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Research article

TIBIAL PLATEAU ANGLE MEASUREMENT IN DOGS – COMPARISON OF THREE DIFFERENT METHODS

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The aim of this study was to establish two new methods for measuring the tibial plateau angle (TPA): proximal tibial circle (PTC) as well as full tibial circle (FTC) method, and to test their reliability in comparison to the classical method (CM). Three radiologists implemented each method, and measurements were repeated three times.

The results of consecutive measurements obtained by two observers had excellent reliability with an interclass correlation coefficient (ICC) greater than 0.9 for all methods, while measurements obtained by the third observer had good reliability for the CM (ICC=0.885) and PTC method (ICC=0.851).

The results obtained by the three observers for all methods indicate good reliability for the PTC and FTC methods (ICC=0.848 and 0.880, respectively) and excellent reliability for CM (ICC = 0.909); the results of the different observers for each method were not significantly different.

The significant difference resulting from the applied measurement method (ICC = 0.447 and $P<0.01$) was confirmed. Statistically significant differences were not found between the CM and PTC method ($P>0.05$), while differences between the PTC and FTC, as well as CM and FTC methods, were statistically significant ($P<0.01$).

New methods for TPA measurements based on shorter tibial axes may be an alternative to a method based on the full-length axis. A high correlation between the methods indicates the precision of each of them. Newly established methods can be used when the tarsal joint is not included in radiographs or is affected by degenerative changes, making use of the classical method not possible.

Keywords: dog, cranial cruciate ligament, stifle joint, tibial axis, tibial plateau angle, tibial plateau slope

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INTRODUCTION

Cranial cruciate ligament (CrCL) disease is the most frequent orthopedic condition of the stifle joint in dogs and typically leads to rupture [1]. The etiopathogenesis of cranial cruciate ligament rupture (CrCLR) remains unclear, and the most appropriate treatment is still under discussion [2]. Numerous surgical approaches related to the treatment of CrCLR have been proposed, divided into intracapsular, extracapsular, and tibial osteotomy techniques. Generally, for dogs that weigh more than 15 kg, surgery is the best treatment option to recreate the function of CrCL [3]. Tibial osteotomy techniques, such as tibial plateau leveling osteotomy (TPLO), create dynamic stability in the CrCLR, changing the bone geometry [4]. This procedure is used to achieve rotation of the tibial plateau with the desired tibial plateau angle (TPA) of 5 to 6.5 degrees [5,6], respectively. An essential preoperative factor for TPLO is a determination of the TPA on mediolateral stifle radiographs [7]. Slocum and Devine [8] defined TPA as the angle formed between the slope of the medial tibial condyle and the line perpendicular to the longitudinal axis of the tibia. Data regarding the TPA vary between breeds and individual dogs, with the average TPA in large-breed dogs ranging from 23.5 to 27.5±5 degrees [9]. However, radiographic studies made by Fettig [10] showed that the TPA of different breeds can range between 12 and 36.5° with a mean value of 24.1°, while Duerr [11] states that the mean ± SD of the TPA is 41.7±4.9 degrees (range, 35 to 59 degrees).

Other TPA measurement methods focusing on tibial plateau slope determination using different types of proximal tibial axes have also been described in the literature [12-14]. However, regardless of the method used, radiographic evaluation of TPA is still very subjective [9]. It was confirmed that TPA measurements can be misinterpreted in cases of poor limb positioning when the x-ray beam is not centered on the stifle joint during radiographic imaging [15]. Also, severe osteophyte formations around tibial condyles can hinder the identification of the cranial and caudal margins of the tibial plateau [10]. This is very important given that a precise preoperative measurement of the TPA of an individual dog is important for the best outcome of TPLO because the initial measurement directly affects the degree of proximal tibial rotation the surgeon wants to achieve [10].

This study aimed to compare the results of TPA measurement using the classical method (CM) established by Slocum and Devine [8] with two new methods for TPA measurement obtained from shorter reference axes that avoid the tarsal joint in order to identify the most reliable.

MATERIALS AND METHODS

Animals

In this study, 40 stifle joints from medium- to large-breed adult dogs were included (Golden retriever n=8; Bernese mountain dog n=7; Labrador retriever n=6; Akita n=4; Bouvier n=3 Rottweiler n=2; Belgian Shepherd n=2; German Shepherd n=2; Groenendael n=2; Bull Terrier n=2; Mixed breed n=2). All animals were imaged for diagnostic reasons. Only stifles not presenting any degenerative joint disease changes were included in the measurement process.

All the radiographs were performed using a digital radiography system EDR6, EKLIN device from Canon (Canon Medical Systems). Only radiographs made in lateral recumbency with stifles placed in a neutral lateral position were used for the study. The x-ray beam was centered over the stifle joint, with the x-ray beam collimated to include the stifle and tarsocrural joint. A true lateral position is achieved when there is superimposition of the femoral condyles and of the tibial condyles, and rotation is avoided [16]. Measurements were made using the post-processing software OSIRIX Open Source DICOM viewer.

Measurements

Three different measurement methods for estimating the TPA were used in this study: the classical method, the proximal tibial circle method, and the full tibial circle method.

The classical method (CM) is based on estimating the TPA relative to the mechanical tibial axis, also known as the functional tibial axis (Figure 1). The mechanical tibial axis is defined as a line that connects the center of the thallus, which is equidistant from the anterior and posterior borders of the trochlea and the midpoint between the two intercondylar eminences of the tibia. A second line corresponding to the tibial plateau slope was drawn for TPA determination. This line connects the most cranial aspect of the tibial plateau (the insertion of the cranial cruciate ligament) and the most caudal aspect of the tibial plateau, where the caudal cruciate ligament attaches. The TPA was measured between the line perpendicular to the mechanical tibial axis and the line representing the tibial plateau slope [8].

The proximal tibial circle (PTC) method is not based on the assessment of the TPA relative to the mechanical tibial axis. In this method, TPA estimation was performed in relation to the short axis that does not include the distal part of the tibia. This axis connects the centers of two circles: the proximal circle, which was drawn so that it touches the most proximal, the most anterior, and the most posterior points of the tibial cortex, and the second, distal circle, the center of which was positioned on the perimeter of the proximal circle fitting within the anterior and posterior tibial cortices (Figure 2).

The full tibial circle (FTC) method is also not based on an assessment of the TPA relative to the mechanical tibial axis. It implies TPA measuring using the longer tibial axis that connects the center of the proximal circle, positioned so that it touches the most proximal, the most anterior, and the most posterior cortices of the tibia and the second circle, which is drawn within the distal tibia, connecting the anterior, posterior and distal tibial cortices (Figure 3).

In both methods (PTC and FTC), the TPA was measured between the line that corresponds to the tibial plateau slope and the line perpendicular to the previously described tibial axes.

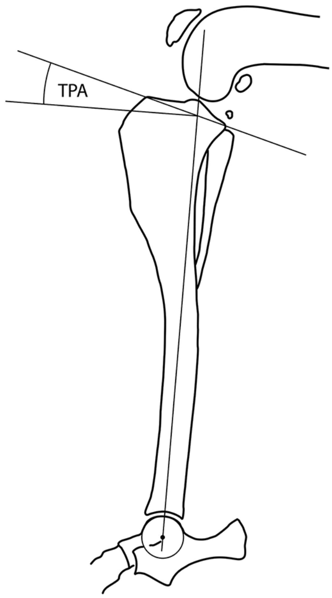

Figure 1. The classical method for measuring the TPA

In order to investigate the intra-observer variability for each examined method, measurements were performed three times by the same person, with a minimum interval of 21 days between each measurement. The same number of measurements (three) was performed by three experienced observers (radiologists) in order to assess inter-observer variability. The observers were not given all identifying radiographic information, and each observer was "blinded" to the previously obtained measurement.

Statistical analysis

Statistical analysis was carried out using the commercially available software *TIBCO® Statistica*™13 for descriptive statistics and ANOVA, and MS Excel for the Bland-Altman plot and interclass correlation. Comparison of measurements and quantification of reliability for each observer (intra-observer reliability) was performed using the interclass correlation (ICC) with a 95% confidence interval (CI). The ICC with the same CI (95%) was obtained to quantify the reliability of measurements between observers for each method (inter-observer reliability) and between all three methods. The differences between the applied methods were also obtained using the Bland-Altman plot.

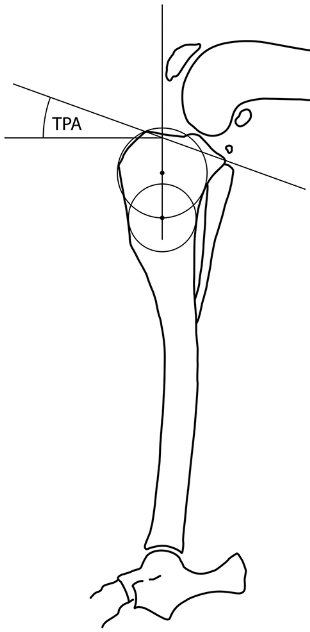

Figure 2. The proximal tibial circle method for measuring the TPA

Figure 3. The full tibial circle method for measuring the TPA

RESULTS

The mean values and standard deviations of consecutive individual TPA measurements performed by each observer (intra-observer reliability) for all three measurement methods are shown in Table 1. Comparison of the results was performed using the ICC, and the obtained value for two observers (observers 1 and 3) showed excellent reliability (greater than 0.9) for all three methods of measurement, while for observer 2, good reliability (between 0.75 and 0.9) was found for both the CM (ICC=0.885) and PTC (ICC=0.851) method.

The mean values and standard deviations of the TPA measurements performed by three observers (inter-observer reliability) for all three measurement methods are shown in Table 2. Comparison of the results of measurements indicates good reliability for the PTC and FTC methods (ICC=0.848 and 0.880, respectively) and excellent reliability for the CM (ICC=0.909). No statistically significant differences were observed between the measurement results of different observers for each of the examined methods.

Table 1. Differences between some measurements of each observer (intra-observer).

		Observer 1	Observer 2	Observer 3
PTC	M1 (°)	23.68	24.92	23.78
	M2 (°)	24.14	24.09	24.31
	M3 (°)	24.29	23.58	24.07
	SD (°)	0.887	1.294	0.686
	CV (%)	3.83	5.43	2.84
	SE	±0.512	±0.747	±0.396
	95% CI (°)	22.89-25.18	22.52-25.87	23.17-24.94
	ICC	0.911	0.851	0.943
CM	M1 (°)	24.16	24.51	24.42
	M2 (°)	23.92	24.25	24.77
	M3 (°)	24.54	23.91	24.65
	SD (°)	0.741	1.054	0.723
	CV (%)	3.09	4.45	2.97
	SE	±0.428	±0.608	±0.417
	95% CI (°)	23.25-25.17	22.86-25.59	23.68-25.55
	ICC	0.931	0.885	0.931
FTC	M1 (°)	29.39	29.81	29.48
	M2 (°)	29.62	29.85	29.00
	M3 (°)	29.61	29.32	29.17
	SD (°)	0.743	0.871	0.578
	CV (%)	2.51	2.95	1.99
	SE	±0.429	±0.503	±0.334
	95% CI (°)	28.58-30.50	28.53-30.79	28.47-29.97
	ICC	0.927	0.905	0.946

Abbreviations: 95% CI (°) confidence interval; CV (%), coefficient of variation; ICC, interclass correlation coefficient M1 (°), measurement 1; M2 (°), measurement 2; M3 (°), measurement 3; SD, standard deviation; SE, standard error; PTC, proximal tibial circle; CM, classical method; FTC, full tibial circle.

A comparison of the differences in TPA measurements using three different methods (Table 3) indicates that there is a statistically significant difference between results from the applied methods (ICC = 0.447 and $P<0.01$). However, statistically significant differences were not confirmed between the CM and PTC method ($P>0.05$), while differences between the PTC and FTC methods, as well as CM and FTC method, were statistically significant ($P<0.01$).

Table 2. Difference between observers for each method (inter-observers)

	PTC	CM	FTC
O1 –M (°)	24.04	24.21	29.54
O2 –M (°)	24.20	24.23	29.66
O3 –M (°)	24.05	24.61	29.22
SD (°)	1.074	0.803	0.790
CV (%)	4.56	3.39	2.70
SE	±0.620	±0.464	±0.456
95% CI (°)	22.70-25.48	23.31-25.39	28.45-30.49
ICC	0.848	0.909	0.880
F-test	0.173	2.572	1.961
P-value	0.842	0.083	0.148
Significance	ns	ns	ns

Abbreviations: 01-M (°), observer 1; O2 –M (°), observer 2; O3 –M (°)-observer 3; SD, standard deviation; CV (%), coefficient of variation, SE, standard error; 95% CI (°) confidence interval; ICC, interclass correlation coefficient; PTC, proximal tibial circle; CM, classical method; FTC, full tibial circle.

Table 3. Difference between the three methods.

	PTC	CM	FTC
Mean	24.058	24.295	29.391
SD (°)	3.212	2.977	2.887
CV (%)	13.33	12.23	9.79
SE	±0.508	±0.471	±0.456
95% CI (°)	22.96-25.23	23.29-25.40	28.45-30.49
ICC		0.447	
F-test		381.68	
P-value		0.00000	
Significance		P<0.01	
r-values for correlation with PTC	N/A	0.80	0.79
r-values for correlation with CM	0.80	N/A	0.89

Abbreviations: 95% CI (°) confidence interval; CV(%), coefficient of variation; ICC, interclass correlation coefficient SD, standard deviation; SE, standard error; PTC, proximal tibial circle; CM, classical method; FTC, full tibial circle.

The differences between the applied methods were also investigated using the Bland-Altman plot, and the results are shown in Figure 4. A comparison of the measurements obtained by the CM and PTC method (bias = 0.253) indicates the existence of a small difference between the results of these two applied methods. In contrast, significant differences were observed between the CM and FTC method (bias = 5.124) and PTC and FTC methods (bias = 5.377). However, the dispersion of measurement results shown by points distributed evenly around the bias indicates good agreement, consistent with the high correlations between the compared methods.

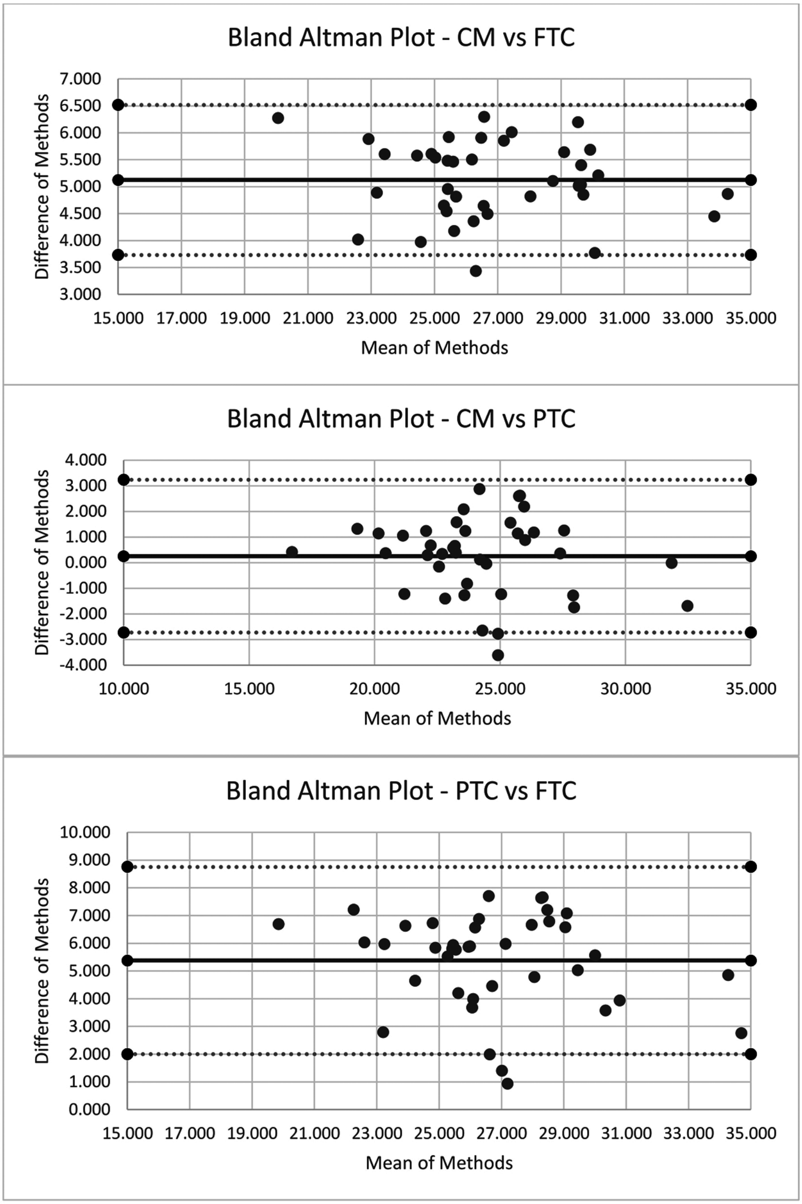

Figure 4. The differences between the applied methods using the Bland-Altman plot

DISCUSSION

In dogs with CrCLR, radiography is the most frequently used imaging technique for TPA measurement, and precedes the surgical treatment of this pathological condition. To obtain good-quality images, radiography should be performed on sedated animals positioned in lateral recumbency. The mediolateral tibial radiograph should be centered on the stifle joint in a neutral position, including the entire tibia and tarsocrural joint. If the dog is positioned correctly, the femoral condyles, as well as the tibial condyles, are superimposed on each other [16].

Considering that cranial and proximal positioning of the normal limb relative to the primary x-ray beam causes an overestimation of the TPA measurement, with variability among dogs reported to be 1.1 degree [10]. It has also been demonstrated that cranial and proximal positioning of the limb relative to the radiographic beam can show notable overestimation of the tibial plateau slope measurement [15]. In our investigation, the x-ray beam was centered on the stifle joint space, with collimation including the stifle and tarsocrural joints of all animals.

In dogs with osteoarthritis, it is often difficult to define the appropriate points from which the TPA measurement should be obtained [10]. In the case of degenerative changes on the tarsal joint, it is also difficult to determine the center of the talus in order to place the mechanical axis. Hence, the application of the classical TPA measurement method is unreliable. Therefore, the advantage of these new methods is that the tarsal joint does not have to be included in the radiograph to measure TPA.

A reliable method of measuring the TPA is crucial for the successful outcome of TPLO. In this study, two new methods were compared with the classical method.

The method of TPA measurement established by Slocum and Devine [7] relied on the inclination of the tibial plateau slope in relation to the mechanical (functional) axis that connects the mid-point between the medial and lateral intercondylar tubercles and the center of the talocrural joint. This method of measurement is most often used to assess the TPA in clinical practice, and in the literature, there are numerous data related to the tibial plateau slope in healthy dogs of different breeds [16-20] as well as in animals with ruptures of the anterior cruciate ligament [17,20-22]. Thus, in large breeds of healthy dogs, TPA mean ± SD values measured by the classical method are in a range from 18.1±4.03 degrees [17] to 27.97±0.66 degrees [20] with an average value of 23.64±3 degrees [23]. In our investigation, the mean TPA value ± SD for CM was 24.295±2.977, which corresponds to the mentioned literature data.

In addition to the TPA measurement method that refers to the mechanical tibial axis [8], other TPA measurement methods focusing on tibial plateau slope determination using different types of proximal tibial axes have also been created. They mainly rely on the influence of the proximal tibial part conformation on the CrCLR occurrence. Methods of TPA measurement using only the proximal portion of the tibia were described by Abel [12] and Stehlic [13]. Both authors considered proximal tibial width, defined as the distance between the proximal point of the tibial crest and the caudal point of the medial tibial condyle surface. The obtained results showed that the values of the tibial plateau slope measured in relation to different proximal axes correlate with the values of the slope measured in relation to the mechanical axis of the tibia, with the degree of correlation significantly depending on the length of the proximal axis [12] and its position [13].

It was concluded that TPA measurement, using the shortest proximal reference axis formed by a line that connects the cranial aspect of the medial tibial condyle and the point distally determined by bisecting the tibia at distances equal to proximal tibial width, is not accurate and differs from the results obtained by the CM (r=0.69-0.78) [12]. Contrary to data from the literature mentioned above [12], our results revealed no statistical difference between measurements obtained by the CM and PTC method ($P>0.05$), which refers to the shorter tibial axis. Furthermore, a significant difference ($P<0.01$) was confirmed between the CM and FTC method, which also relate to the longer tibial axis, as well as between the PTC and FTC ($P<0.01$), whose axes differ in length. However, the dispersion of the results confirms good agreement, which is consistent with the high correlations between the different methods of measurement.

The significance of the craniocaudal distance at the distal aspect of the tibial crest was also confirmed in a study in which the angle between the mechanical and anatomical tibial axis was measured [14]. The authors concluded that increasing this distance increases the angle, whereby values greater than 1.87 degrees predict cranial cruciate ligament rupture [14].

By comparing the ICC values of individual observers and applied methods used in our study, it was observed that the highest reliabilities by observers were found with the FCT method, indicating that this method gives consistent results of freedom from error that occurs between observers. All three methods suited the observers because the differences between the values of the observers were minimal (ICC from 0.851 to 0.946), and the ability to reproduce measurements was high for all three observers. The absence of differences between the observers can be linked to their experience.

The limitation of this study lies in the fact that only large-breed dogs were included in the trial. Further research is needed to validate the tested TPA measurement methods on a broader population of healthy dogs of different sizes and breeds. Furthermore, the methods should be tested in healthy dogs as well as in those with CrCLR.

CONCLUSION

Although the numerical values of the TPA obtained by the methods used are very different because the TPA is measured in relation to different axes, the results of the tibial plateau slope measurement using the two new methods have a high degree of reliability. This is important in situations where the tarsal joint is not included in the image or is affected by degenerative changes, so measurement using the classic method is not possible.

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Authors' contributions

TA performed study design, TPA measurements, acquisition and analysis of data, drafting, editing, revising the manuscript for intellectual content, and submitting the final manuscript. KN performed study design, TPA measurements, data acquisition and analysis, and revising the manuscript for intellectual content. ŽD performed study, acquisition, and analysis of data, statistical analysis, and revising the manuscript for intellectual content. Van VBH performed study design, acquisition, and analysis of data, drafting, editing, and revising the manuscript for intellectual content. GI performed study design, acquisition and analysis of data, drafting, editing, and revising the manuscript for intellectual content. LMM performed study design TPA measurements, acquisition, and data analysis and drafted, edited, and revised the manuscript for intellectual content. All authors read and approved the final manuscript.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Statement of Informed Consent

The owner understood procedure and agrees that results related to investigation or treatment of their companion animals, could be published in Scientific Journal Acta Veterinaria-Beograd.

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MERENJE TIBIJALNOG PLATOA PASA - POREĐENJE TRI RAZLIČITE METODE

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Cilj ove studije je da se ustanove dva nova metoda merenja ugla tibijalnog platoa (engl. *tibial plateau angle – TPA*): proksimalno tibijalni kružni (PTC) i proksimalno-distalni tibijalni kružni (FTC), kao i da se ispita njihova pouzdanost u odnosu na klasični metod merenja (CM). Svaki od navedenih metoda merenja obavljen je po tri puta od strane tri radilologa.

Rezultati uzastopnih merenja obavljenih od strane dva ispitivača imali su izuzetno visok stepen pouzdanosti sa koeficijentom korelacije (ICC) većim od 0.9 za sve metode merenja, dok su rezultati uzastopnih merenja obavljenih od strane trećeg ispitivača imali značajan stepen pouzdanosti u slučaju klasičnog (CM) metoda (ICC=0,885) i proksimalno-distalnog tibijalnog kružnog (FTC) metoda (ICC=0,851).

Rezultati dobijeni od strane tri ispitivača za sva tri metoda merenja ukazuju na to da postoji značajan stepen pouzdanosti za PTC i FTC metod (ICC=0,848 i 0,880, respektivno) i izuzetno visok stepen pouzdanosti za klasični (CM) metod (ICC = 0,909); Rezultati različitih ispitivača za svaki metod merenja nisu pokazali značajna odstupanja.

Značajne razlike u rezultatima merenja između primenjenih metoda potvrđene su u ovom istraživanju (ICC = 0,447 and P<0,01). Statistički značajne razlike nisu ustanovljene između CM i PTC metoda (P>0,05), dok su razlike između PTC i FTC, kao i CM i FTC metoda bile statistički značajne (P<0,01).

Novi metodi merenja TPA bazirani na kraćim tibijalnim osovinama mogu biti alternativa klasičnom metodu merenja koji se oslanja na dugačku (mehaničku) osovinu tibije. Visok stepen korelacije između metoda ukazuje na preciznost svakog od njih. Novoustanovljeni metodi mogu biti upotrebljeni u slučajevima kada tarzalni zglob nije obuhvaćen rendgenskim snimkom ili kada je on zahvaćen degenerativnim promenama, što upotrebu klasičnog metoda čini nemogućom.