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Research Article

Effect of Tibial Plateau Leveling Osteotomy on Mechanical Tibial Axis Shift in Dogs: Two-Dimensional Bone Study in Sagittal Plane

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A B S T R A C T

To determine the tibial axis shift (TAS), change in tibial plateau angle (TPA), and the position of the tibial articular surface after tibial plateau leveling osteotomy (TPLO) simulation in the tibiae of dogs, tibias of 91 dogs from 23 different breeds were used. The TPA, tibial length, midshaft width, medial tibial condyle length, and distances between the tibial axis (TA) and cranial-most point of the medial condyle were measured on the tibial images. After simulated TPLO, all measurements were retaken. Paired t-tests were used to compare pre- and postoperative variables. Pearson correlation analysis was conducted to assess whether the difference between pre- and postoperative TAS was related to tibial length, tibial width, medial condyle length, and/or the degree of TPA rotation. The results showed that TPLO shifted the cranial-most point of the medial condyle caudally and distally, and the caudal-most point caudally and proximally. These shifts resulted in significant differences between pre- and postoperative distances between the TA and the cranial-most point and its percentage to the medial condyle length. It is concluded that the TPLO led to caudal TAS and altered the position of the articular surface of the medial condyle with respect to the distal part of the tibia.

Keywords*: Dog, tibia, tibial axis, Tibial Plateau Leveling Osteotomy*

Köpeklerde TPLO’nun Mekanik Tibial Eksen Kayması Üzerine Etkisi: Sagital Düzlemde İki Boyutlu Kemik Çalışması

Ö Z E T

Köpeklerde tibial plato düzleştirme osteotomisi (TPLO) simülasyonu sonrasında tibial eksen kaymasını (TAS), tibial plato açısındaki (TPA) değişimi ve tibial eklem yüzeyinin konumunu belirlemek için, 23 farklı ırktan 91 köpeğe ait tibialar kullanıldı. TPA, tibial uzunluk, “midshaft” genişliği, tibianın condylus medialis uzunluğu ve tibial eksenle (TA) condylus medialis’in en cranial noktası arasındaki mesafe tibia görüntüleri üzerinden ölçüldü. Simülasyonu gerçekleştirilmiş TPLO’dan sonra tüm ölçümler tekrar gerçekleştirildi. Pre- ve postoperatif değerleri karşılaştırmak için Paired t-test kullanıldı. Pre- ve postoperative TAS değerleri ile tibianın uzunluğu, tibianın genişliği, condylus medialis uzunluğu, ve/veya TPA’nın rotasyon derecesi arasında ilişkinin farklı olup olmadığı değerlendirmek için Pearson korelasyon analizi yapıldı. Çalışmanın sonuçları, TPLO ile medial condylusun en cranial noktasının caudale ve distale, en caudal noktasının ise caudale ve proximale doğru kaydığını gösterdi. Bu kaymalar, operasyon öncesi ve sonrası TA ile en cranial nokta arasındaki mesafe değerinde ve en cranial noktanın condylus medialis uzunluğundaki yüzde değerinde önemli farklılığa neden oldu. TPLO’nun, caudal TAS ve medial condylusun eklem yüzeyinin, tibianın distal parçasına göre pozisyonunu değiştirdiği sonucuna varıldı.

Anahtar Kelimeler*: Köpek, tibia, tibial eksen, Tibial Plato Düzleştirme Osteotomisi*

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Introduction

A large tibial plateau angle (TPA) may lead to an increase in cranial tibiofemoral shear force, creating stress on the cranial cruciate ligament (CrCL), which is prone to injury in dogs (Griffons, 2010; Jerram and Walker, 2003; Liu and Maitland, 2003; Slocum and Devine, 1983; Warzee et al., 2001). The execution of tibial plateau leveling osteotomy (TPLO) to create a postoperative TPA of 5–6.5° is recommended to eliminate this source of stress on the CrCL (Shahar and Milgram, 2006; Warzee et al., 2001). Previous studies have focused on TPA measurement because of the importance of its accuracy pre- and postoperatively in CrCL-deficient dogs (Caylor et al., 2001; Fettig et al., 2003; Ocal and Sabanci, 2013a; Reif et al., 2004; Ritter et al., 2007). The postoperative TPA may deviate from that planned preoperatively due to movement of the central point of the intercondylar tubercles (IC) (Duerr et al., 2008; Kowaleski and McCarthy, 2004; Kowaleski et al., 2005; Roh et al., 2020). This movement, resultant tibial axis shift (TAS), may have adverse clinical effects due to the change in location of the proximal tibial plateau segment with respect to the distal tibial and distal femoral segments (Kowaleski and McCarthy, 2004; Kowaleski et al., 2005). To avoid TAS, it is suggested that TPLO should be centered on the IC (Kowaleski and McCarthy, 2004; Kowaleski et al., 2005). However, the articular surface of the proximal tibia is moved in the sagittal plane during this procedure. The articular surface is ignored when determining the tibial axis (TA), whereas the mechanical axis of a long bone is defined as a line drawn between the centers of the proximal and distal articular surfaces (Brinker and O'Conner, 2010; Dismukes et al., 2008; Tomlinson et al., 2007). Under these circumstances, the question of whether the position of the articular surface changes in the absence of a change in the IC position during TPLO arises. In the current study, two-dimensional computer-generated models of TPLO were used to test the hypotheses that (i) TAS would be related to tibial plateau rotation, despite the centering of the osteotomy on the IC; and (ii) the postoperative TPA and the position of tibial joint surface would change with respect to TAS.

Materials and Methods

Bones of 98 dogs of 23 different breeds were obtained from the Veterinary Anatomy Department collections of Aydın Adnan Menderes and Istanbul Universities in Turkey. Proximal tibial physis fusion and the absence of gross pathological changes were determined by visual inspection; any bone not meeting these criteria was excluded from the study.

The tibiae were photographed from the medial aspect with a ruler for scale to enable measurement. Special attention was given to the standardisation of bone position, particularly superimposition of the cranial ends of the medial and lateral tibial condyles. The camera was placed at the level of the proximal aspect of the tibia, at a fixed distance from the bone, and focused on the central point of the intercondylar tubercles (Figure 1). The images were transferred to a computer in JPEG format and calibrated.

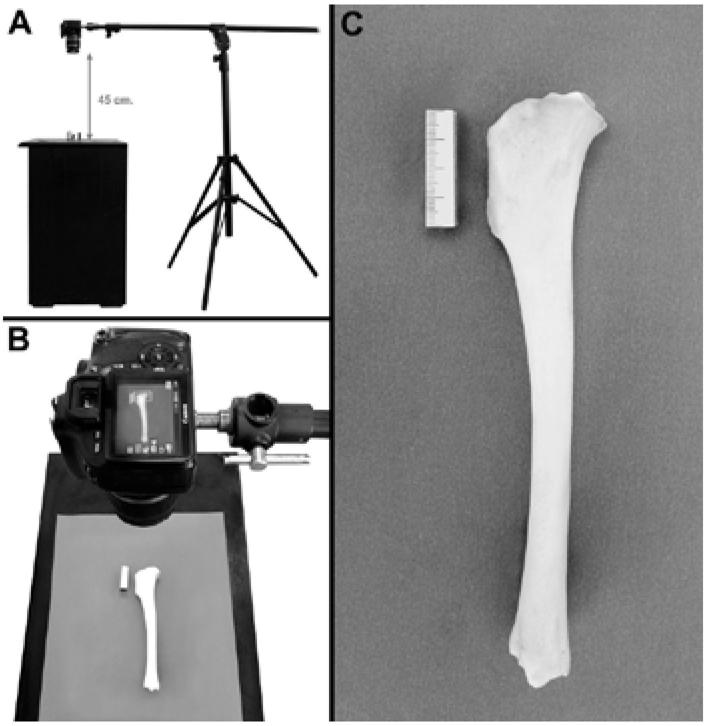

Figure 1. Showing the photographic setting system from side (A) and above (B), and the appearance of the tibia (C).

Measurements were taken according to the following procedure. First, the following reference points were marked on the calibrated photographs: the most cranial (Cr) and most caudal (Ca) points of the medial tibial condyle, to define the joint orientation line; and the IC and center of the circle that best fit the distal tibial extremity, to define the TA. The TPA was then measured in the standard manner using the TA and joint orientation line (Brinker and O'Conner, 2010; Dismukes et al., 2008). The tibial length and midshaft width were measured on each tibia. The medial condyle length was measured from the Cr to Ca points of the medial tibial condyle. The distance between the point of the TA on the medial condyle and the Cr was measured as the (cranial length of medial condyle) MCLcr (Figure 2A). Two-dimensional graphic representations of these points and axes in the sagittal plane were created using software (SolidWorks 2010, Massachusetts, USA).

TPLO was simulated for all specimens, on the 2D graphical representation. A circle with a 24-mm radius was placed on the TA at the IC, and the tibial plateau was rotated to achieve a TPA of 5° (Kowaleski and McCarthy, 2004). All measurements were retaken on these simulations, and vertical and horizontal movements of the Cr and Ca were measured using the same software. The percentages of MCLcr were calculated as a formula; MCLcr / Medial Condyle Length. The postoperative TPA was measured using the joint orientation line and the TA that the proximal point of TA defined according to the preoperative MCLcr ratio (Figure 2B). The tibial plateau rotation in mm was also calculated as; (Preoperative TPA – 5°) x $2\pi r$ / 360° (Reif et al., 2002).

Statistical analyses were performed using software (SPSS, version 20.0 for Windows; California, USA). Data are reported as means, standard deviations, ranges, and 95% confidence intervals (CIs). Paired t-tests were used to compare pre- and postoperative TPAs, MCLcrs, and percentages of MCLcr. Pearson correlation analysis was conducted to assess whether the difference between pre- and postoperative MCLcrs was related to tibial length, tibial width, medial condyle length, and/or the degree of TPA rotation. The level of significance was set to P<0.05 for all analyses.

Results

Fourteen tibiae from 7 dogs were excluded from the study because of osteophyte formation (5 dogs) and incomplete fusion of the proximal tibial physis (2 dogs). Thus, a total of 182 tibiae from 91 adult dogs were used. These specimens were from 23 breeds: German Shepherd (n=19), Anatolian Shepherd (n=13), mixed breed (n=13), Rottweiler (n=7), Boxer (n=6), Doberman Pinscher (n=5), Pointer (n=4), Cocker Spaniel (n=3), Siberian Husky (n=3), collie (n=2), Slovensky Kopov (n=2), Setter (n=2), St. Bernard (n=2); and 1 representative each of Akbash, Bulldog, Canaan, Chow Chow, Clumber Spaniel, Great Dane, Golden retriever, Malamute, Mastiff, and Shar-Pei. Forty-six (51%) dogs were female and 45 (49%) were male.

The mean tibial length was 197 ± 30.2 mm (range, 107–276 mm; 95% CI, 193–202 mm) and mean midshaft width was 16.5 ± 2.75 mm (range, 9.23–22.7 mm; 95% CI, 16.1–16.9 mm). The mean medial condyle length was 23.9 ± 3.70 mm (range, 15.1–33.9 mm; 95% CI, 23.4–24.5 mm). The mean preoperative TPA, MCLcr and percentage of MCLcr were shown in Table 1.

To obtain postoperative TPAs of 5°, tibial plateaus were rotated a mean of 18.9±3.19° (range, 11.3–26.2°; 95% CI, 18.4–19.3°). The mean rotation of tibial plateau was 7.89±1.33 mm (range, 4.72-11.0 mm; 95% CI, 7.70-8.09 mm). Cr was moved an average of 3.69±0.89 mm (range, 1.67–7.59 mm; 95% CI, 3.56–3.82 mm) distally and 0.56±0.31 mm (range, -0.22–1.57 mm; 95% CI, 0.51–0.60 mm) caudally, and Ca point was moved an average of 3.78±0.92 mm (range, 1.94–7.07 mm; 95% CI, 3.65–3.92 mm) proximally and 2.77±0.77 mm (range, 1.03–5.50 mm; 95% CI, 2.66–2.87 mm) caudally (Figure 2B). The mean postoperative TPA, MCLcr and percentage of MCLcr were shown in Table 1.

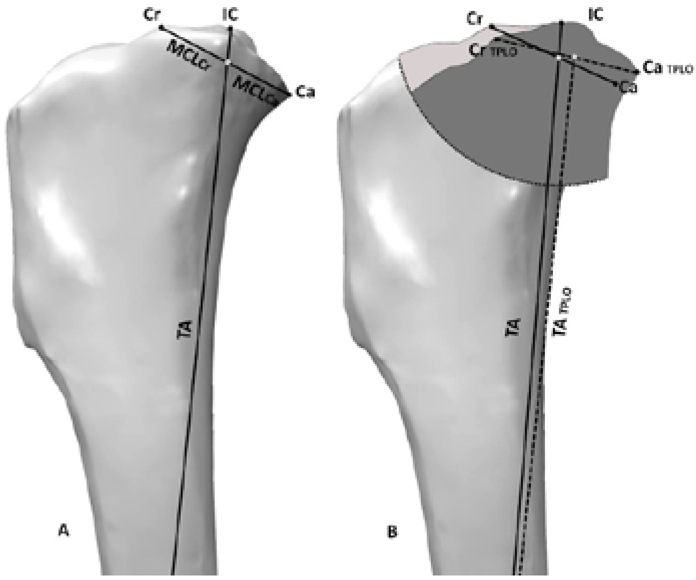

Figure 2. Depiction of tibial measurement landmarks in the sagittal plane before TPLO (A), rotation of the tibial plateau (light gray area) after TPLO (B). The center of the intercondylar tubercles (IC), cranial (Cr) and caudal (Ca) points of the medial condyle, and distances between TA and Cr (MCLcr), and TA and Ca (MCLca) are depicted, as are TPLO-induced shifts in TA (TA_{TPLO}), Cr (Cr_{TPLO}), and Ca (Ca_{TPLO}).

The mean difference between pre- and postoperative MCLcrs was 1.72±0.51 mm (range, 0.60–3.28 mm; 95% CI, 1.64–1.79 mm). Pre- and postoperative MCLcrs and percentages of MCLcr differed significantly (both P < 0.001), with mean reductions indicating a caudal shift of the TA (Figure 2B) and reduced TPA (mean, 0.52±0.15°; range, 0.23–1.05°; 95% CI, 0.50–0.54°; P < 0.001). The change in MCLcr showed a significant but fair degree of correlation with the degree of tibial plateau rotation (P<0.001, r=0.547), medial condylar length (P<0.001, r=0.495), tibial length (P<0.001, r=0.427) and midshaft width (P<0.001, r=0.402) positively.

Table 1. Comparison between the pre- and postoperative values.

Parameters	Preoperative			Postoperative			P
	Mean±SD	Range	95% CI	Mean±SD	Range	95% CI	
TPA (°)	23.9±3.19	16.3-31.2	23.4-24.3	23.3±3.09	15.9-30.7	22.9-23.8	0.001
MCLcr (mm)	12.6±2.35	6.29–18.2	12.2–12.9	10.9±2.12	5.60–16.4	10.5–11.2	0.001
Percentage of MCLcr (%)	52.5±4.71	36.6–62.0	51.8– 53.2	45.3±4.64	31.0–55.5	44.6–46.0	0.001

TPA, tibial plateau angle; **MCLcr**, distances between the tibial axis and the most cranial point of medial condyle;
MCLcr %, its percentage.

Discussion

In TPLO, deviation from the planned TPA is likely to originate from TAS (Duerr et al., 2008; Kowaleski and McCarthy, 2004; Kowaleski et al., 2005). We observed that TAS significantly reduced the TPA, but the greatest difference between pre- and postoperative values (1.05°) was not clinically significant, as differences in TPA ≤ 2° may be ignored in dogs (Ritter et al., 2007). Among potential reasons for postoperative TPA deviation (Baroni et al., 2003; Caylor et al., 2001; Fettig et al., 2003; Ocal and Sabanci, 2013a; Reif et al., 2004), limb positioning appears to be important, as the preoperative position may be difficult to recreate accurately after an invasive operation, such as TPLO.

A mechanical axis of a long bone is defined to be drawn between the centers of the proximal and the distal joints (Allen and Mann, 2013; Brinker and O'Conner, 2010; Dismukes et al., 2007; Paley, 2002; Tomlinson et al., 2007; Wood et al., 2014). In human, the center of the knee joint is demonstrated approximately the same using a point at the center of the tibial spines or the midpoint of the tibial plateaus (Moreland et al., 1987). The former approach was adopted in dogs and the IC has been used as the proximal point of the TA in TPA measurements (Dismukes et al., 2008; Fettig et al., 2003; Headrick et al., 2007; Lister et al., 2008; Morris and Lipowitz, 2001; Sathya et al., 2014). However, there has not been any study whether the IC is corresponded to the central point of the articular surface of the medial tibial plateau or not in dogs. The pre and postoperative percentages of MCLcr were 52.5%±4.71 and 45.3%±4.64, respectively. This decrease indicated the change for the intersection of the TA and the medial tibial plateau after TPLO. The proximal point of TA should be at the central point of the medial condyle for eliminating both TAS and difference in TPA measurement postoperatively in TPLO. For similar reasons, the studies have been continued to determine the ideal osteotomy center and its applicability in TPLO; the medial collateral ligament (Ley et al., 2014) or the intersection of the tibial plateau and the TA (Kowaleski et al., 2012).

Most studies have shown that TPLO improves limb function in dogs with CrCL insufficiency (Christopher et al., 2013; Duerr et al., 2008; Nelson et al., 2013; Oxley et al., 2013; Thieman et al., 2006). However, osteoarthritis progression has been observed in stifle joints treated with TPLO (Hurley et al., 2007; Lazar et al., 2005; Shimada et al., 2020). The present study found that this procedure caused a caudal shift of the articular surface of the medial condyle, with the displacement of Cr distally and Ca proximally. Such movement of the tibial articular surface creates greater joint flexion (Boudrieau, 2009) and appears to alter the relationship between the femoral and tibial articular surfaces. An in vitro biomechanical study confirmed that the caudal shift of the articular surface of the medial tibial condyle resulted in contact with a more caudal part of the medial femoral condyle (Kim et al., 2009). This positional change after TPLO may partially explain the progression of osteoarthritis in the stifle joint, which results from a change in the load-bearing area of the articular cartilage (Andriacchi et al., 2004).

We found that TAS was correlated significantly with the degree of tibial plateau rotation, medial condyle length, tibial length, and midshaft width; all these variables except the rotation angle are unchangeable characteristics, and TPLO should avoid alteration of the tibiofemoral contact point. To prevent from TAS, the applying reduced rotation angle also contradicts the aim of TPLO, because a postoperative TPA of 5 – 6.5° is recommended to eliminate the stress on the CrCL (Nanda and Hans, 2019; Shahar and Milgram, 2006; Warze et al., 2001). This study has several limitations. TPLO was simulated, which naturally differed from the actual procedure. For example, the saw kerfs may have contributed to the observed differences in values. A circle with a 24-mm radius was applied to all tibiae, with no consideration of differences in bone size (due mostly to differences in tibial length and midshaft width) among specimens. Such standardization of the osteotomy simulation was not expected to cause significant differences in values. Furthermore, the complex structure of the tibial plateau and variations therein may be considered limiting factors for accurate tibia positioning (Ocal et al., 2013b). We tried to minimize this limitation by paying special attention to the standardization of bone position and obtaining pre- and postoperative measurements on the same images. No record of the dogs' age or soft tissue stifle joint injuries was available due to the age of the anatomical collection from which specimens were drawn. For this reason, only adult dog tibiae with no gross pathological change were included in the study.

In the sagittal plane of the tibia, the IC was located in the approximate center of the medial condyle length according to the percentage value of the MCLcr. The position of articular surface of the medial condyle was changed with respect to the IC after TPLO. The rotation of the tibial plateau during TPLO led to shift the intersection point of the TA and articular surface caudally, shortening the MCLcr by >7%. Thus, the IC would not represent to be proximal point of the TA postoperatively since the mechanical axis is a straight line connecting two joint center points.

Conclusion

The results of the present study clearly demonstrate that TPLO alters the position of the medial tibial articular surface, but not TPA clinically. Therefore, the central point of the medial condyle length is suggested to be a more suitable landmark than the IC for the proximal point of the TA in TPLO.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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