relationship of lameness time with the variables of weight, age, degree of luxation, tibial bone healing and torsion time, as well as the relationship among tibial torsion, age, bone healing score, lameness time and percentage of tibial fragment transposition, Spearman's correlation analysis was used for non-parametric variables, with estimates of the coefficients using the bootstrapping method with 1000 replications. To verify whether the animals that underwent meniscus removal showed differences in lameness scores, the non-parametric Mann–Whitney test was used. To determine whether lameness time scores differed between the pre- and post-operative periods (30, 60 and 90 days), the non-parametric Friedman test was used.

Three means were obtained for each animal. The results of the pre-operative and immediate post-operative aLDFA and mMPTA measurements were compared using the paired *t*-test. To compare the TPA data among the pre-operative, immediate post-operative, and final post-operative periods, a repeated-measure analysis of variance was used. The assumption of data sphericity was validated using Mauchly's test; degrees of freedom were adjusted using Greenhouse–Geisser correction and *p* values using the Bonferroni method.

Table 1
Classification of pre- and post-operative lameness (Fauron et al., 2017).

Lameness grade	Clinical findings
1 - I	No lameness
2 - II	Mild lameness after exercise
3 - III	Mild to moderate intermittent lameness, but the limb sustains the weight consistently
4 - IV	Severe weight-bearing "toe touching" lameness
5 - V	No weight-bearing on the affected limb

3. Results

A total of 16 dogs undergone DFO + mTPLO in the period. Among then, a total of 12 patients (75 %) met the inclusion criteria and were included in this study. Of these, both pelvic limbs were affected in 2 dogs (16.6 %), totaling 14 surgical procedures. The most affected breed was Yorkshire, totaling 28 % of the patients. The weight ranged from 2 kg to 27.5 kg (mean 13.3 kg). The age ranged from 1 year to 7 years. The individual information is summarized (Table 1). The severity of patellar luxation was grade II in three limbs, grade III in five limbs and grade IV for six limbs. Complete CCLD was identified in 13 limbs, and only one case was classified as an incomplete rupture.

All dogs exhibited external tibial torsion, and eight were classified with 5° of torsion, four with 10°, one with 15°, and another with 20° of torsion (Petazzoni and Jaeger, 2008). In six patients, a CT scan was performed, but no patient was diagnosed with relevant pathological femoral torsion. Auxiliary procedures were performed at the surgeon's discretion. The trochleoplasty technique was performed in 10 limbs (71.4 %), whereas lateral imbrication and release of the medial retinaculum were performed in all patients. The partial meniscectomy was done in nine patients (64.3 %). Regarding tibial translation for subjective stifle extensor mechanism realignment, the average translation identified was 36 % of the tibial width. Only locked plates were used (Fixin Intrauma S.p.A. Turin, Italy). In the tibia, T-plates were used in 11 patients and L-plates in 3 patients. Five straight plates were used in the femur as well as nine dedicated femoral condyle plates. In one patient, two straight plates were used, one medial and one lateral.

All patients were radiographically reassessed every 30 days until bone healing was observed. The time of bone healing was similar for femoral and tibial osteotomy. In the first follow-up, one patient (7.1 %) had already achieved bone healing; in the second follow-up, bone healing was observed in 10 patients (71.4 %), and in the third, in 12 patients (85.5 %) (Fig. 2).

In two patients (14.2 %), it was not possible to identify the specific interval of complete radiographic bone healing because they did not exhibit lameness during the initial follow-up consultations, and the tutors did not return for radiographic follow-up. However, through telephone contact, the tutors informed the evaluator that no lameness was occurring. Based on lameness scores, four patients did not exhibit lameness 30 days after surgery, seven patients at 60 days, and three patients at 90 days (Fig. 3). There were no major perioperative or postoperative complications.

The lameness duration score did not show a statistically significant correlation with age, weight, luxation score, bone healing time score, or tibial deformity ($p > 0.05$). Similarly, the tibial torsion grade was not correlated with age, weight, luxation score, bone healing time score, or percentage of tibial tuberosity translation ($p > 0.05$). Lameness time

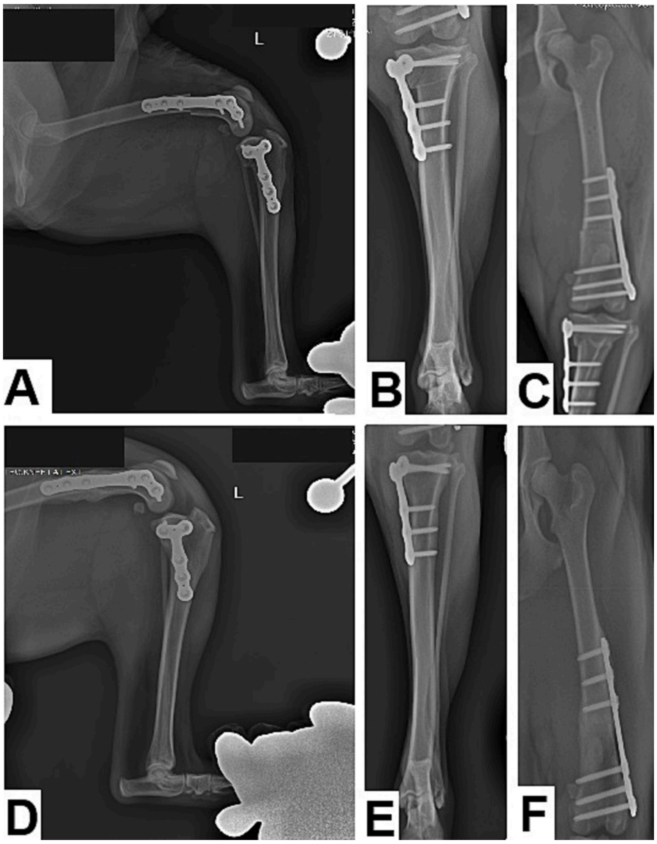

Fig. 2. Immediate post-operative radiographic evaluation of the tibia in the mediolateral (A) and craniocaudal (B) projections and the femur in the craniocaudal projection (C). Evaluation 60 days after the surgery of the tibia in the mediolateral projection (D), of the tibia in the craniocaudal projection (E) and of the femur in the craniocaudal projection (F). Simultaneous bone healing of the tibial and femoral osteotomies observed at 60 days (D, E and F).

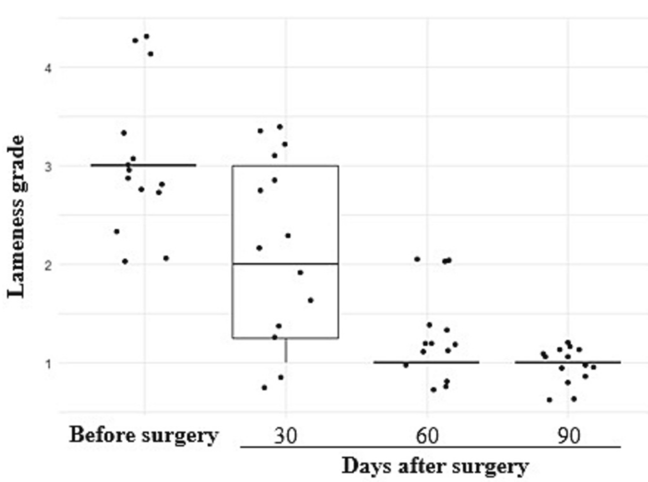

Fig. 3. Lameness time scores evaluated every 30 days after the surgery. The dots represent the distribution of the observations. The central lines represent the median and upper and lower limits of the boxes, respectively, the 75th and 25th percentiles. The outer line applied to the box represents the upper limit.

scores did not differ between animals with and without meniscus partial injury/removal ($p = 0.664$). However, they did differ between the pre- and post-operative evaluation times ($p < 0.05$). Significant statistical differences were observed between the lameness scores in the pre-operative period and at 60 days ($p = 0.0005$) and 90 days ($p = 0.00008$), as well as between the 30-day and 90-day periods ($p = 0.0142$). The scores from the preoperative period did not differ from the 30-day period ($p = 0.5755$). No patients exhibited lameness 90 days after the surgery.

The means and standard deviations of the variables aLDFA, mMPTA and TPA at different time points are summarized (Table 2). These three variables evidenced statistical difference between the pre- and post-operative periods ($p = 0.000000026$, $p = 0.031$ and $p = 0.000000000023$, respectively). Additionally, the correlation and statistical analysis among the three evaluators were highlighted (Table 3), revealing that aLDFA and mMPTA were the main variables showing statistical differences between two surgeons during the evaluation periods, while TPA did not differ between the periods and evaluators. (See Table 4.)

4. Discussion

While the efficacy of DFO for treating femoral varus and mTPLO for addressing CCLD and torsional deviation of the tibial tuberosity has been described individually in previous studies (Swiderski and Palmer, 2007; Roch and Gemmill, 2008; Langenbach and Marcellin-Little, 2010; Perry et al., 2017; Flesher et al., 2019), the combination of these techniques within a single surgical procedure requires evaluation. In this study, we hypothesized that the combination of closing-wedge DFO and mTPLO could effectively align the stifle extensor mechanism, allow the patellar repositioning, and provide dynamic stabilization in the transverse plane. Our results confirmed this hypothesis. Furthermore, we observed rapid functional recovery with no instances of patellar reluxation or major complications.

The MPL is known to result from a complex pathophysiology. The failure to completely align the stifle extensor mechanism during surgical correction attempts invariably results in high complication rates, especially reluxation (Perry and Déjardin, 2021). The combination of techniques evaluated in this study allowed the alignment of the femur and tibia in the frontal plane, considering the post-operative mean of $95.4 \pm 2.4^\circ$ for aLDFA, which permitted successful patellar stabilization. Although studies have already described the frontal alignment of the femur using DFO (Brower et al., 2017) and proved the same for the tibia with mTPLO (Flesher et al., 2019), the performance of these techniques in combination has so far not been objectively evaluated. Additionally, the mean post-operative TPA of $6.3 \pm 3.2^\circ$ made it possible to validate the adequate levelling of the tibial plateau and consequently the simultaneous stabilization of the stifle that undergone CCLD (Warzee et al., 2001).

The results of the subjective evaluation of locomotion and the relatively early bone healing of osteotomies made it possible to expect a consistent functional return of the limb in a maximum period of 90 days. This result is like or even better than previous descriptions using other combinations (Leonard et al., 2016; Livet et al., 2019; Hackett et al., 2021). The stability resulting from tibial plateau levelling osteotomy (TPLO) and the judicious and precise alignment of the stifle extensor mechanism were undoubtedly crucial for such results, as patients with high-grade patellar luxation alone would be a great challenge for surgeons with regard to early functional return (Perry and Déjardin, 2021). Additionally, the non-occurrence of peri- or post-operative complications must be noted, even though there are only 14 procedures, as it is not uncommon to report significant complication rates in the correction procedures for both concomitant conditions (Leonard et al., 2016; Flesher et al., 2019; Candela-Andrade et al., 2020; Hackett et al., 2021; Redolfi and Grand, 2024).

Despite the numerous techniques described and applied in treating concomitant MPL and CCLD, none have shown consistent success rates. These techniques have been reported to be associated with high rates of complications, especially patellar luxation recurrence (Langenbach and Marcellin-Little, 2010; Flesher et al., 2019; Redolfi and Grand, 2024). It is believed that the results obtained in the present study using a

Table 2
Basic data of the patients as well as the time of bone healing and lameness.

Pelvic limb	Breed	Age	Weight (kg)	Bone healing time	Pre-operative lameness	Post-operative lameness (30 days)	Post-operative lameness (60 days)	Post-operative lameness (90 days)
1	English Bulldog	1 year	27.5	90 days	Grade IV	Grade III	Grade II	Grade I
2	Mongrel	3 years	22	60 days	Grade III	Grade III	Grade II	Grade I
3	Yorkshire	6 years	2.5	60 days	Grade III	Grade I	Grade I	Grade I
4	Yorkshire	4 years	7.5	60 days	Grade III	Grade II	Grade I	Grade I
5	Pitbull	1 year	26	60 days	Grade IV	Grade II	Grade I	Grade I
6	Pitbull	1 year	27	60 days	Grade IV	Grade I	Grade I	Grade I
7	Pomeranian	1 year	6	After 30 days[1]	Grade II	Grade I	Grade I	Grade I
8	York	2 years	2	After 60 days[1]	Grade III	Grade II	Grade I	Grade I
9	Shih-tzu	7 years	5.6	90 days	Grade III	Grade II	Grade I	Grade I
10	Pomeranian	1 year	4	60 days	Grade III	Grade III	Grade I	Grade I
11	Pomeranian	1 year	5	60 days	Grade II	Grade III	Grade I	Grade I
12	Maltese	2 years	4.4	30 days	Grade II	Grade III	Grade II	Grade I
13	Mongrel	4 years	22	60 days	Grade III	Grade III	Grade I	Grade I
14	Yorkshire	1 year	2.4	60 days	Grade III	Grade I	Grade I	Grade I

[1] For both patients who did not return for radiographic follow-up, the interval of bone healing time was not identified.

Table 3
Means and standard deviations of the variables of anatomical lateral distal femoral angle (aLDFA), mechanical medial proximal tibial angle (mMPTA) and tibial plateau angle (TPA) at different moments.

Variables	Pre-operative	Immediate post-operative	Final post-operative
aLDFA	104.8° ± 3.9°	95.4° ±2.4°	95.4° ±2.4°
mMPTA	94.3° ± 3.3°	92.1° ±2.3°	92.1° ±2.3°
TPA	26.2° ± 3.7°	6.3° ±3.2°	6.5° ± 3.3°

Table 4
Interobserver Pearson's correlation (r) for anatomical lateral distal femoral angle (aLDFA), mechanical medial proximal tibial angle (mMPTA), and tibial plateau angle (TPA) at different time points, for three evaluators.

Variable	Moments	Evaluators	r	Confidence Interval 95 %	*p*-value
aLDFA	Pre-operative	1 × 2	0,97	0,91 a 0,99	<0,001
		1 × 3	0,27	−0,31 a 0,70	0,359
		2 × 3	0,28	−0,30 a 0,70	0,338
	Post-operative	1 × 2	0,94	0,83 a 0,98	<0,001
		1 × 3	0,58	0,07 a 0,85	0,029
		2 × 3	0,57	0,05 a 0,84	0,035
mMPTA	Pre-operative	1 × 2	0,94	0,81 a 0,98	<0,001
		1 × 3	0,28	−0,30 a 0,71	0,325
		2 × 3	0,13	−0,43 a 0,62	0,657
	Post-operative	1 × 2	0,97	0,90 a 0,99	<0,001
		1 × 3	−0,43	−0,78 a 0,13	0,122
		2 × 3	−0,45	−0,79 a 0,11	0,111
TPA	Pre-operative	1 × 2	0,46	−0,09 a 0,79	0,098
		1 × 3	0,30	−0,27 a 0,72	0,299
		2 × 3	0,59	0,09 a 0,85	0,026
	Post-operative	1 × 2	0,31	−0,27 a 0,72	0,288
		1 × 3	0,48	−0,07 a 0,80	0,083
		2 × 3	0,19	−0,38 a 0,65	0,516

combination of mTPLO and DFO are consistent and encouraging for treating these conditions with lower complication rates for these patients.

The distal femoral alignment in the frontal plane has been objectively described in some dog breeds, and certain degrees of physiological distal varus have been determined (Tomlinson et al., 2007; Soparat et al., 2012; Žilinčík et al., 2018). Therefore, it is recommended to consider the extent of physiological deviation when deciding the need for correction. Previous studies have described the findings for specific breeds, and it is not necessarily guaranteed that the same values would apply to other breeds even if they are similar (Tomlinson et al., 2007; Soparat et al., 2012; Žilinčík et al., 2018). Despite this fact and even in view of the breed diversity in the present study, 94° was used as a reference for the anatomical lateral distal femoral angle. The correction of the deformity was suggested with a deviation starting from 8° above the accepted limit, as previously recommended (Brower et al., 2017). It is believed that planning and execution aiming at 94° aLDFA is appropriate for the correction of femoral varus as this target angle is the reference value for the Pomeranian breed and is within the standard deviation for the Yorkshire breed (95.63 ± 2.14) (Žilinčík et al., 2018). In view of the recommendations (Brower et al., 2017) and with an aLDFA of 95.4 ± 2.4° being obtained, the alignment of the femur was efficiently achieved after corrective DFO, which was reflected in the clinical result.

Although the medial transposition of the proximal fragment after TPLO has been successfully described in dogs (Langenbach and Marcellin-Little, 2010; Flesher et al., 2019), its planning and surgical technique remain poorly standardized and are subjective with respect to the alignment of the quadriceps mechanism. Flesher et al. (2019) have observed that the transposition represented 20 % of the width of the tibia at the point of the osteotomy, whereas the present study showed a significantly higher value (36 %). This metric might have directly contributed to the success of the tibial alignment in the frontal plane, considering the lower rates of complications when compared with a previous study (Flesher et al., 2019). Additionally, the more marked transposition was not correlated with peri- or post-operative complications. The mMPTA values validated the absence of iatrogenic valgus or varus deviations. This result could be attributed to the use of a jig during the execution of the technique (Curuci et al., 2021).

Despite successfully establishing alignment of the extensor mechanism through a combination of the DFO and mTPLO techniques, all patients underwent reinforcement of the lateral retinaculum with sutures and a medial relaxation incision. While bone components are widely recognized as contributing to patellar luxation, the soft tissues surrounding the patella also play a role in limb positioning (Perry and Déjardin, 2021). The absence of surgical correction in this regard may lead to persistent patellar reluxation (Candela-Andrade et al., 2020; Hackett et al., 2021). The incorporation of medial retinacular release alongside osteotomy techniques is essential for achieving optimal patellar positioning, as confirmed by the results presented here. Additionally, wedge-shaped trochleoplasty was performed in 10 out of the 14 stifles before adaptive remodeling of the trochlear sulcus (Perry and Déjardin, 2021). This procedure is necessary when the femoral trochlea is significantly damaged. While the need to perform trochleoplasty in conjunction with osteotomies remains somewhat unclear, considering a depth of approximately 50 % of the patella's height within the trochlear sulcus (Brower et al., 2017; Perry and Déjardin, 2021) in combination with other techniques yielded favorable outcomes for the patients in this study.

Considering the complexity of the procedures when performed concomitantly, a short bone healing time was obtained for the tibial and femoral osteotomies. This corroborates the data published for these techniques performed in isolation (Brower et al., 2017; Flesher et al., 2019), evidencing that both procedures at the same time may not be related to an increased convalescence period. Previous studies have not demonstrated clinical success via the evaluation of post-operative lameness when using these techniques in isolation (Langenbach and Marcellin-Little, 2010; Brower et al., 2017; Flesher et al., 2019). In one study, mTPLO appeared to yield good results for lateral patellar luxation as the patient did not exhibit lameness at 90 days after the surgery; however, only one patient was evaluated (Curuci et al., 2021). In the current study, the combination of these two techniques proved effective in achieving a positive clinical outcome for the treated patients. The 60-day postoperative follow-up revealed significant improvements in limb function among the patients.

The main limitation of this study is the reduced number of cases and the relatively short evaluation period, which may be one of the reasons for the absence of perioperative or postoperative complications, differing from other studies (Langenbach and Marcellin-Little, 2010; Flesher et al., 2019; Redolfi and Grand, 2024). Despite this, there was success in bone healing and marked improvement in the patients' gait. Additionally, the preoperative and postoperative subjective radiographic analysis of tibial torsion at 5° (Petazzoni and Jaeger, 2008) could lead to errors in surgical planning and re-evaluation. Nevertheless, the postoperative results were better than expected compared to previous studies (Langenbach and Marcellin-Little, 2010; Candela-Andrade et al., 2020; Redolfi and Grand, 2024). Nonetheless, it is believed that the results of this study are robust and may be sufficient to evaluate this combination of techniques. In two cases, it was not possible to follow up bone healing, which might have improved the data for the absence of post-operative complications. Eight patients did not undergo preoperative CT and therefore did not have femoral torsion evaluated, which could have changed the decision regarding their treatment.

5. Conclusion

The combination of mTPLO and DFO was effective in aligning the extensor mechanism of the quadriceps and simultaneously allowed the levelling of the tibial plateau in canine patients with MPL associated with varus angular deviation of the distal femur, external tibial torsion and CCLD.

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CRediT authorship contribution statement

Jose Sergio Costa Junior: Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Eloy Henrique Pares Curuci:** Writing – review & editing, Resources, Project administration, Methodology, Data curation, Conceptualization. **Rafael Kretzer Carneiro:** Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Matheus Nobile:** Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Rogério Giufrida:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Luís Gustavo Gosuen Gonçalves Dias:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Conceptualization. **Alefe Luiz Caliani Carrera:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Bruno Watanabe Minto:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Conceptualization.

Declaration of competing interest

None.

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