Comparison of four methods to determine cage width in tibial tuberosity advancement

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Vergleich von vier Messmethoden zur Bestimmung der Käfiggrösse bei der Vorverlagerung der *Tuberositas tibiae*

Das Ziel dieser Studie war es, unter einer präoperativen radiologischen Untersuchung eine Methode zur Bestimmung der Käfiggrösse bei der Kranialisierung der *Tuberositas tibiae* (Tibial Tuberosity Advancement (TTA)) zu testen, ohne dass das Kniegelenk gestreckt werden muss. Die TTA-Käfiggrösse wurde anhand von vier verschiedenen Methoden mittels Röntgenbilder in medio-lateraler Richtung an vollständig gestreckten Kniegelenken bei Hunden (n = 43) mit und ohne natürlich vorkommender kranialer Kreuzbanderkrankung bestimmt: Parallelverschiebung (PS)-Methode, Common Tangent (CT) Methode, «2,1»-Methode (Käfiggrösse = 2,1 × Tibiaplateaulänge – Breite der *Tuberositas tibiae*) und Margo cranialis (MC)-Methode (Käfiggrösse = Länge von MC/6*1,75). Zwei neue Methoden, «2,1» und MC, wurden mit den bestehenden CT- und PS-Methoden verglichen. Alle 4 Methoden führten zu zuverlässigen Käfiggrössen. Der Interklassen-Korrelationskoeffizient zeigte eine hervorragende Übereinstimmung der CT und PS gegenüber der «2,1»-Methode und eine gute Übereinstimmung gegenüber der MC-Methode. Zusammenfassend lässt sich sagen, dass die TTA-Käfiggrösse der Tibiaanatomie allein auf Röntgenbildern bestimmt werden kann, ohne dass das Kniegelenk vollständig gestreckt werden muss. Basierend auf den Ergebnissen werden zwei verschiedene Methoden zur Messung der Käfiggrösse empfohlen, um die diagnostische Genauigkeit zu erhöhen und das Einsetzen suboptimaler Käfige zu verhindern.

Schlüsselwörter: Alternative Messung, Käfig, Kreuzband, Hund, Radiologie, TTA

Summary

The objective of this study was to test a method for determining the width of the tibial tuberosity advancement (TTA) cage without the need for extension of the stifle joint, while producing preoperative radiographs. TTA cage size was determined by applying 4 different methods using radiograph images in mediolateral direction of fully extended stifles of dogs (n=43), with and without naturally occurring cranial cruciate ligament disease: parallel shift (PS) method, common tangent (CT) method, «2,1» method (cage size = 2,1 × tibia plateau length – tibial tuberosity width), and margo cranialis (MC) method (cage size = length of MC/6*1,75). Two new methods, «2,1», and MC were compared to the existing CT and PS methods. All 4 methods resulted in reliable cage sizes. Intraclass correlation coefficients showed an excellent reliability of the CT and PS to the «2,1» method and a good reliability in regards to the MC method. In conclusion, TTA cage size of the tibia anatomy alone can be determined on radiographs without the need of full extension of the stifle joint. Based on the results, two different methods of cage size measurement are recommended in order to increase diagnostic accuracy and to prevent the insertion of suboptimal cages.

Keywords: Alternative measurement, Cage, Cruciate Ligament, Dog, Radiology, TTA

https://doi.org/10.17236/sat00345

Eingereicht: 06.06.2021
Angenommen: 12.12.2021

Introduction

Tibial tuberosity advancement (TTA) has become a widely used technique for repairing cranial cruciate deficient stifles.[13,18] The goal is to achieve an angle of ≤90° between the patellar tendon and the tibial plateau in the stance phase.[9] In order to mimic the stance phase in preoperative radiographic evaluation of the canine stifle, a stifle flexion angle of about 135° was proposed,[11] and the desired advancement of the tibial tuberosity was estimated by the use of a template, provided by the producer of the TTA implants. The measurement carries the risk of malalignment of the stifle joint while producing the radiographs and may not reflect true stance phase in individual dogs. Furthermore, the planning method is susceptible to errors when determining the landmarks on the stifle, leading to an inconsistent outcome and a selection of cages of potentially inappropriate widths.[2,12] Selecting undersized cages and subsequent instability during movement may lead to postoperative meniscal damage.[16,17]

Cage width measurements without the need of correct angulation of the stifle joint would exclude this source of error. This study introduces two new methods to determine cage width, which are independent of the femorotibial angle. The so called «2,1» method is based on the risk factor determination by Inauen et al.[7] Tibial tuberosity width (TTW) after TTA was calculated as 2,07 x tibial plateau length. Because many of the cage sizes were underestimated in the first years of the use of TTA[21], the factor was raised to 2,1 and the cage width determined by comparison to the preoperative TTW.

A second alternative method uses the tibial crest (margo cranialis, MC) and determines the cage width as a relation to its length (A. Torrington, personal communication, Brighouse/UK, 2012). It assumes, that the cage size should be proportional to the plate size. Plate size is calculated by the length of the tibial crest, divided by 6, the latter being the distance between the tines of the fork. Initially, the plate size was multiplied by the factor 1,5 and raised to 1,75 in order to prevent postoperative

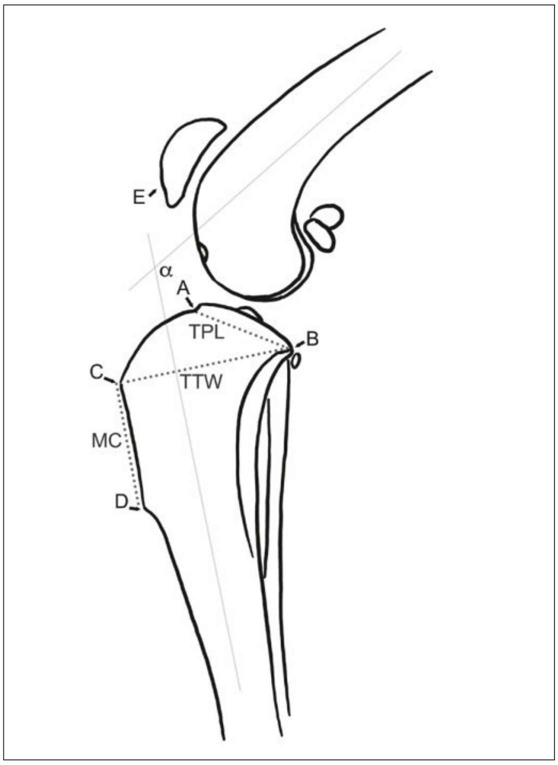

Figure 1: Schematic illustration of a canine stifle in a mediolateral view. TPL: tibial plateau length, distance between A (most cranial point of the tibial plateau) and B (most caudal point of the tibial plateau, represented by the midpoint of the medial and lateral tibial condyles); TTW: tibial tuberosity width, distance between B and C (most proximal point of the margo cranialis); MC: length of the margo cranialis, distance between C and D (most distal point of the margo cranialis); E: origin of the patellar ligament, α: femorotibial angle.

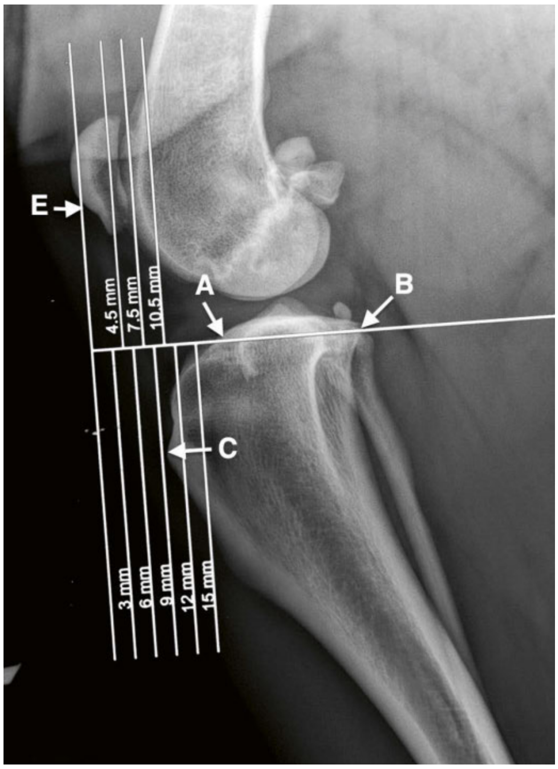

Figure 2: Parallel shift (PS) method for the determination of tibial tuberosity advancement (TTA) cage width in dogs. A line through the endpoints of the tibial plateau (point A,B) is drawn. Parallel lines perpendicular to the tibial plateau line are added. The PS template is then shifted until the most cranial of parallel lines reaches the distal patellar pole at the origin of the patellar ligament (point E). The distance between the most cranial line to the most proximal point of the tibial crest (point C) corresponds to the cage width. A cage width of 9 mm would be selected, based on this method.

meniscal trauma.[21] Both new cage width measurements make use solely of the anatomy of the proximal tibia.

The aim of the study was to test the new methods for TTA cage width determination independent of the femorotibial angle. The hypothesis was, that the «2,1» and the MC methods would lead to a similar cage width to the one that was determined by the parallel shift (PS) and common tangent (CT) methods, which are described as original methods for cage width determination.

Materials and methods

Animals and radiographs

In a series of clinical cases undergoing TTA for cranial cruciate ligament disease or patellar surgery at the Daniel Koch Small Surgery Referrals, Diessenhofen, Switzerland, mediolateral radiographs of the stifle joint were performed on anesthetized dogs. The stifles were held in maximal extension to reflect physiological stance phase. The tarsal region was held slightly in external rotation to allow superimposition of the femoral and tibial condyles, respectively. All patients, whose radiographs showed femorotibial angles outside a range of 130° to 140° degrees, or a shift of the femoral condyle centers of more than 15 % of the femoral condyle diameter, were excluded from the study. In total, radiographs of 43 dogs met the inclusion criteria. They were digitally stored and imported to the Synedra View 3.1.0.4 Software for further measurements.

Definition of landmarks and distances

Measurements on radiographs were performed according to the following criteria and landmarks, which are visualized in Figure 1.

Tibial Plateau Length (TPL), according to Inauen et al.[7]: Distance between the most cranial (A) and the most caudal point of the tibial plateau (B). In case of slight deviation of the caudal tibial condyles, the midpoint of the two end points was chosen.

TTW according to Inauen et al. [7]: Distance between the most proximal point of the tibial crest (C) and B.

MC: Length of the tibial crest between C and the most distal point of the tibial crest (D).

Origin of the patellar ligament (E)

Femorotibial angle (α): Angle between the long axis of the femur and the tibia. The long axis of the femur was defined as a line between the midpoint of the femur at the isthmus of the diaphysis and the midpoint of the femur at the height of the proximal patella pole. The long axis of the tibia was defined as a line between the midpoint of the tibia at the isthmus of the diaphysis and the midpoint of the tibia at the distal end of the tibial crest.

Cage width determinations

TTA cage width was determined according to the following 4 methods (PS, CT, «2,1», MC).

1) Parallel-Shift (PS) method (Figure 2):
The PS was the first method issued by the inventor of the TTA technique.[20] According to the PS method, a line through the endpoints of the tibial plateau is drawn. A special PS template is positioned over the tibial plateau line. This template contains a series of parallel lines which form perpendicular lines to an auxiliary line. The PS template is then shifted until the most cranial of parallel lines reaches the distal patellar pole at the origin of the patellar ligament (point E). The distance between the most cranial line to the most proximal point of the tibial crest (point C) determines to the cage width.

2) Common-Tangent (CT) method (Figure 3):
The CT method is a refinement of the PS method and is regarded as the standard method for TTA cage width determination.[11] Based on a CT template with concentric circles, the centers of the femoral and tibial condyles

Table 1: Intraclass correlation coefficient (ICC) – average measure and 95 % confidence interval between methods (common tangent (CT); parallel shift (PS); «2,1»; margo cranialis (MC))

		95 % confidence interval	
	Intraclass correlation	lower bound	upper bound
CT – PS	0,946	0,900	0,971
CT – «2,1»	0,951	0,910	0,974
CT – MC	0,809	0,648	0,897
PS – «2,1»	0,933	0,876	0,964
PS – MC	0,843	0,709	0,915
«2,1»– MC	0,857	0,735	0,922

Table 2: Descriptive analysis of methods (common tangent (CT); parallel shift (PS); «2,1»; margo cranialis (MC)) displayed as number of samples (N), mean and standard deviation (SD). Individual difference to CT is displayed as mean and SD for each method (PS. 2,1, MC).

	N	Mean and SD (mm)	Difference to CT by mean and SD (mm)
CT	43	9,28 ± 2,64	–
PS	43	9,77 ± 2,88	0,84 ± 1,05
«2,1»	43	8,90 ± 2,84	0,87 ± 0,88
MC	43	7,64 ± 2,45	2,13 ± 1,51

are determined. In case of shifting of the medial and lateral condyles centers, the midpoint of the two centers is chosen. The centers of the tibial and femoral condyles are connected and the common tangent of both circles drawn. The template is shifted parallel until the most cranial line reaches the distal patellar pole at the origin of the patellar ligament (point E). The distance to the most proximal point of the tibial crest (point C) corresponds to the cage width.

3) «2,1» method:
Based on two measurements – the tibia plateau length (TPL) and the tibial tuberosity width TTW – the TTA cage width is calculated according to the following formula:
TTA cage width = 2,1 x TPL – TTW

4) Margo-Cranialis (MC) method:
The length of the tibial crest is measured – from the most distal to the most proximal point (MC). As the original TTA plate hole distance is 6 mm, the division by 6 corresponds to the number of tines on the fork, which equals to the plate size. Multiplication of the plate size by 1,75 results in the cage width. The TTA cage width is calculated according to the following formula:
TTA cage width = MC / 6 x 1,75.

CT and PS results are given as results from the template fitting to an existing cage width. Cage widths are available from 3 to 15 mm, with increments of 1,5 mm. «2,1» and MC were calculated as results from the respective formula and then approximated to the nearest existing cage width. All measurements were executed twice by one author (DK). Whenever the calculations did not result in the same cage width, the measurements were recalculated until they matched a specific cage width.

Data analysis

The data set of the study was statistically analyzed using a commercial software package (IBM SPSS Statistics for Mac, version 25.0, IBM Corp. Armonk, NY, USA). Four methods (CT; PS; «2,1»; MC) were descriptively analysed (mean, standard deviation (SD); absolute difference to CT by mean and standard deviation; number of correct cage size selection). Comparison of CT and PS to «2,1» and MC methods were displayed using Bland and Altman plots.[1] All methods were tested against each other using intraclass correlation coefficient (ICC) and 95 % confidence interval (CI). According to Koo at al.[10], ICC values indicated reliability (<0,50: poor, 0,50 – 0,75: moderate, 0,75 – 0,90: good; >0,90: excellent).

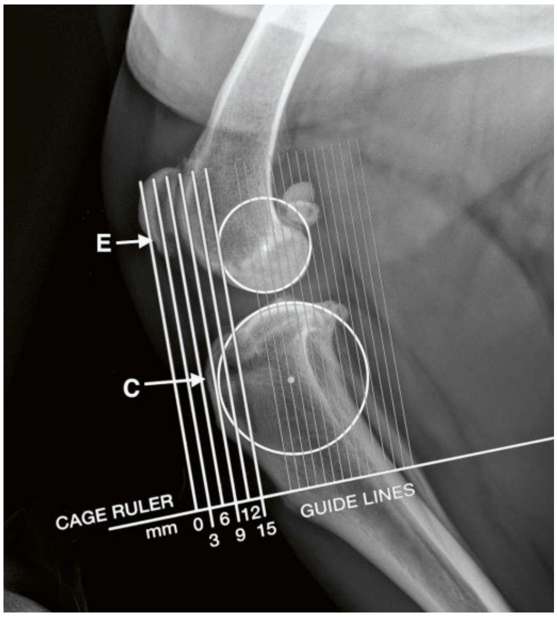

Figure 3: Common tangent (CT) method for the measurement of tibial tuberosity advancement (TTA) cage width in dogs. With the use of the CT template, the center of a circle representing the joint surface of the femoral condyle and the center representing the area of contact of the tibial plateau, is identified. A line is drawn between the midpoints of these circles, and a second line, the common tangent. The CT template is then shifted along the common tangent, until the most cranial of parallel lines reaches the distal patellar pole at the origin of the patellar ligament (point E). The distance between the most cranial line to the most proximal point of the tibial crest (point C) corresponds to the cage width. A cage width of 7,5 mm would be selected, based on this method.

Results

Overall 43 dogs met the inclusion criteria (24 female, 19 male). The age of the study population ranged from 0,7 to 13,4 years (median 5,6 years) and the body weight ranged from 2,1 to 60,0 kg (median 25 kg). The two existing methods (CT, PS) showed an excellent correlation with a ICC of 0,946. The «2,1» method resulted in an excellent ICC of 0,951 against the CT method and 0,939 against the PS method. The MC method showed a low-

Table 3: Number of different cage size selection in relation to common tangent (CT) method (1 size difference corresponds to 1,5 mm increment in cage width)

Method	Same as CT	1 size (1,5 mm)	2 sizes (3 mm)	3 sizes (4,5 mm)	4 sizes (6 mm)
Parallel Shift (PS)	24	14	5	0	0
«2,1»	20	21	2	0	0
Margo Cranialis (MC)	8	16	13	5	1

er, but still good ICC of 0,809 (against CT) and 0,843 (against PS) (Table 1). The individual plots are displayed in figures 4 to 7, displaying the individual difference to the mean of the compared methods. The lowest difference to the standard method CT was found in the PS method (0,84 mm ± 1,05 mm), followed by «2,1» (0,87 mm ± 0,88 mm) and MC (2,13 mm ± 1,51 mm) (Table 1). The «2,1» and MC methods resulted in smaller cages sizes than the CT and PS methods. The highest cage measurements were recorded with the PS method (9,77 mm ± 2,88 mm), followed by CT (9,28 mm ± 2,64 mm), «2,1» (8,90 mm ± 2,84 mm) and MC (7,64 mm ± 2,45 mm) (Table 2).

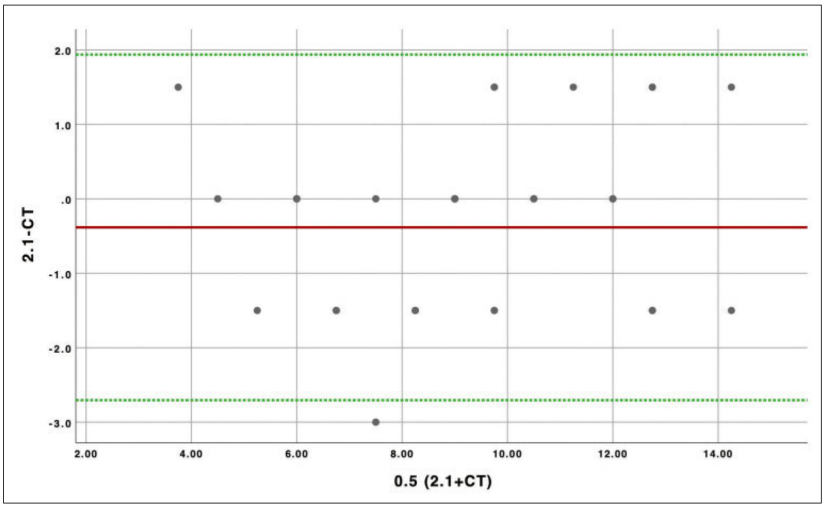

Figure 4: Individual difference between common tangent (CT) and «2,1» method compared to the mean between CT and «2,1» (Bland-Altman-plot). Green lines: 95% confidence intervals.

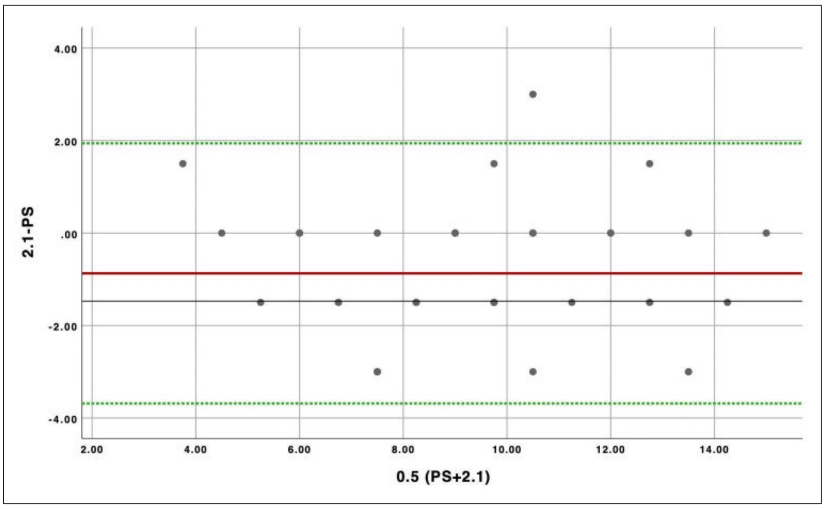

Figure 5: Individual difference between parallel shift (PS) and «2,1» method compared to the mean between PS and «2,1» (Bland-Altman-plot). Green lines: 95% confidence intervals.

Discussion

One of the critical aspects in the determination of the TTA cage width is the femorotibial angle. A radiographic study[8] using femorotibial angles between 146° and 77° in the same dog resulted in a big variance in TTA cage measurements of 15 mm (ranging from 6 mm to – 9 mm). Cage width determination without the use of femorotibial angle is a potential alternative approach. The results of our study will help to overcome this possible source of error, as two methods («2,1» and «MC», respectively) rely on proximal tibia anatomy only. Kinematic studies using fluoroscopy in several breeds are helping to understand this observation.[5,6] They describe, that stifle and tarsal joints do not have a large range of motions during walking, trotting and galloping. Kinematic energy must therefore go into compression of the tibia and adjacent joints. To hold the stifle stable while body weight is loaded onto the stifle, the quadriceps muscle must prevent flexion, thereby pulling on the tibial crest. We assume now, that dogs at risk[19,22] such as those with naturally occurring hyperextension or overweight dogs would generate high load onto the caudal tibial plateau and high tension onto the tibial crest in order to balance the stifle joint. In a puppy, this biomechanical situation would create plastic deformation, which later can be identified as increased tibial slope[14] or small tibial tuberosity width,[7] which both could be found as risk factors in the same dogs suffering from cranial cruciate ligament rupture.[4] The fact that the «2,1» method, using the tibial width as a reference, had a better correlation to the CT and PS methods than the MC method, which is solely based on the length of the margo cranialis, further support the idea that the tibia anatomy reflects the potential for a cruciate ligament deficiency.

The «2,1» and the MC methods simplify the preoperative planning for the surgeon. Not every radiograph is made in the desired femorotibial angulation of 135° according to Lafaver et al.[11] Typical reasons for an insufficient femorotibial angulation are limitations to repeating suboptimal radiographs (radiation protection), unexperienced technicians (not focusing on the correct angulation), or limited range of movement of the patients (osteoarthritis, pain or other anatomic hurdles). Furthermore, breed-specific differences increase the difficulty for reliable measurements. Dogs with physiologically steep hindlimbs, such as Bullterriers or Bulldogs, may have other natural femorotibial angulation than dogs with more flexed hindlimbs such as German Shepherd Dogs.[6]

There was a trend towards smaller cages when using the two new methods. The mean difference of less than 1 mm in the «2,1» method seems to be negligible, as in most cases, the cage size was not affected. The MC method however may result in slightly underestimated

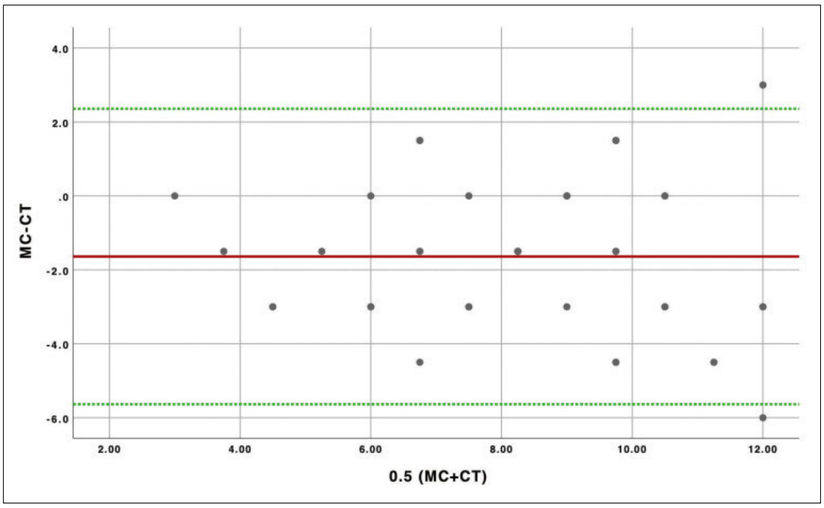

Figure 6: Individual difference between common tangent (CT) and margo cranialis (MC) method compared to the mean between CT and MC (Bland-Altman-plot). Green lines: 95 % confidence intervals.

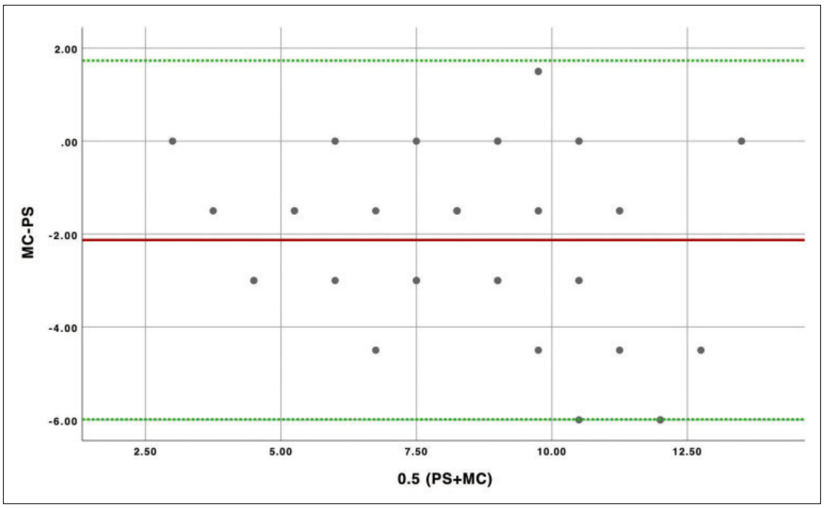

Figure 7: Individual difference between parallel shift (PS) and margo cranialis (MC) method compared to the mean between PS and MC (Bland-Altman-plot). Green lines: 95 % confidence intervals.

cases. This difference could be corrected by a new factor for the MC method (2,0 instead of 1,75) and needs further investigation.

All methods carry some potential for errors. The definition of the femorotibial angle is unknown and executed in different ways. [3,11,12,15] We have chosen a method, which could be used on cropped radiographs and therefore decided to mimic the midline of the femoral endosteal cavity by a simple technique. The PS method is highly dependent on the definition of the axis through the base of the tibial plateau, the femorotibial angle and the determination of the distal patellar pole. The CT method was thought to be an improvement over the PS method. However, interobserver reliability, while determining the angle between tibial plateau and patellar tendon, was poor, while intra observer reliability was moderate.[12] We therefore decided to use only one author to carry out all measurements in the present study. Determining the location of a suitable circle into the tibial and femoral condyles requires some experience, especially when the quality of the radiograph is poor, and the medial and lateral femoral condyle are not superimposed.

In case of circle shift, we used the midpoint of the two femoral condyle circles midpoints. The resulting common tangent is easy to draw. It replaces the line through the tibial plateau used in the PS method and is normally parallel to it. The «2,1» method depends highly on the correct individual measurement of the TPL and TTW. An error of 2 mm in TPL can result in 4 mm under- or overestimation of the cage width. We therefore recommend verifying the «2,1» derived cage width with an alternative measurement. Most difficulties arose from the definition of the tibial plateau endpoint in osteoarthritic patients, or when rotating the tibia about its long axis, when the medial and lateral caudal tibial plateau endpoints had a great distance. Again, we used the midpoint, but we recommend producing perfect mediolateral radiographs of the stifle joint by external rotation of 20° and by lifting the tarsus from the table. The simplest method was the MC, because the margo cranialis is quite clear to identify on mediolateral radiographs and it is not susceptible to errors while positioning the hindlimb for radiographs, unless the tibia is not parallel to the x-ray table.

In conclusion, we were able to demonstrate, that TTA cage width can be determined without full extended stifle joint radiographs. We propose that TTA cage width determination should be performed by two of the described methods in order to increase diagnostic accuracy and to prevent the insertion of suboptimal cages. The newly introduced methods «2,1» and MC must be executed with care, and radiographs retaken, when the landmarks cannot be identified. «2,1» or MC derived cage measurements are slightly underestimated compared to the CT and PS method. Any measurement based on the new methods should be rounded up to the next available cage size. The CT or PS method is always chosen, when extended stifle radiographs are available. If the two measurements match with negligible difference, then the cage size is determined. In case of large differences, e.g. more than 3 mm, measurements should be repeated, a third method used, or the radiograph retaken.

Acknowledgments

The authors declare that there were no conflicts of interest.

Comparaison de quatre méthodes pour déterminer la largeur de la cage dans l'avancement de la *tubérosité tibiale*

L'objectif de cette étude était de tester une méthode pour déterminer la largeur de la cage d'avancement de la tubérosité tibiale (TTA) sans avoir besoin d'extension du grasset, tout en réalisant des radiographies préopératoires. La taille de la cage TTA a été déterminée en appliquant 4 méthodes différentes, utilisant des images radiographiques dans l'axe médiolatéral des grassets complètement étendus de chiens (n = 43), avec et sans pathologie naturelle du ligament croisé antérieur: méthode du décalage parallèle (PS), méthode de la tangente commune (CT), méthode «2,1» (taille de la cage = 2,1 × longueur du plateau du tibia – largeur de la tubérosité tibiale) et méthode de la *margo cranialis* (MC) (taille de la cage = longueur de MC/6*1,75). Deux nouvelles méthodes, «2,1» et MC ont été comparées aux méthodes CT et PS existantes. Les 4 méthodes ont abouti à des tailles de cage fiables. Les coefficients de corrélation intra classe ont montré une excellente fiabilité du CT et du PS avec la méthode «2,1» et une bonne fiabilité vis-à-vis de la méthode MC. En conclusion, la taille de la cage TTA de l'anatomie du tibia seule peut être déterminée sur des radiographies sans qu'il soit nécessaire d'étendre complètement l'articulation du grasset. Sur la base des résultats, deux méthodes différentes de mesure de la taille des cages sont recommandées afin d'augmenter la précision du diagnostic et d'empêcher la mise en place de cages sous-optimales.

Mots clés: Mesure alternative, Cage, Ligament croisé, Chien, Radiologie, TTAe

Confronto di quattro metodi di misurazione per determinare la larghezza della gabbia nell'avanzamento della *tuberosità tibiale*

Lo scopo di questo studio era di testare un metodo per determinare la larghezza della gabbia per l'avanzamento della tuberosità tibiale (TTA) durante un esame radiologico preoperatorio senza dover estendere l'articolazione del ginocchio. Le dimensioni della gabbia TTA sono state determinate con quattro metodi diversi utilizzando radiografie in direzione medio-laterale su articolazioni del ginocchio completamente estese in cani (n = 43) con e senza malattia del legamento crociato craniale. I metodi utilizzati sono: metodo Parallel Shift (PS), metodo Common Tangent (CT), metodo «2,1» (dimensione della gabbia = 2,1 × lunghezza del piatto tibiale – larghezza della tuberosità tibiale) e metodo *Margo cranialis* (MC) (dimensione della gabbia = lunghezza del MC/6*1,75). I due nuovi metodi, «2,1» e MC, sono stati confrontati con i metodi già esistenti CT e PS. Tutti e 4 i metodi hanno ottenuto delle dimensioni affidabili delle gabbie TTA. Il coefficiente di correlazione interclasse ha mostrato un'eccellente concordanza del metodo CT e PS rispetto al metodo «2,1» e una buona concordanza rispetto al metodo MC. In conclusione, la dimensione della gabbia TTA dell'anatomia tibiale può essere determinata dalle sole radiografie senza la necessità di estendere completamente l'articolazione del ginocchio. Sulla base dei risultati, si raccomandano due diversi metodi di misurazione delle dimensioni della gabbia per aumentare l'accuratezza diagnostica e prevenire l'inserimento di gabbie non ottimali.

Parole chiave: misura alternativa, gabbia, legamento crociato, cane, radiologia, TTA

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