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Tibial tuberosity conformation as a risk factor for cranial cruciate ligament rupture in the dog

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Summary
The influence of the tibial tuberosity conformation on cranial cruciate ligament (CrCl) rupture was evaluated and the size of the tibial tuberosity of healthy dogs (group H) was compared with dogs with CrCl rupture (group R) and dogs treated by tibial tuberosity advancement (TTA) (group T). The medio-lateral radiographs of 219 stifle joints were evaluated. Relative tibial tuberosity width (rTTW), proximal tibial tuberosity angle (PTTA), tibial plateau angle (TPA), tibial width (TW) and tibial plateau length (TPL) were measured on each radiograph. Body weight (BW) was measured and relative body weight (rBW) was calculated. The data from group H was compared with that of group R and group T. Group H had significantly larger rTTW, lower BW, lower rBW and smaller PTTA than group R. A comparison of groups H and T showed that dogs from group H were significantly younger, had a lower BW, a lower rBW, a greater PTTA and a smaller rTTW. In each of the comparisons, the TPA and the TW/TPL were not significantly different. The conformation of the canine tibial tuberosity has a significant influence on CrCl rupture. We hypothesized that the smaller the tibial tuberosity width, the larger the cranial tibial thrust, which results in more rapid CrCL degeneration, thus leading to rupture in a younger population of dogs. The rTTW could be a helpful measurement for breeding selection. Only dogs with a rTTW of more than 0.90 should be used for breeding.

Keywords
Tibial tuberosity, cranial cruciate ligament rupture, breeding selection, tibial tuberosity advancement, dog

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Introduction

Rupture of the cranial cruciate ligament (CrCL) is one of the most common causes of hind limb lameness in dogs (1). In contrast to humans, the pathophysiology is not explained by trauma, but rather by degeneration (2–4). A review of the literature reveals many theories about the aetiology, among which are immune-mediated arthropathies (5–7), bodyweight (8, 9), breed predisposition (9), abnormal bone conformation (10–14), genetic factors (3, 8, 9) and the tibial plateau slope (15–17)

In 1978, Henderson postulated that two main forces exist between the femur and tibia: one force being a compressive force acting through the stifle, and the other a sheer force acting parallel to the joint surfaces. The latter force is generated by the gastrocnemius muscles and is counteracted by the CrCL (15). Slocum (17), re-investigated the forces acting around the stifle joint. He concluded that an increased tibial plateau slope increased the load on the CrCL and promoted degeneration and subsequent partial and complete rupture (17). Many authors confirmed his ideas (18–22), however, contradictionary investigations (23, 24) demonstrate that the aetiopathogenesis is still not clearly understood. Slocum's idea concerning the pathogenesis of CrCL rupture led to him to develop the tibia plateau levelling osteotomy surgery (25). In this surgery, the stifle biomechanics are altered in order to reduce the shear forces to nearly zero, thus making the CrCL redundant.

Another group (26) calculated the stifle forces differently than Slocum did, and proposed an advancement of the tibial tuberosity (TTA). The quadriceps muscle was identified as the main force in the stifle joint. Its insertion on the tibial tuberosity is set to 90° by the TTA, thereby neutralizing the cranial tibial thrust. This fact has recently been demonstrated (27, 28).

The fact that the tibial tuberosity geometry influences the stifle biomechanics, as well as the clinical observation that the tibial tuberosities have individual shapes, led us to the hypothesis that dogs with large tibial tuberosities would have a decreased risk of sustaining a CrCL rupture.

The aim of this study was to detect risk factors for cranial cruciate ruptures in the anatomy of the tibial tuberosity. These risk factors could then be used for breeding guidelines. Furthermore, the study should have the potential to be useful in clinical routine situations. Therefore, the investigation was made on routine radiographs of the stifle joint.

Material and methods

Radiographs

The medio-lateral radiographs of 219 stifle joints were evaluated. The radiographs were taken between April 2004 and April 2006. All of the radiographs on which the caudal margin of the medial and lateral tibial condyles were separated less than 4 mm were included in the study.

Radiographic analysis (Fig. 1)

The following points were identified on the medio-lateral radiographs:

- A: most proximal point of the margo cranialis tibiae

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- B: most distal point of the margo cranialis tibiae
- C: most caudal point of the tibial plateau, represented by the midpoint between the medial and lateral tibial condyles
- D: most cranial point of the tibial plateau

The following points, lines and angles were calculated by geometric measures:

- E: cross point of a circle with the center C and the radius CD, and the line AC
- F: cross point of the circle with the center D and the radius 2 x DB, and the cranial border of the tibial cortex
- G: cross point of the circle with the center D and the radius 2 x DB, and the caudal border of the tibial cortex
- Proximal tibial tuberosity angle (PTTA): α, angle formed by DAE
- Tibial plateau angle (TPA): β, angle formed by ACD
- Tibia width (TW): distance between F and G
- Tibial plateau length (TPL): distance between C and D
- Relative tibial tuberosity width (rTTW): AE/EC

The relation of tibial width to tibial tuberosity width was calculated by the quotient TW/AE. The relation of tibial width to the caudal tibial plateau length was calculated by the quotient TW/EC.

The body weight (BW) of each dog was measured and the relative body weight (rBW) was calculated by the quotient BW/TW.

Clinical data collection

The radiographs were assigned to three main groups: healthy dogs (H), dogs with confirmed partial or complete CrCL rupture (R), and dogs with a TTA treatment (T). The diagnosis of the partial or complete CrCL in the R and T groups was made by clinical testing, or by surgical exploration. Subdivision was made into dogs younger than five years (Y), and dogs five years of age and older (O), resulting in six subgroups. Age and body weight (BW) were noted.

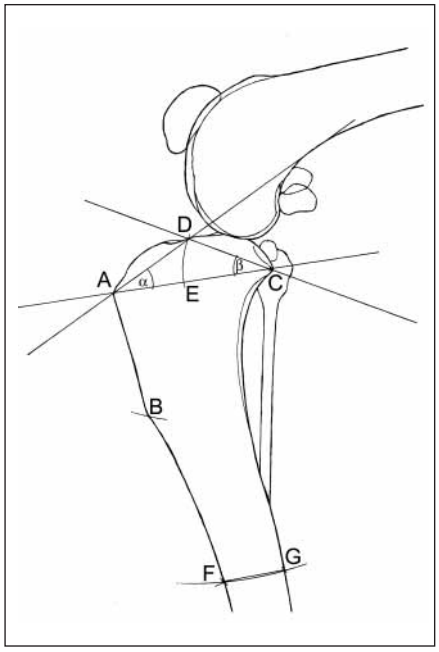

Fig. 1 Schematic illustration of a canine stifle in a medio-lateral view. A: most proximal point of the margo cranialis tibiae; B: most distal point of the margo cranialis tibiae; C: most caudal point of the tibial plateau, represented by the midpoint between the medial and lateral tibial condyles; D: most cranial point of the tibial plateau; E: cross point of a circle with the center C and the radius CD, and the line AC; F: cross point of the circle with the center D and the radius 2 x DB, and the cranial border of the tibial cortex; G: cross point of the circle with the center D and the radius 2 x DB, and the caudal border of the tibial cortex

Statistical analysis

The analysis was performed with StatView 5.1 (SAS: StatView 5.0 Statistical Software, Cary, NC, USA, 2002). A factorial analysis of variance (ANOVA) was calculated. The Bonferroni/Dunn analysis was made for the subgroups HY, HO, RY, RO, TY, TO with the following parameters: BW, age, PTTA, TPA, rTTW, rBW, TW/EC and TW/AE. Level of significance was set to $p < 0.05$ and to $p < 0.0033$ with Bonferroni/Dunn correction.

Results

The data collection is given in Table 1 and the Bunferroni/Dunn analysis in Table 2. The most important differences were as follows: the dogs with stifles from Group H (Fig. 2) had a greater rTTW, a lower BW, a lower rBW, a smaller PTTA, a smaller TW/AE and were younger than those patients from Group R (Fig. 3). A comparison of Groups H and T (Fig. 4) revealed that dogs from Group H had a smaller rTTW, a lower BW, a lower rBW, a greater PTTA, a greater TW/AE and were younger.

In each of the comparisons, there was a lack of significant difference in TPA and TW/EC.

Discussion

The identification of the described anatomical landmarks was easy. The only problem was that the medial and lateral condyles were not superimposed in the radiographic views. We chose the mid-point, between the

Table 1 Group assignment and data collection of radiographs of 219 stifle joints.

Category	Number of cases	BW (kg)	Age (years)	PTTA (°)	TPA (°)	rTTW
H	73	24.5 (4–60)	4.1 (0.7–11.8)	27.6±4.2	33.6±3.7	0.91±0.18
HY	40	25.6 (4–62)	1.8 (0.7–3.8)	27.1±3.5	33.1±4.0	0.92±0.16
HO	33	23.2 (4–65)	7.0 (5–11.8)	28.2±4.9	34.2±3.2	0.90±0.21
R	74	31.9 (4–65)	6.4 (0.7–13)	29.8±3.6	33.7±4.1	0.78±0.14
RY	21	36.1 (7–65)	3.3 (0.7–4.9)	30.4±4.2	35.1±5.3	0.77±0.16
RO	53	30.1 (3–53)	7.6 (5–13)	29.5±3.3	33.1±3.4	0.79±0.13
T	72	34.5 (7.5–65)	6.4 (1.4–13)	24.5±3.1	33.9±4.5	1.07±0.15
TY	19	38.6 (25–65)	3.5 (1.4–4.9)	24.9±3.5	33.8±4.5	1.06±0.14
TO	53	33 (7.5–60)	7.4 (5–13)	24.3±2.9	34.0±4.5	1.08±0.16

Table 2 P-values of the Bonferroni/Dunn variance analysis comparing the groups and subgroups.

Category	BW	Age	PTTA	TPA	rTTW	rBW	TW/EC	TW/AE
H:R	**– 0.0003**	**– 0.0001**	**– 0.0004**	– 0.8978	**+ < 0.0001**	**+ 0.0003**	+ 0.8421	**- < 0.0001**
HY:RY	**– 0.0012**	**– 0.0013**	**– 0.0009**	– 0.0605	**+ 0.0004**	+ 0.0253	– 0.1305	**- < 0.0001**
HO:RO	**– 0.0090**	– 0.0948	– 0.1100	+ 0.2188	**+ 0.0018**	**+ 0.0017**	+ 0.0497	– 0.3119
H:T	**- < 0.0001**	**- < 0.0001**	**+ < 0.0001**	– 0.5871	**- < 0.0001**	**+ < 0.0001**	– 0.2535	**+ 0.0001**
HY:TY	**– 0.0001**	**– 0.0003**	+ 0.0278	– 0.4990	**– 0.0014**	+ 0.0035	– 0.0583	+ 0.3688
HO:TO	**– 0.0003**	– 0.2448	**+ < 0.0001**	– 0.8191	**- < 0.0001**	**+ 0.0001**	+ 0.4478	**+ < 0 0001**

Significant p-values (< 0.0033; Bonferroni correction) are displayed in bold. Positive or negative prefixes indicate whether the first group had higher or lower values.

medial and lateral tibial condyles, in order to determine the caudal point of the tibial plateau.

The method used to measure the TPA in this study differed from other methods employed in the literature (19, 20, 30) as it does not require the determination of the functional axis of the tibia. It was our aim to establish a method to measure TPA that did not require radiograph views of the whole tibia. In conclusion, the TPA was set relative to a horizontal line from the most proximal end of the margo cranialis to the caudal end of the tibial plateau. This angle depends considerably upon the form of the tibial tuberosity and may therefore carry the risk of being influenced by a dependent value. Our conclusion is that the TPA might not be directly comparable to the tibial plateau slope angle as it is traditionally defined (19, 20, 30). We did not find any significant difference in TPAs between the groups. Further studies are warranted in order to validate this method of TPA measurement.

The width of the tibial tuberosity AE was set relative to the distance EC. There were not any significant differences when comparing the quotient of EC:TW. As this quotient can be regarded as constant, the tibial diaphysis and the caudal tibial plateau length are likely to be proportional to one another. The comparison of the

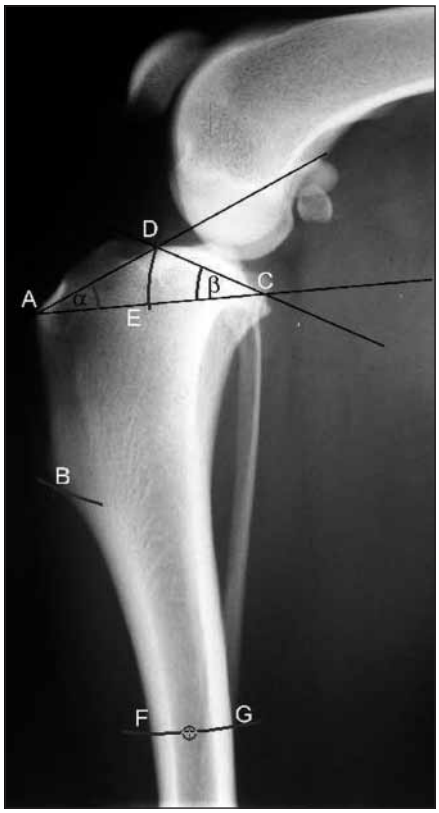

Fig. 2 Medio-lateral radiographic view of stifle of a German Shepherd Dog from Group H. (For legend see Fig. 1). This dog underwent surgery because of a patellar luxation. rTTW = 0.98, PTTA = 25°, TPA = 29°, rBW = 0.55.

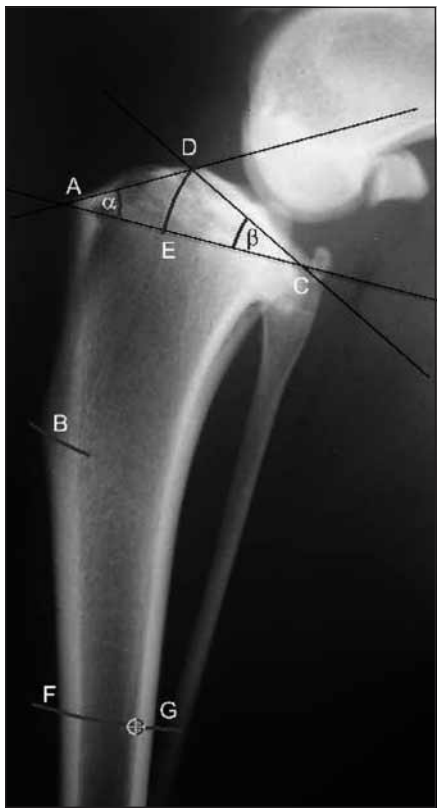

Fig. 3 Medio-lateral radiographic view of stifle of a Great Dane from Group R. (For legend see Fig. 1). This dog had a complete CrCl rupture. rTTW = 0.61, PTTA = 26°, TPA = 25°, rBW = 0.43.

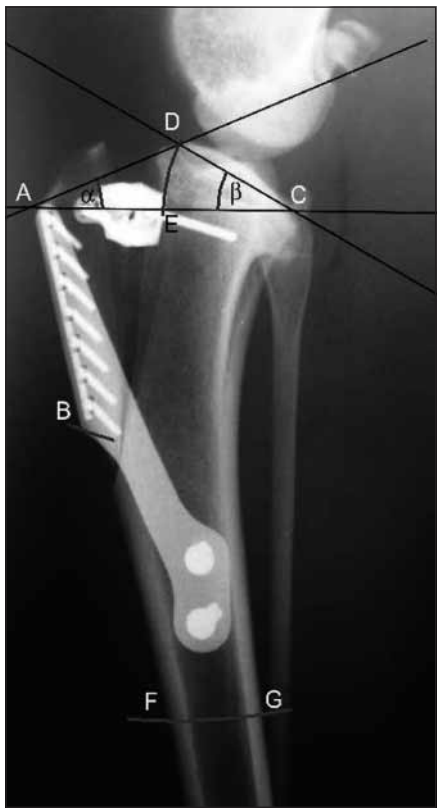

Fig. 4 Medio-lateral radiographic view of stifle of a Great Dane from Group T. (For legend see Fig. 1). This dog had TTA operation because of a complete CrCl rupture. rTTW = 1.04, PTTA = 20°, TPA = 25°, rBW = 0.43.

distances AE with EC or TW revealed significant differences. This means that the tibial tuberosity width varies between individuals.

The most striking result was that rTTW significantly differed between healthy dogs and dogs with a CrCL rupture. The difference was even greater in the group of dogs that were younger than five years of age. This leads to the conclusion that the tibial tuberosity width is a real risk factor. We propose that the smaller the tibial tuberosity width, the larger the cranial tibial thrust will be, and the earlier the dog will get a CrCL rupture. The fact that we did not find any difference in tibial plateau angles between groups supports the notion of advancing the tibial tuberosity to treat the CrCL deficient stifle. The advancement of the tibial tuberosity following TTA, as shown in our data, results in a tibial tuberosity width that is much greater than that which was measured in healthy dogs. This apparant overcorrection of the tibial tuberosity width makes sense, since when the CrCL is no longer present, the tibial tuberosity must be sufficiently advanced enough in order to counteract cranial tibial thrust.

The special anatomical situation and the differences in healthy and CrCL deficient dogs must not be seen alone in its osseous part. The most important function of the tibial tuberosity is to take the force of the quadriceps muscle. Montavon et al. (26) proposed that the direction of this force be changed to about 90° by doing a TTA. These measurements are normally done on radiographs of stifles in maximal extension. It could be argued that the TPLO procedure (29) would do exactly the same if the tibial plateau were to be reduced to an angle perpendicular to the patellar ligament. However, this explanation was never given by these authors, nor by others who were trying to prove the concept of TPLO (18, 20, 21), although it is possibly more correct than levelling the tibial plateau to an angle of 90° to the long axis of the tibia. Further support for this concept comes from a recently published study which showed that a centered osteotomy position is biomechanically more effective than a distal position (30). When measurement of the rTTW has been completed, the centered osteotomy increases the rTTW, whereas a distal osteotomy decreases the rTTW. We conclude that in a centered TPLO it is not only the tibial plateau angle that leads to biomechanical changes in the stifle joint, rather it is the increasing the rTTW which is also important for the success of this operation.

Body weight was another factor which turned out to be a risk factor. However, we did not determine the risk by absolute body weight. We measured BW relative to TW, by which we got a parameter for either overweight in terms of over nutrition, or overweight in terms of an underdeveloped skeleton. Clinical observations support the results of this investigation, because typically dogs that sustain a CrCL rupture are either large or overweight.

This investigation can also be used to develop an alternative method in order to determine the cage size for the TTA method. The original method uses measurements on medio-lateral radiographs of extended stifle joints. The tibial tuberosity advancement is estimated where the patellar ligament would cross the tibial plateau at 90 degrees. However, this method is dependent upon the relative angulation of femur and tibia and is subject to errors when the extended position is not achieved, or when the stifle is subluxated. Our new method relies on the tibia alone and is not influenced by the anatomy of the distal femur, which also affects the direction of the patellar ligament. The results of the present study indicate that the desired advancement is achieved when the rTTW is 1.07.

Mankind has changed the canine remarkably over the past decades. It could be argued that the selective breeding has resulted in oversized dogs with small rTTWs. Indeed, several large breeds have become larger in a very short period of time. It is possible that parts of the skeleton could not develop as fast as it was needed. One of these anatomical structures might be the tibial tuberosity, which remained smaller than the rest of the structures around the stifle joint, thereby reducing the angle of insertion of the patellar ligament and consequently leading to higher loading of the CrCL. The latter would then partially, or eventually even completely, rupture. This hypothesis helps to explain why a lot of giant breed dogs, whose nature would not have made that large (e.g. Italian Mastiffs, Newfoundlands, Rottweilers) are admitted at a very early age with CrCL ruptures. For breeding purposes, a possible recommendation would be that only dogs with a rTTW of more than 0.90 have a decreased risk of sustaining a CrCL rupture.

This investigation revealed that the TTA method is a suitable treatment for CrCL rupture, because it tends to establish a situation closer to that seen in non-affected dogs. Furthermore, the breeding from dogs that have a rTTW of more than 0.9 may lessen the risk of sustaining a CrCL rupture.

References

1. Vasseur PB. Stifle joint. In: Slatter D (ed). Textbook of small animal surgery. Philadelphia: W.B. Saunders, 1993, pp 1817–1865
2. Moore KW, Read RA. Cranial cruciate ligament rupture in the dog--a retrospective study comparing surgical techniques. Aust Vet J 1995; 72: 281–285.
3. Vasseur PB, Pool RR, Arnoczky SP et al. Correlative biomechanical and histologic study of the cranial cruciate ligament in dogs. Am J Vet Res 1985; 46: 1842–1854.
4. Beck P, Montavon PM. Was diagnostizieren Sie? Welche Behandlung schlagen Sie vor? Schweizer Arch Tierheilkunde 1987; 129: 493-495.
5. Galloway RH, Lester SJ. Histopathological evaluation of canine stifle joint synovial membrane collected at the time of repair of cranial cruciate ligament rupture. J Am Anim Hosp Assoc 1995; 31: 289–294.
6. Lawrence D, Bao S, Canfield PJ et al. Elevation of immunoglobulin deposition in the synovial membrane of dogs with cranial cruciate ligament rupture. Vet Immunol Immunopathol 1998; 65: 89–96.
7. Niebauer GW, Wolf B, Bashey RI et al. Antibodies to canine collagen types I and II in dogs with spontaneous cruciate ligament rupture and osteoarthritis. Arthritis Rheum 1987; 30: 319–327.
8. Duval JM, Budsberg SC, Flo GL et al: Breed, sex, and body weight as risk factors for rupture of the cranial cruciate ligament in young dogs. J Am Vet Med Assoc 1999; 215: 811–814.
9. Whitehair JG, Vasseur PB, Willits NH. Epidemiology of cranial cruciate ligament rupture in dogs. J Am Vet Med Assoc 1993; 203: 1016–1019.
10. Aiken SW, Kass PM, Toombs JP: Intercondylar notch width in dogs with and without cranial cruciate ligament injuries. Vet Comp Orthop Traumatol 1995; 8: 128–132.
11. Read RA, Robins GM. Deformity of the proximal tibia in dogs. Vet Rec 1982; 111: 295–298.
12. Selmi AL, Padilha Filho JG. Rupture of the cranial cruciate ligament associated with deformity of the proximal tibia in five dogs. J Small Anim Pract 2001; 42: 390–393.

13. Shelbourne KD, Davis TJ, Klootwyk TE: The relationship between intercondylar notch width of the femur and the incidence of anterior cruciate ligament tears. A prospective study. Am J Sports Med 1998; 26: 402–408.
14. Osmond CS, Marcellin-Little DJ, Harrysson OL et al. Morphometric assessment of the proximal portion of the tibia in dogs with and without cranial cruciate ligament rupture. Vet Radiol Ultrasound 2006; 47: 136–141.
15. Henderson RA, Milton JL. The tibial compression mechanism: a diagnostic aid in stifle injuries. J Am Anim Hosp Assoc 1978; 14: 474–479.
16. Nisell R. Mechanics of the knee. A study of joint and muscle load with clinical applications. Acta Orthop Scand 1985; (Suppl) 216: 1–42.
17. Slocum B, Devine T. Cranial tibial thrust: a primary force in the canine stifle. J Am Vet Med Assoc 1983; 183: 456–459.
18. Baroni E, Matthias RR, Marcellin-Little DJ et al: Comparison of radiographic assessments of the tibial plateau slope in dogs. Am J Vet Res 2003; 64: 586–589.
19. Morris E, Lipowitz AJ. Comparison of tibial plateau angles in dogs with and without cranial cruciate ligament injuries. J Am Vet Med Assoc 2001; 218: 363–366.
20. Reif U, Hulse DA, Hauptman JG. Effect of tibial plateau leveling on stability of the canine cranial cruciate-deficient stifle joint: an in vitro study. Vet Surg 2002; 31: 147–154.
21. Reif U, Probst CW. Comparison of tibial plateau angles in normal and cranial cruciate deficient stifles of Labrador retrievers. Vet Surg 2003; 32: 385–389.
22. Zeltzman PA, Pare B, Johnson GM et al. Relationship between age and tibial plateau angle in dogs with cranial cruciate rupture. J Am Anim Hosp Assoc 2005; 41: 117–120.
23. Venzin C, Howard J, Rytz U et al. Tibial plateau angles with and without cranial cruciate ligament rupture. Vet Comp Orthop Traumatol 2004; 17: 232–240.
24. Wilke VL, Conzemius MG, Besancon MF et al: Comparison of tibial plateau angle between clinically normal Greyhounds and Labrador Retrievers with and without rupture of the cranial cruciate ligament. J Am Vet Med Assoc 2002; 221: 1426–1429.
25. Slocum B, Devine T. Cranial tibial wedge osteotomy: a technique for eliminating cranial tibial thrust in cranial cruciate ligament repair. J Am Vet Med Assoc 1984; 184: 564–569.
26. Montavon PM, Damur DM, Tepic S. Advancement of the tibial tuberosity for the treatment of cranial cruciate deficient canine stifle. In: Proceedings of the 1st World Orthopedic Veterinary Conference, Munich 2002, pp. 152.
27. Miller JM, Shires PK, Lanz OI et al. Effect of 9 mm tibial tuberosity advancement on cranial tibial translation in the canine cranial cruciate ligament-deficient stifle. Vet Surg 2007; 36: 335–340.
28. Apelt D, Kowaleski MP, Boudrieau RJ. Effect of tibial tuberosity advancement on cranial tibial subluxation in canine cranial cruciate-deficient stifle joints: an in vitro experimental study. Vet Surg 2007; 36: 170–177.
29. Slocum B, Slocum TD. Tibial plateau leveling osteotomy for repair of cranial cruciate ligament rupture in the canine. Vet Clin North Am Small Anim Pract 1993; 23: 777–795.
30. Kowaleski MP, Apelt D, Mattoon JS et al. The effect of tibial plateau leveling osteotomy position on cranial tibial subluxation: an in vitro study. Vet Surg 2005; 34: 332–336.

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