FULL ARTICLE

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Comparative digital study of two cranial rotation methods of the proximal fragment on the center of rotation of angulation-based leveling osteotomy planning with different tibial distal anatomical axes*

Estudo digital comparativo de dois métodos de rotação craniana de fragmento proximal no planejamento da osteotomia de nivelamento baseada no centro de rotação de angulação com diferentes eixos anatômicos distais tibiais

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ABSTRACT

The center of rotation of angulation (CORA)-based leveling osteotomy (CBLO) technique was developed for cranial cruciate ligament (CrCL) rupture treatment, aiming to modify the mechanical-anatomical angle (AMA), which is described as a predictive risk factor for the disease and is recommended to be taken into consideration when one is choosing a surgical procedure for tibial plateau slope alteration. Identifying a tibial distal anatomical axis (DAA) is essential in CBLO surgical planning and measuring AMA amplitude. The aim of this study was: to evaluate two methods of cranial rotation of the proximal fragment using four different tibial distal anatomical axes for digital planning on the CBLO technique, comparing its effectiveness in achieving the desired tibial plateau angle (TPAd) and closing the AMA angle. Tibial measurements were made with the vPOP pro software using 30 mediolateral radiographs of canine stifles. The DAA described by four authors was used based on the amount of Rotation completed (Rc) for each. The rotation methods evaluated were: 1) commercial CBLO table (RT) and 2) overlapping the tip of the intercondylar eminence with the corresponding DAA line (RE). The TPAd to be obtained was fixed at 10°, and the final AMA to be achieved at 0°. The mean values and standard deviations of the final TPA and final AMA with the rotation method were TPA(RT)f(%TPAd), TPA(RE)f(%TPAd), AMA(RT)f(%AMAzero), AMA(RE)f(%AMAzero). The results of each author were Hulse 10.0 ± 0.3(46.6%), 9.9 ± 0.1(60%), 0.3 ± 0.3(33.3%), 0.3 ± 0.3(13.3%), Osmond 10.1 ± 0.2(75%), 10,1 ± 0.2(83.3%), 0.4 ± 0.4(33.3%), 0.4 ± 0.3(8,3%), Miles 10.0 ± 0.1(66.6%), 10.0 ± 0.1(75%), 0.2 ± 0.1(16.6%), 0.2 ± 0.1(8.3%), Tudury 9.6 ± 0.6(31.2%), 9.5 ± 0.2(31.2%), 1.0 ± 0.7(18.7%), 1.0 ± 0.6(12.5%), respectively. The initially described RT obtained a higher percentage of AMA at zero degrees. Therefore, the RE method is discarded for use as an alternative to CBLO planning.

Keywords: Angle. Canine. Cranial cruciate ligament. Mechanical axis. Stifle.

RESUMO

A técnica da osteotomia de nivelamento baseada no centro de rotação de angulação (CORA) chamada CBLO foi desenvolvida para o tratamento da ruptura do ligamento cruzado cranial (RLCCr), visando modificar o ângulo mecânico-anatômico (AMA), o qual é descrito como fator de risco preditivo para a doença e é recomendado que seja levado em consideração na escolha do procedimento cirúrgico para alteração da inclinação do platô tibial. A identificação de um eixo anatômico distal da tíbia (EAD) é um passo fundamental no planejamento cirúrgico da CBLO e para avaliar a amplitude do AMA. O objetivo deste estudo foi: avaliar dois métodos de rotação craniana do fragmento proximal utilizando quatro eixos anatômicos distais tibiais diferentes para o planejamento digital da técnica CBLO, comparando sua eficácia para atingir o ângulo do platô tibial desejado (TPAd) e no fechamento do AMA. As medidas tibiais foram feitas no software vPOP pro usando 30 radiografias medio-laterais de joelhos caninos. Foi utilizado o EAD descrito por quatro autores diferentes, baseada na quantidade de Rotação concluída (Rc) para cada um deles. Os métodos de rotação avaliados foram: 1) tabela comercial de CBLO (RT) e 2) sobreposição da ponta da eminência intercondilar com a linha EAD correspondente (RE). O TPAd a ser obtido foi fixado em 10° e o AMA final a ser alcançado em 0º. A média e o desvio padrão do TPA final e AMA final com o método de rotação: TPA(RT)f(%TPAd), TPA(RE)f(%TPAd), AMA(RT)f(%AMAzero), AMA(RE)f(%AMAzero) e o resultado de cada autor foram Hulse 10,0 ± 0,3(46,6%), 9,9 ± 0,1(60%), 0,3 ± 0,3(33,3%), 0,3 ± 0,3(13,3%), Osmond 10,1 ± 0,2(75%), 10,1 ± 0,2(83,3%), 0,4 ± 0,4(33,3%), 0,4 ± 0,3(8,3%), Miles 10,0 ± 0,1(66,6%), 10,0 ± 0,1(75%), 0,2 ± 0,1(16,6%), 0,2 ± 0,1(8,3%), Tudury 9,6 ± 0,6(31,2%), 9,5 ± 0,2(31,2%), 1,0 ± 0,7(18,7%), 1,0 ± 0,6(12,5%) respectivamente. O RT inicialmente descrito obteve um percentual maior de AMA em zero graus, portanto, o método RE é descartado para utilizá-lo como alternativa no planejamento CBLO.

Palavras-chave: Ângulo. Canino. Ligamento cruzado cranial. Eixo mecânico. Joelho.

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Introduction

Cranial cruciate ligament (CrCL) rupture is the main cause of lameness in dogs and leads to stifle instability (Bennett et al., 1988; Jerram & Walker, 2003). The caudal shift in the tibial weight-bearing mechanical axis (MA) from the tibial anatomical axis (AA), which was quantified by the magnitude of the angle between these two axes (AMA), reflects the caudal angulation of the entire tibia (Glassman et al., 2011; Mostafa et al., 2009; Osmond et al., 2006). One study showed that an AMA angle higher than 1.9° had a sensitivity of 0.941 (95%) and a specificity of 0.965 (97%) in predicting CrCL rupture compared to other factors described (Guénégo et al., 2017). Another study found that a sensitivity of 0.95 and a specificity of 0.95 with an AMA angle equal to or greater than 2.4° predicted CrCL rupture (Guénégo et al., 2020).

The anatomical axis is represented by a single contoured line centered between the cranial and caudal cortices along the entire length of the tibia, connecting the center of the proximal and distal articular surfaces (Paley, 2002; Petazzoni & Jaeger, 2008). The choice of approximation to the anatomical axis is somewhat arbitrary (Miles, 2020). The identification of the distal anatomical axis (DAA) of the tibia is of fundamental importance during the surgical planning of several osteotomy procedures for stifle stabilization in dogs with CrCL rupture (Hulse, 2014; Mazdarani et al., 2021; Piras & Dunlop, 2012; Tudury, 2021) and in the investigation of possible causative risk factors of the disease (Guénégo et al., 2017, 2020; Osmond et al., 2006).

Many surgical procedures for CrCL rupture treatment have been described (Lampart et al., 2020; Putame et al., 2019). Some cases of tibial plateau leveling osteotomies at five degrees have a late onset of weight-bearing joint injury (Drygas et al., 2010; Hulse et al., 2010a). Furthermore, the osteotomy is not based on the anatomic center of rotation of angulation (CORA). As such, the angulation correction axis (ACA) is not aligned with the anatomic CORA, resulting in mal-alignment of the proximal and distal anatomical axis and secondary translation, which leads to caudal displacement of the weight-bearing axis and focal increase in joint force (Hulse et al., 2010b; Hulse, 2014; Raske et al., 2013).

The CORA-based leveling osteotomy (CBLO) technique modifies the normal *procurvatum*, and among its advantages are the alignment of the proximal and distal segment anatomical/mechanical axis and the maintenance of approximately 30% of the normal cranial tibial thrust (Hulse et al., 2010b; Raske et al., 2013; Vasquez et al., 2018). A final angle of 8-12° is obtained by reducing the tibial plateau angle (TPA) by 30 to 35% (depending on the original slope degree) determined by the preoperative TPA (TPAd=TPAx0.35) (Drygas et al., 2010; Hulse, 2014; Vasquez et al., 2018). A commercial table (Vetimplants®) of the correlation between saw blade radius and the CORA magnitude was created, thus determining the amount of rotation in millimeters that must be maintained (Hulse, 2014; Raske et al., 2013).

Because the magnitude of the AMA angle has been associated with an increased risk of the development of CrCL rupture in several studies (Guénégo et al., 2017, 2020; Ševčík et al., 2022), this suggests that it should be taken into consideration when the tibial plateau slope alteration procedure must be chosen (Guénégo et al., 2020, 2021; Guénégo & Bureau, 2022). A modified cranial closing wedge osteotomy based on AMA angle (AMA-based -CCWO) was developed using the same concept of the CBLO, allowing for an alignment of the anatomic/mechanical axis following rotation of the tibial plateau slope, which could contribute to maintaining more normal stress distribution and kinematics of the stifle during weight bearing, and good outcomes have been described (Guénégo et al., 2016, 2018, 2021).

This study aimed to evaluate two methods of cranial rotation of the proximal fragment using four different tibial distal anatomical axes for digital planning on the CBLO technique, comparing its effectiveness in achieving the desired TPA and closing the AMA angle. The hypothesis was that if the mechanical axis is determined by a line drawn between the center of the talus and the midpoint of the two tibial intercondylar eminences, moving the proximal fragment cranially until the intercondylar eminence overlaps with the line of the corresponding DAA, a zero-degree AMA would be achieved.

To find out if it is possible to recommend the second method of rotation proposed as an alternative to performing the CBLO planning, comparing four different distal anatomical axes of the tibia to improve digital planning and obtain the desired results.

Material and Methods

Radiographs

In one retrospective study, 29 adult dogs of random breed, sex, weight, and age were included. Thirty digital radiographic studies, with a real-size template, of canine patients diagnosed with CrCL rupture were used. All these images came from the routine staff of the Bruselas Specialty Veterinary Hospital (HVEB) from 2019-2022. The diagnosis was determined through orthopedic evaluation and complementary tests, confirmed in surgery, and obtained from a digital database.

The radiographs included were mediolateral projections with the stifle joint and tarsus flexed at a 90° angle, at which the best overlap of the femoral and tibial condyles was observed (with condylar overlap < 2 mm as previously described) (Caylor et al., 2001; Fettig et al., 2003; Reif et al., 2004) and no evidence of any other concurrent stifle pathology. Digital measurements were made using the commercial software *Veterinary Preoperative Orthopedic Planning* (vPOP pro). All results were collected and tabulated for further analysis.

Tibial measurements

Using a predetermined software (*Markup Editor in Photos for Macintosh Operating System*) and to standardize the individual measurements of each of the evaluated methods (Buirkle et al., 2019; Fettig et al., 2003; Unis et al., 2010), five marks were made on tibial radiographs (Figure 1).

Determination of the initial tibial plateau angle (TPAi)

The TPA was defined as the difference between the tibial plateau slope and the line drawn perpendicularly to the mechanical axis of the tibia in the sagittal plane (Buirkle et al., 2019; Petazzoni & Jaeger, 2008). A circle was drawn first at the center of the talus, using landmarks representing the joint orientation line of the distal tibia, which are the distal aspect of the distal intermediate ridge of the tibia cranially and the caudodistal aspect of the cochlea tibia. The center of the circle corresponding to the talus established the distal reference mark for the mechanical axis of the sagittal plane (Figure 1) (Dismukes et al., 2008; Petazzoni & Jaeger, 2008).

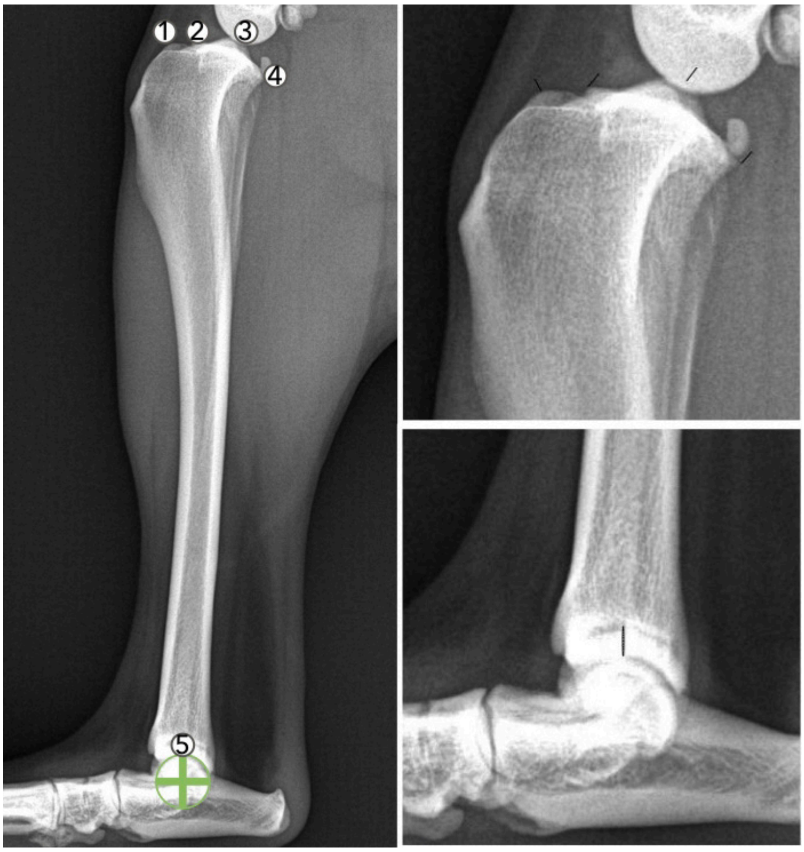

Figure 1 – Initial marks of the key points for CBLO planning on the tibia. On the mediolateral view, the following points are identified: (1) at the most proximal point cranial to the tendon groove of the long digital extensor ligament, (2) at the most cranial point of the tibial plateau, (3) at the intercondylar eminence, (4) at the most caudal point of the tibial plateau, and (5) at the end of the tibia immediately proximal to the talus. Green (+) indicates the center of the circle created by the talus.

The slope of the tibial plateau was determined by tracing the joint orientation line of the proximal tibia connecting the most cranial point of the medial condyle of the tibia (mark at point two) to its most caudal point (mark at point four) (Buirkle et al., 2019; Paley, 2002). The mechanical axis (MA) was determined by a line drawn between the circle created in the center of the talus and the midpoint of the two tibial intercondylar eminences (mark at point three). Finally, the TPA was measured as the angle between the tibial plateau axis and the line drawn perpendicular to the tibial MA (Buirkle et al., 2019; Dismukes et al., 2008; Fettig et al., 2003).

Location of the distal anatomical axes (EAD)

The distal anatomical axis (DAA) of the tibia can be defined as a line connecting midpoint A and midpoint B between the cranial and caudal cortices of the tibia shaft length (Dismukes et al., 2008; Glassman et al., 2011; Osmond et al., 2006). Four different distal anatomical axes were determined using the *Anatomic Axis* tool in the software (vPOP pro). This tool allows for modification of the location of the two midpoints placed along the tibia. Marks from points one and five were used to determine the tibial length. The first DAA was set at the level of the distal border of the tibial crest and at the diaphyseal/metaphyseal junction distally where the tibia widens (Hulse, 2014), the second DAA at 33% and 66% (Tudury, 2021), the next DAA was set at 50% and 75% (Osmond et al., 2006), and finally the DAA at 50% and 95% of the tibial length (Miles, 2020).

Determination of the initial mechanical-anatomical angle (AMAi)

The AMAi (Glassman et al., 2011; Mostafa et al., 2009; Osmond et al., 2006) was determined as the angle formed by the tibial mechanical axis (MA) described above to measure the TPAi and the tibial distal anatomical axis (DAA) created with the *Anatomic Axis* tool in vPOP pro. The procedure was performed for each DAA as described by four authors (Hulse, 2014; Miles, 2020; Osmond et al., 2006; Tudury, 2021). Their obtained magnitude was recorded, and their results were compared with the final AMA.

CBLO technique digital planning

First, the center of rotation of angulation (CORA) magnitude used in the CBLO was determined and defined at the point at which the proximal and distal axis lines intersect (Paley, 2002). Using the joint orientation line of the proximal tibia for the TPA, the proximal anatomical axis (PAA) was drawn by placing a line beginning at the tibial intercondylar eminence and coursing distally to intersect at the desired TPA (TPAd) at 10º; therefore, the caudal angle between the PAA and the tibial plateau slope was fixed at 80° (Kishi & Hulse, 2016; Raske et al., 2013). Subsequently, the line of the DAA was drawn as described by four authors (Hulse, 2014; Miles, 2020; Osmond et al., 2006; Tudury, 2021). The axis line around which the correction is performed is the angulation correction axis (ACA) and is drawn as a line passing through the CORA (Paley, 2002). The size of the saw was determined by placing the center of the saw on the CORA or the ACA line; thus, the cranial exit of the radial saw was tangential to the cranial tibial cortex (eccentric), leaving as much of the tibial tuberosity as possible, as recommended (Dycus & Hulse, 2022). For this purpose, the proximal fragment was verified as having enough space to place a CBLO plate, using the standard VOI® implant templates (Veterinary Orthopedic Implants) in software (vPOP pro) and setting the most caudal proximal hole screw in front of the lateral cortical (visible more cranially and radiodense) (Penaforte, 2022). When the saw blade, due to its radius, did not meet these criteria, the rotation was considered unfinished. Only the completed rotation (Rc) planning results were used to measure the final TPA and final AMA.

Determination of rotation of the proximal fragment

Two different rotation methods were used: 1) the first method used the CBLO rotation table of the proximal fragment by Vetimplants®, and 2) in the second method, the tip of the intercondylar eminence (tubercle) was placed at the tip of each DAA. Cranial rotation was determined depending on the method used, employing the radial cutting tool of the vPOP pro software (Figure 2 - Image 1). The millimeters of cranial rotation required by each DAA were recorded, and the results obtained between these two methods were compared to determine how many AMA at zero degrees were achieved in each of them. In addition, the number of rotations using the table method that obtained the same quantity of millimeters as the rotation of the eminence method (RT=RE) was recorded to determine the percentage that coincided.

Rotation table (RT)

The first rotation was performed using the CBLO commercial table (Figure 2 - Image 2). This chart uses the CORA's magnitude and the saw's blade size ($2\pi r=360$) to determine how many millimeters the proximal fragment must be cranially rotated as pre-established (Hulse, 2014).

When a CORA magnitude with variations of 0.5 degrees or greater was obtained, it was rounded up to the next number, while in those in which the variation was less than 0.5 degrees, the same number was maintained in order of matching as indicated in the table (Vetimplants®). The number of millimeters of cranial rotation required by each DAA was recorded, and their results were compared.

Rotation eminence (RE)

In the second method, the proximal fragment was rotated until the tip of the intercondylar eminence (tubercle) overlapped with the line drawn for the DAA as described by four different authors (Hulse, 2014; Miles, 2020; Osmond et al., 2006; Tudury, 2021), using mark three previously made on the eminence, as a reference for all axes (Figure 2 - Image 3). As the MA of the tibia was drawn from the center of the talus to the tip of the intercondylar eminence, if the proximal fragment moved cranially until the intercondylar eminence overlapped with the line of the corresponding DAA, hypothetically, an AMA of zero degrees would be achieved. Likewise, each DAA's required number of millimeters of cranial rotation was recorded, and their results were compared.

Post-rotation measurement completed

Determination of the final TPA (TPAf)

The MA of the tibia and the joint orientation line of the proximal tibia using the reference marks made were re-drawn as previously described. The new TPA angle was obtained between the tibial plateau slope and the line drawn perpendicular to the tibial MA (Figure 3). Thus, the TPAf was established by referring to the CBLO table method (TPA(RT)f) and the TPAf by the eminence method (TPA(RE)f). Then, the result was compared between each of the different DAA used. The percentage of TPA obtained at ten degrees (10°) was recorded and compared between each method (TPAd/RT and TPAd/RE) to determine its accuracy in getting the TPAd.

Determination of the final mechanical-anatomical angle (AMAf)

The new AMA angle formed between the traced MA corresponding to the TPAf and the previously outlined DAA was obtained. The obtained AMAf was determined using the CBLO table method (AMA(RT)f) and the AMAf using the eminence method (AMA(RE)f) (Figure 4). The results were compared with the different DAA and the two rotation methods for AMA angle reduction. The percentage of AMA at zero degrees obtained in both rotation methods (AMA0°/RT and AMA0°/RE) was recorded to establish their accuracy in getting the desired results.

Statistical analysis

The mean of the results obtained from all measurements performed on the 30 tibias, using the DAA of the methods as described by four different authors (Hulse, 2014; Miles, 2020; Osmond et al., 2006; Tudury, 2021), were compared by Student's t-test, using R Software version 4.2.1 (R Core Team, 2022).

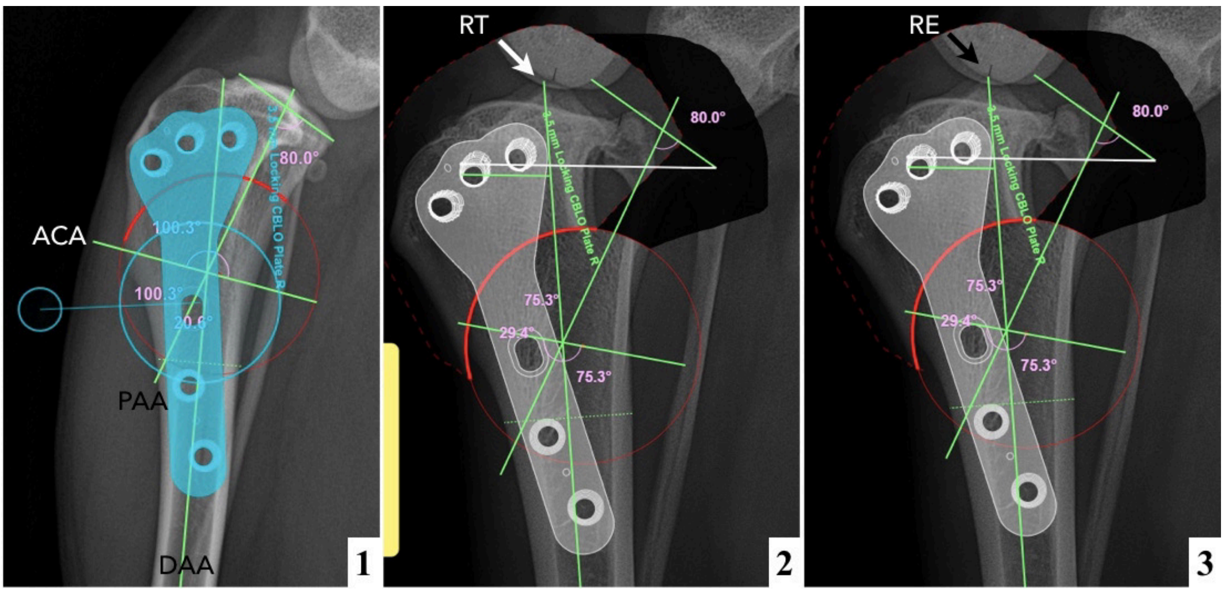

Figure 2 – Determination of cranial rotations of the proximal fragment. Two rotation methods were performed on the same patient's mediolateral radiographs. (1) Measurements before rotation: angulation correction axis (ACA), proximal anatomical axis (PAA), distal anatomical axis (DAA); (2) White arrow = indicates the rotation using the CBLO table (RT); (3) Black arrow = indicates the rotation placing the tip of the intercondylar eminence at the tip of the DAA line (RE).

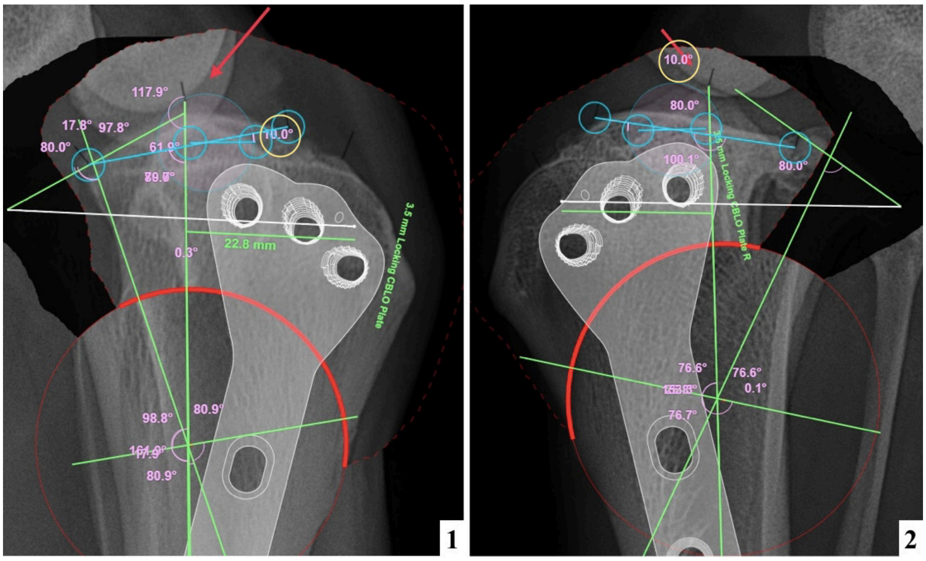

Figure 3 – TPAf representation of completed rotations. On the mediolateral radiographs of the same patient, measurements of the final angle of the tibial plateau (TPAf) were made after cranial rotation of the proximal fragment. (1) TPAf of the CBLO table method (TPA(RT)f); (2) TPAf of the eminence method (TPA(RE)f); TPAf at 10º (yellow circle); intercondylar eminences (red arrow).

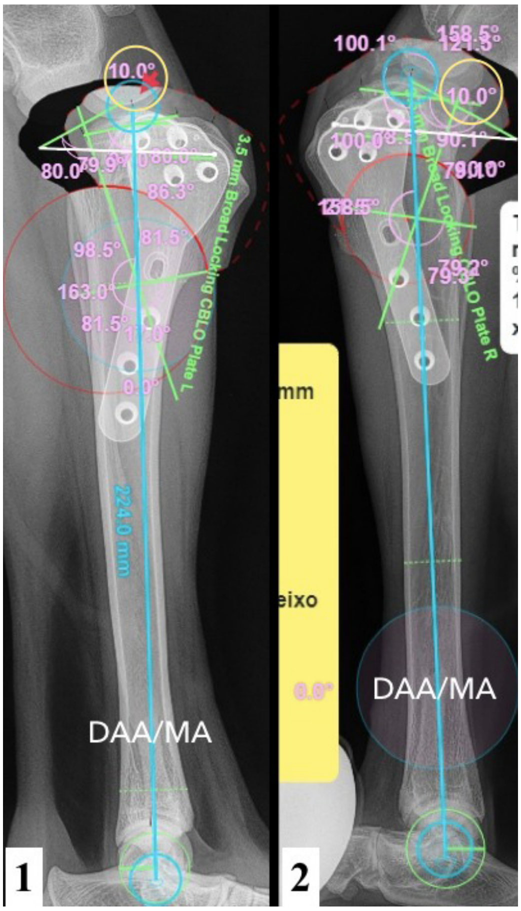

Figure 4 – AMAf representation of completed rotations. On the mediolateral radiographs of the same patient, measurements of the final mechanical-anatomical angle (AMAf) were made after cranial rotation of the proximal fragment. (1) AMAf of the CBLO table method (AMA(RT)f); (2) AMAf of the eminence method (AMA(RE)f); distal anatomical axis (DAA); tibial mechanical axis (MA); AMA between DAA and MA (blue line); TPAf at 10º (yellow circle); intercondylar eminences (red arrow).

Significance was set at a value of $p<0.05$ (5%), and the variables were significantly different when the value of $p<0.1$ (10%). The qualitative data were expressed as percentages when necessary.

Results and Discussion

Thirty radiographic examinations of 29 dogs with a mean weight of 30.7 ± 8.0 kg and a range of 16.8-45.5 were included. Sixteen dogs were male, and 14 were female. The mean age was 4.6 ± 2.3, with a range between 1.0 years to 9.0 years. Twenty left and 10 right stifles were observed, with only one bilateral case. The breeds were mixed (n=9), Boxer (n=4), Pitbull (n=2), American Staffordshire Terrier (n=2), Labrador (n=2), German Shepherd (n=2), Akita (n=2), and one each of the following: Staffordshire Bull Terrier, American Bully, Beagle, Great Dane, Bernese, and Siberian Husky.

Although an increased magnitude of the AMA angle has been associated with an increased risk of CrCL disease based on comparative studies of predisposed dogs with and without CrCL rupture (Guénégo et al., 2017, 2020; Ševčík et al., 2022), there are insufficient data to indicate that decreasing the AMA angle by itself is an aid to joint stability (Guénégo et al., 2021; Mazdarani et al., 2021). However, induced alignment of the proximal and distal anatomic axes of the tibia after the performance of CBLO has reported good outcomes (Kishi & Hulse, 2016; Peycke et al., 2022; Vasquez et al., 2018). Four tibial distal anatomical axes were used to evaluate the different results of these two methods of rotation of the proximal fragment in CBLO and compare their effectiveness in obtaining the AMAf and TPAf, as other DAA has been used for the planning of the CBLO (Hulse, 2014; Mazdarani et al., 2021) and to determine the AMA angle (Guénégo et al., 2017, 2020).

The mean TPAi was 25.3 ± 4.4, which corroborates Aertsens et al. (2015), in which angles between 23 and 25 degrees were reported in normal dogs with a wide range of variations according to breed (13-34°). Although a relationship between the magnitude of TPA has been described as a risk factor for CrCL rupture presentation (Ichinohe et al., 2015; Mostafa et al., 2009) and while an *ex vivo* study has demonstrated that decreasing this angle decreased stain in the intact CrCL (Haynes et al., 2015), its relationship has not been confirmed in other studies (Guénégo et al., 2017; Venzin et al., 2004) and an association was established between TPA as a set with other risk factors for the development of the disease (Reif & Probst, 2003; Witsberger et al., 2008).

The mean millimeters of rotation required using the CBLO table method (RT) and the intercondylar eminence (RE) method with every DAA are shown in Table 1. The same significant differences at 5% ($p<0.05$) were found with both rotation methods results between the DAA of Hulse and Osmond, between the DAA of Hulse and Miles, between the DAA of Osmond and Tudury, and between the DAA of Miles and Tudury. No significant differences were found between the DAA of Hulse and Tudury and between the DAA of Osmond and Miles in both rotation methods results. The percentage of rotations that coincided with the same number of millimeters of rotation between the RT and RE methods (RT=RE) was 53.3% with Hulse's DAA, 41.6% with Osmond's DAA, 50% with Miles's DAA, and 25% with Tudury's DAA (Table 2). Furthermore, no significant differences were found between the results of the RT and RE using the Hulse, Miles, and Tudury DAA, respectively, but a significant difference at 5% ($p<0.05$) was found between the RT and RE results of the Osmond DAA. With these results, we can assume that both RT and RE methods could be used to plan the CBLO and obtain a similar amount, in millimeters, of rotation between them.

The mean TPAf of the CBLO table method (TPA(RT)f) is shown in Table 3. Significant differences at 10% ($p<0.1$) were found between the DAA results of Hulse and Osmond and between those of Tudury and Osmond. No significant differences were observed between the DAA of Hulse and Miles, between the DAA of Hulse and Tudury, between the DAA of Osmond and Miles, and between the DAA of

Table 1 – Outcome measurement in 30 canine tibias for cranial rotation of the proximal fragment by the CBLO table method (RT) and by the eminence method (RE) for each distal anatomical axis (DAA). The data are expressed as mean and standard deviation

Measurements	Hulse (2014)	Miles (2020)	Osmond et al. (2006)	Tudury (2021)
RT (mm)	8.3 ± 2.7[a-g, c]	6.2 ± 2.5[b-i]	6.1 ± 2.2[d, e-o]	7.9 ± 2.0[f-q]
RE (mm)	8.3 ± 2.7[a-g, c]	6.2 ± 2.5[b-i]	6.1 ± 2.1[d, e-o]	8.0 ± 2.1[f-q]

[a -g]significant difference at 5% between Hulse and Osmond; [b-i]significant difference at 5% between Hulse and Miles; [f-q]significant difference at 5% between Miles and Tudury; [e-o]significant difference at 5% between Osmond and Tudury; [c]no significant difference between Hulse and Tudury; [d]no significant difference between Osmond and Miles; p-value using a Student's t-test comparison. Significant at 5% ($P<0.05$).

Table 2 – Outcome measurement in 30 canine tibias for rotations completed (Rc) for each distal anatomical axis (DAA). Qualitative data

	Hulse (2014)	Miles (2020)	Osmond et al. (2006)	Tudury (2021)
Variable		Absolute (%)		
Rc	15/30 (50)	12/30 (40)	12/30 (40)	16/30 (53.3)
TPAd/RT	7/15 (46.6)	8/12 (66.6)	9/12 (75)	5/16 (31.2)
TPAd/RE	9/15 (60)	9/12 (75)	10/12 (83.3)	5/16 (31.2)
AMA 0(º)/RT	5/15 (33.3)	2/12 (16.6)	4/12 (33.3)	3/16 (18.7)
AMA 0(º)/RE	2/15 (13.3)	1/12 (8.3)	1/12 (8.3)	2/16 (12.5)
RT=RE	8/15 (53.3)	6/12 (50)	5/12 (41.6)	4/16 (25)

CBLO table rotation method (RT); eminence rotation method (RE); mechanical-anatomical angle (AMA); desired tibial plateau angle (TPAd), TPAd/RT= %TPA at 10º for RT; TPAd/RE= %TPA at 10º for RE; AMA 0(º)/RT= %AMA at 0º for RT; AMA 0(º)/RE= %AMA at 0º for RT; RT=RE= % rotations that coincided with RT and RE.

Table 3 – Outcome measurement in 30 canine tibias for final tibial plateau angle (TPAf) by the CBLO table rotation method (TPA(RT) f) and by the eminence rotation method (TPA(RE)f) for each distal anatomical axis (DAA). The data are expressed as mean and standard deviation

Measurements	Hulse (2014)	Miles (2020)	Osmond et al. (2006)	Tudury (2021)
TPA(RT)f (º)	10.0 ± 0.3[a-h, c]	10.0 ± 0.1[b]	10.1 ± 0.2[d, e-p]	9.6 ± 0.6[f]
TPA(RE)f (º)	9.9 ± 0.1[a-g, c]	10.0 ± 0.1[b]	10.1 ± 0.2[d, e-o]	9.5 ± 0.2[f-r]

[b]no significant difference between Hulse and Miles; [c]no significant difference between Hulse and Tudury; [d]no significant difference between Osmond and Miles; [f]no significant difference between Miles and Tudury; [a-g]significant difference at 5% between Hulse and Osmond; [e-o]significant difference at 5% between Osmond and Tudury; [a-h]significant difference at 10% between Hulse and Osmond; [e-p]significant difference at 10% between Osmond and Tudury; [f-r]significant difference at 10% between Miles and Tudury; p-value using a Student's t-test comparison. Significant at 5% ($P<0.05$); Significant at 10% ($P<0.1$).

Tudury and Miles. The mean TPAf of the eminence method (TPA(RE)f) is shown in Table 3. Significant differences at 5% ($p<0.05$) were found between the DAA results of Hulse and Osmond and between those of Tudury and Osmond. An important difference at 10% ($p<0.1$) was found between Miles and Tudury's DAA results. No significant differences were found between Hulse and Miles, Hulse and Tudury, and Osmond and Miles.

A final TPA was set at 10°. Leveling the inclination of the tibial plateau at 8 to 12° (Drygas et al., 2010; Raske et al., 2013) prevents further damage to the articular cartilage by eliminating excessive tibial overload (Kishi & Hulse, 2016; Vasquez et al., 2018). No significant differences were found between the TPA(RT)f and TPA(RE)f of all DAA results for each author. To determine the effectiveness of the method in obtaining the desired TPA set at 10 degrees (TPAd at 10º), a success rate of 46.6% was obtained with the CBLO table rotation method (RT) with Hulse; the rates were 75% with Osmond, 66.6% with Miles, and 31.2% with Tudury (Table 2). Likewise, the percentage of TPAd obtained with the intercondylar eminence (RE) rotation method was 60% for Hulse, 83.3% for Osmond, 75% for Miles, and 31.2% for Tudury (Table 2). Therefore, it is considered that both rotation methods would be effective in obtaining the same TPAf results within each DAA.

Because the AMA angle and TPA are strongly correlated with TPA >30°, it should be taken into consideration when a tibial plateau slope alteration procedure must be chosen (Guénégo et al., 2017, 2020, 2021). Good outcomes have been recorded with a modified CCWO, AMA-based CCWO to reduce the AMA angle (Guénégo et al., 2016, 2018, 2021). Although CBLO aligns the anatomical and mechanical axes of the proximal and distal segments (Hulse, 2014; Raske et al., 2013; Vasquez et al., 2018), the literature has not reported how many procedures result in a final AMA of 0° and whether it is possible to determine an alternative method to facilitate rotation planning by simply bringing the intercondylar eminence to the DAA line tip to obtain this result.

The mean initial AMA angle (AMAi) with each DAA was 5.4 ± 1.1 with Hulse and 5.9 ± 1.4 with Tudury. The mean with Miles's AMAi was 3.2 ± 1.5 in contrast to that reported in the literature (Mazdarani et al., 2021), and 3.0 ± 1.3 was obtained with Osmond's DAA, used by Guénégo et al. (2017, 2020) to determine the AMA angle and, the result in this study accords with the findings previously described in patients with complete rupture of CrCL (Guénégo et al., 2017, 2020; Ševčík et al., 2022). Mean AMAf using the CBLO table method (AMA(RT)f) and the eminence method (AMA(RE)f) with every DAA was shown in Table 4. The mean of AMA(RT)f accords with Mazdarani et al. (2021), which used Miles's DAA to evaluate the initial and final AMA on CBLO planning. The same significant differences at 5% ($p<0.05$) were found with both rotation methods results between the DAA of Hulse and Tudury, between the DAA of Osmond and Tudury, and between the DAA of Miles and Tudury. No significant differences were found between Hulse and Osmond, Hulse and Miles, and Osmond and Miles in both rotation methods results.

The AMAf percentage of 0° using the CBLO table rotation (RT) method obtained in this study was 33.3% with both Hulse and Osmond, 16.6% with Miles, and 18.7% with Tudury (Table 2). The AMAf percentage of 0° using the intercondylar eminence superimposed on the DAA rotation (RE) method obtained in this study was 13.3% with Hulse, 8.3% with both Osmond and Miles and 12.5% with Tudury (Table 2). No significant differences were shown between the results of the AMA(RT)f and the AMA(RE)f using the DAA of Hulse, Osmond, Miles, and, Tudury, respectively. Nevertheless, although the RE method obtained similar results in terms of the number of millimeters compared with the RT and the TPAd between both methods, the use of the RE as an alternative method in CBLO planning was discarded because of the obtaining of a lower percentage of AMA at 0° using this proposal. As stated at the beginning, the primary purpose of using the RE was to improve performance in reducing the AMA at 0°, and this objective was superiorly achieved by the RT method initially described.

Under-correction of the TPA is associated with an over-correction of the AMA angle: While TPA references the mechanical axis, the CORA-based correction references the distal anatomical axis (DAA), which does not necessarily pass through the center of the talus (Mazdarani et al., 2021).

Table 4 – Outcome measurement in 30 canine tibias for final mechanical-anatomical angle (AMAf) by the CBLO table rotation method (AMA(RT)f) and by the eminence rotation method (AMA(RE)f) for each distal anatomical axis (DAA). The data are expressed as mean and standard deviation

Measurements	Hulse (2014)	Miles (2020)	Osmond et al. (2006)	Tudury (2021)
AMA(RT)f (º)	0.3 ± 0.3[a, c-k]	0.2 ± 0.1[b]	0.4 ± 0.4[d, e-o]	1.0 ± 0.7[f-q]
AMA(RE)f (º)	0.3 ± 0.3[a, c-k]	0.2 ± 0.1[b]	0.4 ± 0.3[d, e-o]	1.0 ± 0.6[f-q]

[a]no significant difference between Hulse and Osmond; [b]no significant difference between Hulse and Miles; [d]no significant difference between Osmond and Miles; [c-k]significant difference at 5% between Hulse and Tudury; [e-o]significant difference at 5% between Osmond and Tudury; [f-q]significant difference at 5% between Miles and Tudury; p-value using a Student's t-test comparison. Significant at 5% ($P<0.05$).

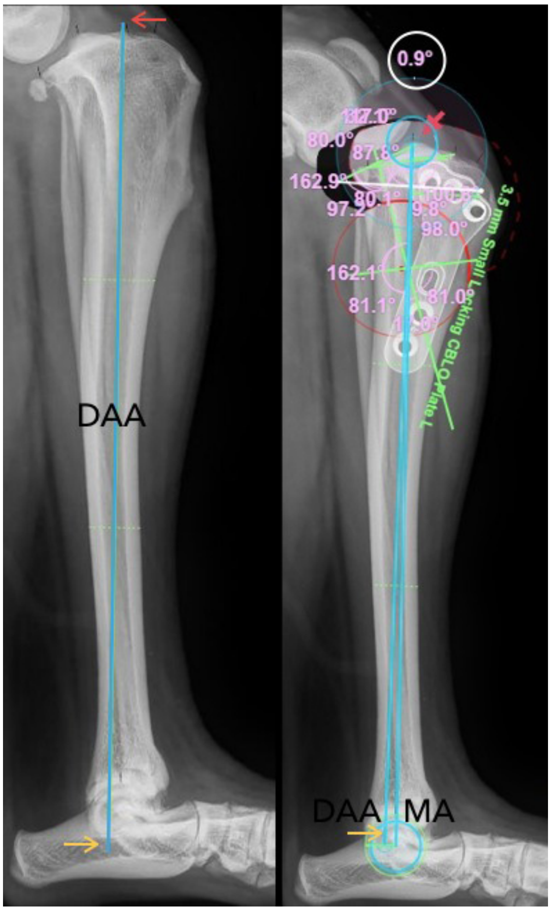

Figure 5 – Over-correction of the final mechanical-anatomical angle (AMAf). Distal anatomical axis (DAA), which does not pass through the center of the talus; mechanical axis (MA); current AMAf magnitude (white circle); the proximal tip of the DAA (red arrow); the distal end of the DAA (yellow arrow).

Although the proximal tip of the DAA overlaps with the intercondylar eminence, the location of the distal end is sometimes over the center of the talus, avoiding complete alignment of both axes along the entire tibia (Figure 5). As described above in this study, the AMAi magnitude of Tudury and Hulse was larger and, thus, needed a more significant rotation and a subsequent TPA under-correction, which could explain an increased representation in the RE method using these DAA. However, this is also observed in the AMAf using the DAA of Miles and Osmond in the RE method. Although the final amplitude of the AMA was reduced in all cases, the distal end of the DAA maintains a degree of amplitude that, despite being reduced, remains an unwanted AMA angle. This phenomenon also occurs in the RT method, although the number of millimeters of rotation used approaches 0° by a more significant percentage.

Conclusion

The RT method initially described in the literature obtained a higher percentage of AMA at zero degrees. Therefore, the RE method is not recommended as an alternative in CBLO planning.

Conflict of interest

The authors declare there are no conflicts of interest.

Ethics Statement

The authors have nothing to disclose. Retrospective study based on historical data.

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