Theoretical discrepancy between cage size and efficient tibial tuberosity advancement in dogs treated for cranial cruciate ligament rupture

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Keywords
Maquet, TTA, tibial tuberosity advancement, trigonometry

Summary
Objectives: To calculate the difference between the desired tibial tuberosity advancement (TTA) along the tibial plateau axis and the advancement truly achieved in that direction when cage size has been determined using the method of Montavon and colleagues. To measure the effect of this difference on the final patellar tendon-tibial plateau angle (PTA) in relation to the ideal 90°.

Methods: Trigonometry was used to calculate the theoretical actual advancement of the tibial tuberosity in a direction parallel to the tibial plateau that would be achieved by the placement of a cage at the level of the tibial tuberosity in the osteotomy plane of the tibial crest. The same principle was used to calculate the size of the cage that would have been required to achieve the desired advancement. The effect of the difference between the desired advancement and the actual advancement achieved on the final PTA was calculated.

Results: For a given desired advancement, the greater the tibial plateau angle (TPA), the greater the difference between the desired advancement and the actual advancement achieved. The maximum discrepancy calculated was 5.8 mm for a 12 mm advancement in a case of extreme TPA (59°). When the TPA was less than 31°, the PTA was in the range of 90° to 95°.

Clinical significance: A discrepancy does exist between the desired tibial tuberosity advancement and the actual advancement in a direction parallel to the TPA, when the tibial tuberosity is not translated proximally. Although this has an influence on the final PTA, further studies are warranted to evaluate whether this is clinically significant.

Introduction
In 2002, Tepic first postulated that tibial tuberosity advancement could neutralise the cranially directed stifle shear forces (cranial tibial thrust) responsible for cranial tibial subluxation during weight bearing in dogs affected by cranial cruciate ligament (CrCl) rupture (1). The rationale for tibial tuberosity advancement (TTA) is based on the assumption that the tibiofemoral compressive force is in the same direction as the patellar tendon force (1). The aim of the TTA is to modify the angle between the patellar tendon and the tibial plateau by advancing the tibial tuberosity. The new position is achieved by an osteotomy of the tibial crest and the insertion of a space-occupying titanium cage in the osteotomy site. Cages are currently available in the following four sizes: 3 mm, 6 mm, 9 mm and 12 mm. Stabilisation is achieved with a dedicated titanium plate that attaches to the tibial crest with a multi-pronged fork and to the tibial diaphysis with screws. Preoperative measurements made on radiographs aim to create a final patellar tendon-tibial plateau angle (PTA) of 90° (2). This is measured with the stifle at an angle of 135° simulating the midstance phase of the gait cycle as determined by kinematics analysis (3). If the PTA is less than 90° a causal tibial thrust is generated and if PTA is more than 90° a cranial tibial thrust is generated (1, 2, 4). Mean PTA before TTA was reported as approximately 100° (5). Failure to decrease this angle to 90° may jeopardise the result of the surgery, as a cranial tibial thrust would persist (4). Initial clinical studies report very promising results for TTA procedures, similar to those obtained with tibial plateau levelling osteotomy (TPLO) (5).

A transparency is used to plan the advancement required in a direction parallel to the tibial plateau (Fig. 1). However the plane of the tibial crest osteotomy is not perpendicular to the tibial plateau, and with limited proximal translation of the tibial crest, the actual advancement of the tibial tuberosity in a direction parallel to the tibial plateau is less than desired. The goal of this study was to explore the difference between the desired and achieved tibial tuberosity advancements, and to explore the discrepancy between the final PTA and the goal of 90°.
Material and methods

All evaluations were theoretical. No case material was evaluated.

Assumptions and definitions

‘Desired advancement’ refers to the size of the advancement that would have been chosen in a hypothetical clinical case by using the standard transparency method.

‘Actual advancement’ refers to the tibial tuberosity advancement that would actually be achieved in a direction parallel to the tibial plateau.

It was assumed that the tibial osteotomy was parallel to the tibial mechanical axis, that there was no proximal translation of the tibial crest but rather that the crest rotated around its distal extremity, and that the cage of the desired size was inserted at the level of the patellar tendon insertion on the tibial tuberosity.

The length of the patellar tendon (PTL) for use in the trigonometry was defined as the distance between the tibial tuberosity and the most distal pole of the patella.

Calculation of the actual tibial tuberosity advancement achieved by placing a given cage

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Calculation of the discrepancy in the final tibial plateau-patellar tendon angle caused by under advancement of the tibial tuberosity

In Figure 3, AD is the desired advancement (►Fig. 3A) and AB is the actual advancement mentioned previously (►Fig. 3B). The discrepancy between the ideal PTA of 90° and that which is actually achieved is angle DCB and is designated angle DCB (►Fig. 3C).

- Tangent DCB = DB/CD.
- CD is the PTL and DB = AD – AB.
- So DCB = tangent⁻¹((AD – AB)/PTL).

That is, the discrepancy in the final PTA = tangent⁻¹((desired advancement – actual advancement)/PTL). It was previously shown that actual advancement = cosine TPA x desired advancement.

Thus:
- discrepancy in final angle = tangent⁻¹(1-cosine TPA) x desired advancement.

If the TPA, the desired advancement and the PTL are known, then the discrepancy in the final PTA which would be achieved can be calculated. This was done for a range of PTL from 20 mm (corresponding to the smallest patients in which the authors would consider doing a TTA procedure) to 70 mm (corresponding to the longest PTL that the authors have encountered in clinical practice, which was in a Great Dane). The calculations were made assuming a TPA of 16° as this represents the minimum TPA reported in a large study of dogs with cranial cruciate ligament rupture (10).

Results

Actual tibial tuberosity advancement achieved by placing a given cage

The results are displayed in ►Table 1. The greater the TPA, the greater the difference between the desired advancement and the actual advancement. This discrepancy was 5.8 mm for a 12 mm advancement in a case of extreme TPA.

The actual advancement necessary to achieve the desired tibial tuberosity advancement in the direction of the tibial plateau (last column of ►Table 1) was derived for cage sizes of 3–12 mm over a range of TPA and results are presented in ►Figure 4. For example, for an advancement measured at 6 mm with the transparency in

<table>
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<th>Desired advancement (A’D’)</th>
<th>Tibial plateau angle (°)</th>
<th>Actual advancement (AB)</th>
<th>Difference between A’D’ and AB</th>
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a dog with a TPA of 49°, the cage required to reach a 6 mm advancement along the tibial plateau axis would be a 9 mm cage.

The discrepancy in the final tibial plateau-patellar tendon angle caused by under advancement of the tibial tuberosity

Considering cages of 3–12 mm and PTL of 20–70 mm gave a desired advancement: 

PTL ratio ranging from 0.04–0.6 ( Appendix 1: Available online at www.vcot-online.com). Figure 5 illustrates the discrepancy of the PTA as a function of the TPA for this range of desired advancement: PTL ratios. Therefore, with knowledge of the TPA, the PTL and the desired advancement of the tibial tuberosity, the discrepancy in the final PTA can be evaluated. Where TPA is less than 31°, the discrepancy in final PTA angle was less than five degrees.

Fig. 5 Discrepancy in final tibial plateau-patellar tendon angle (PTA) as a function of tibial plateau angle (TPA) knowing the desired advancement/length of patellar tendon (PTL) ratio. Desired advancement/PTL can be easily calculated or approximated using Appendix 1 (Available online at http://www.vcot-online.com). This value is used to know which curve to read, then the discrepancy is simply read as a function of TPA.

Discussion

The rationale for the TTA is based on the assumption that the tibiofemoral compressive force is in the same direction as the patellar tendon force (1). A crossover point was reported at a PTA of approximately 90° (1, 2, 4). If the PTA is less than 90°, a caudal tibial thrust is generated, and if PTA is more than 90°, a cranial tibial thrust is generated. Preoperative measurements made on radiographs plan to create a final PTA of 90° with the stifle at 135° which reflects the midstance phase angle of the gait cycle as determined by kinematics analysis (3). Mean preoperative PTA was reported as approximately 100° (7). Failure to decrease this angle to 90° may jeopardise the result of the surgery as this would leave a cranial tibial thrust (4). The final PTA depends on many factors related to tibial conformation. This study provides a better understanding of the role of the TPA in the final PTA. The transparency commonly used to assess the size of the implants leads to an underestimation of the necessary advancement of the tibial tuberosity. The fact that the actual advancement achieved is shorter than the desired advancement leads to insufficient advancement of the tibial tuberosity, hence a final PTA superior to 90° at 135° of stifle extension. The greater the TPA, the more severe is the underestimation. This may explain why it was anecdotally proposed that TPA >30° are not best suited for TTA (11). However the significance of postoperative PTA differing from the intended 90° has not been evaluated. Hoffman et al. reported a final PTA of 95.5° and clinical outcome was comparable to other TTA studies (7, 12–14). This result suggests that an undercorrection of the PTA of less than five degrees may not significantly affect the long-term outcome. It is probable that in many cases, a tibial tuberosity advancement close to 90° may be sufficient to adequately neutralise the tibio-femoral shear forces, but in some dogs this may be more critical (15). However, a suboptimal PTA will leave an instability that may explain the high rate (approximately 22%) of subsequent meniscal tear reported with TTA without meniscal release performed (5, 12). Based on our findings, with a TPA up to 30°, the discrepancy in final

Fig. 4 Advancement necessary as a function of tibial plateau angle (TPA) depending on preoperative measurement based on the transparency. The four curves correspond to the four sizes of cage commercially available. As an example, with a TPA of 49°, if the transparency reads 6 mm, a 9 mm cage should be placed at the level of the tibial tuberosity in order to reach the advancement required.

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PTA cannot reach five degrees. Large clinical studies to evaluate the true effect of the PTA must be conducted before drawing conclusions on the clinically acceptable range of final PTA.

Another point to consider is the tibial tuberosity conformation. The patellar tendon may insert more distally on the tibial crest in some dogs (7). Current recommendations are to place the titanium cage at the proximal extent of the osteotomy (2–3 mm from the proximal tibial bone margin) (5). By doing so, in some cases with low patellar tendon insertion, the cage will be placed higher than the tibial tuberosity, meaning that the advancement at the level of the tibial tuberosity will be less than expected. This point is easily corrected by displacing the cage distally at the level of the tibial tuberosity. In this study, the assumption was made that the cage was placed at the level of the tibial tuberosity.

Some may be tempted to displace the cage distally to the level of the tibial tuberosity. However, it has been advocated that a segment of unsupported bone proximal to the cage may predispose the tibial tuberosity proximal to the cage to fracture (15). Therefore great care should be taken in displacing the cage distally to correct the effect of excessive TPA, as lack of caudal support to the tibial tuberosity may cause a stress riser just proximal to the cage, resulting in tibial crest fracture (15). If the cage is displaced distally, the amount of displacement should be accurately evaluated and mechanical support should be provided caudal to the tibial tuberosity as described in four dogs with excessive tuberosity advancement (15).

Another source of inaccuracy is the variability in preoperative measurements. Variabilities have been extensively described in the measurement of the TPA, but no studies have investigated inter- and intraobserver measurement variability when assessing preoperative planning for TTA (16–18).

The authors recognize the inherent limitations in the theoretical evaluations presented here. The trigonometry is only valid if the tibial crest is not translated proximally during the advancement of the tibial tuberosity. Indeed, when the tibial crest is translated as recommended this will decrease the final PTA (2, 5). This statement is said to compensate for the distal displacement of the patella induced by TTA. To our knowledge, no study has described the consequences of the displacement of the patella after TTA and the need to correct this factor has yet to be proven. No publication has addressed the effect of the tibial crest translation on the final PTA.

The changes in the biomechanics of the stifle cannot be reduced to the simple advancement of the tibial tuberosity influenced by the tibial plateau. As well as the influence of the TPA on the advancement achieved, other parameters must be considered to properly assess the efficacy of the TTA including proximo-distal displacement of the patella, translation of the femur relative to the tibia, the tibia-ground angle, limb conformation, muscular strength and stifle flexion/extension during weight bearing.

In conclusion, we have discussed the discrepancy that exists between the desired tibial tuberosity advancement as measured preoperatively and the actual advancement of the tibial tuberosity after placement of the cage. Until further studies demonstrate the possible correlation between the final PTA and the clinical outcome of the patients, it is impossible to precisely determine the PTA values that would preclude or favour a good clinical function after cranial cruciate ligament rupture.

The data presented in this study are a prerequisite to calculate precisely the amount of proximal translation of the tibial tuberosity needed in order to reach a postoperative PTA = 90°.

References