MANAGING SAGITTAL PLANE DEFORMITIES OF THE STIFLE JOINT: OSTEOTOMY DECISION-MAKING AND THE EFFECT ON QUADRICEPS MECHANISM LOAD

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Proximal tibial and distal femoral osteotomies and ostectomies are commonly performed in dogs to manage disease associated with the cranial cruciate ligament and to treat patella luxation (1–21). Complications have been reported for all techniques, some of which are directly consequent to the effect of distalising the position of the tibial tuberosity. Despite this there is relatively little information detailing the effect of these various osteotomies on quadriceps mechanism load and stifle joint contact mechanics.

The patella is a complex fulcrum acting in a pulley (the trochlea) that increases the moment arm of the stifle extensor mechanism particularly in the early stages of flexion. The patella and the stifle extensor mechanism function as Type 1 and Type 3 levers and modeling stifle joint function throughout the range of motion is difficult (22,23).

Any procedure that distalises the tibial tuberosity (TT) increases the working length of the quadriceps mechanism and so must increase the load in the quadriceps mechanism (37). Distalising the TT distalises the insertion of the quadriceps tendon, increasing the length that the quadriceps mechanism works over. The quadriceps mechanism has been likened to a cable and spring albeit a minimally distensible spring. In this analogy the patella tendon is the “cable” which has little capacity for distension without damage and the quadriceps muscles are the “spring”. How quickly the “spring” can stretch when the quadriceps is lengthened is unknown. Clinical experience would suggest that adaptive lengthening of the muscle bellies is a slow process. Anecdotal clinical reports and experience of complications following “extreme” distalisation (>50% of patella length) would suggest compensatory stretching does not occur at least in the short to medium term. Limitations in the capacity of myotendinous units to elongate is well recognized (51,52). Compensatory stretching of flexor tendons during distraction osteogenesis may not occur without ongoing physical therapy (53).

The effect of distalising the TT by a “small” amount is readily compensated by the animal extending the stifle joint and either “lifting” the hip or circumducting the limb on the swing phase to avoid foot strike by the extended limb. In small distalisations, this compensation is often not apparent. In larger distalisations, the compensatory stance and gait is readily apparent. It is reasonable to consider that the consequence of major distalisation is significant morbidity consequent to the forced stifle joint extension and tension within the quadriceps, and the potential for pathologic change in the patella tendon, implant failure and/or fracture of the patella, tibia, or tibial tuberosity.

Distalisation of the TT can be relatively measured as a ratio of the proximo-distal length of the patella. Drew (2017) in an instrumented limb-press ex-vivo

model showed that distalisation of the TT by as little as 5% of the length of the patella significantly increased quadriceps mechanism load above baseline. Tuberosity distalisation of 20% of the proximodistal length of the patella increased load > 1.75 times the pre-distalisation baseline load.

In the same study, Drew showed that concurrent shortening of the femur by transverse ostectomy of 0.5 – 1.0 times the length of the distalisation of the TT normalized the increased load created by TT distalisation. The recommendation from that study was to shorten the femur by 80% of the length of the TT distalisation if distalisation of the TT was >50-70% of the patella length.

Why does femoral shortening reduce or normalize the increased load in the quadriceps mechanism caused by TT distalisation? Tuberosity distalisation moves the insertion of the quadriceps mechanism distally, thereby lengthening the quadriceps. Shortening the femur brings the origin of the three vastus muscles of the quadriceps closer to the insertion point and thereby reduces the working length of the quadriceps.

Distalization of the tibial tuberosity has been recommended to establish proximodistal alignment of the stifle extensor mechanism with the underlying femur in dogs affected with patella luxation due to patella alta (relatively proximal location of the patella). Pugliese (2015) reported on 11 stifles with patella alta managed with TT distalisation (mean distalisation 14mm; range 9-20mm) stabilized with TTA implants as a tension band. No TT avulsion or implant complications were reported. All cases had PT thickening apparent on radiographs at 8 weeks post-surgery (50).

Drew et al (2018) reported 2 major patella alta cases causing MPL in Flat Coat Retrievers where the TT was distalised 11mm and 13mm. In each case the femur was shortened by a transverse mid-diaphyseal ostectomy of the same length as the TT distalisation. Resolution of the patella luxation and normal function was achieved.

TPLO has been theorized to increase PT load however no published data supports this (7,35). Drew (2018) in an ex-vivo cadaveric model reported no change in stifle extensor mechanism load following TPA rotation to 6^0 and after over-rotation to 1^0 with TPLO compared to prior to rotation. They concluded that TPLO did not significantly alter PT load at either a neutralized or over-rotated tibial plateau angle (33).

TTA has been reported to significantly decrease PT load in a limb press model (36). Some doubt exists over the validity of this conclusion. In this model a load cell and spring were placed in series within the quadriceps turnbuckle and the distal part of the TT was fixed in a proximo-distal position with a hinge. The load experienced by the spring was calculated using Hooke's law of elasticity from the elongation of the spring measured radiographically. The spring load was then subtracted from the load measured by the load cell to determine the "true" PT load. However, as the spring and the load cell were in series, they were each subject to the same load.

Consequently subtracting the spring load from the load measured by the load cell could only erroneously result in a zero load measurement, which was the result of this study (36).

CBLO is a modification of TPLO that levels the TPA and moves the TT cranially and distally (6,21). Use of a headless compression screw (HCS) to compress the TT to the distal tibia reduced “rock back” and loss of TPA reduction compared to CBLO without HCS presumably by better neutralizing the PT load (6,21).

Cranial closing wedge osteotomy (CCWO) causes craniodistal movement of the tibial crest distalising the patella (7,13,37,38). Distalisation results in increased PT load (1,8,37). Unlike CCWO, TPLO does not change the position of the tibial crest or the patella (1). CCWO combined with TPLO has been reported for managing cruciate instability in dogs with excessive tibial plateau angles (eTPA). In a retrospective study of 18 stifle joints complications were reported in 78% of cases overall with PT thickening noted in 61% of cases and implant loosening or breakage in 28%. Despite this, long-term clinical outcome was very good. These cases had longer healing times and a higher complication rate than TPLO cases alone (1). This is not surprising considering the increased PT load resulting from TT distalisation resulting from CCWO (7,13,37).

It is important to recognize that distalisation of the tibial tuberosity significantly increases load in the quadriceps mechanism and may not be a benign procedure. Distalisation of the tibial tuberosity also distalises the patella relative to the trochlea groove.

In cases where tuberosity distalisation is >50-70% of the proximodistal length of the patella, and in other cases where distalisation is <50% but a femoral ostectomy is being performed as part of an angular or torsional correction of the femur, consideration is given to shortening the femur by 0.8 (0.5-1.0) x the distance that the tuberosity is distalised.

Should we be concerned with apparent distal patellar tendon “thickening” commonly seen in follow-up radiographs of proximal tibial osteotomy cases?

Patellar tendon (PT) thickening was initially thought to be a particular problem of TPLO however has now been identified in all of the proximal tibial osteotomies. PT thickening has been reported ranging from 0.3-80% after TPLO and 24-88% after tibial tuberosity advancement (TTA) and modified TTA (mTTA) (11,24–29).
Cora-based leveling osteotomy (CBLO) has been recently described. In 2 CBLO retrospectives, PT thickening was not identified however in each paper the single lateral radiograph documenting bone union showed distal PT thickening (6,21).
Similarly, PT thickening was not mentioned as an outcome assessment in 3 retrospective studies of cruciate disease dogs treated with triple tibial osteotomy (TTO). Patellar tendonitis was identified in 3% of cases in one of

these studies and the image quality in each paper did not allow assessment of PT thickening on any reproduced postoperative radiographs. (4,16,30).
Some confusion still exists over the difference between PT or parapatellar thickening and true patellar tendonitis. Differentiation of the PT from the surrounding soft tissues is difficult without advanced imaging (31). The majority of dogs reported with PT thickening did not have lameness or pain so the diagnosis of apparent tendonitis is questionable (25,31,32). Causes originally proposed for thickening included altered tendon biomechanics and/or exuberant patient activity placing excessive loads on the PT and / or surgical trauma to the tendon either from the saw or from temporary K wire placement, (24,25,32).
Pacchiana (2003) reported PT thickening in 5% of dogs post TPLO and tendonitis in 0.05% of dogs assessed with radiographs. Carey (2005) reported tendon thickening in 80% of dogs and tendonitis in 7% of cases also assessed radiographically. Mattern (2006) identified postoperative thickening in 29 /29 dogs radiographically 1 month postoperatively and in 13/31 on ultrasound at 1 month and in 3/13 at 6 months respectively. No correlation with lameness was reported and variable outcomes associated with individual surgical technique are possible (31).
Whether PT thickening should be classified as a complication following tibial osteotomies has been questioned (11,27,29). Many now consider this to reflect fibrous change involving the fat pad and retinaculum rather than true pathological change in the tendon (27,33).
Increased PT load post TPLO has been implicated as a possible cause of patella tendon fracture. Patellar fracture has been reported in 1/94 dogs, 1/397 dogs and in 6/305 dogs following TPLO (25,32,34). Relative “over-leveling” of the tibial plateau angle has been proposed as a possible cause of patella tendon thickening and patellar fracture (31,34)
The progressive reduction in thickening over time as activity levels and stifle loading increase would suggest however that PT load change is not a causal factor. Furthermore the identification of change predominantly in the distal PT would suggest surgical damage rather than a biomechanical cause as load would be expected to be distributed evenly along the length of the tendon (31).

Learning summary - key points:

- The biomechanics of the stifle extensor mechanism and the effects of the various tibial osteotomies are complex. Distalisation of the tibial tuberosity causes significantly increased load in the quadriceps mechanism which may be associated with increased complications when the magnitude of the distalisation is large.

- Distalisation of the tibial tuberosity will distalise the patella within the femoral trochlea and may be useful as a component of surgical treatment of patella alta.

- Concurrent femoral shortening by transverse ostectomy effectively distalises the origin of the quadriceps muscle relative to the stifle joint

and tibial tuberosity. Femoral shortening between 0.5-1.0 times the amount of tibial tuberosity distalisation normalizes the increased load caused by tibial tuberosity distalisation.

- Where “major” distalisation of the tibial tuberosity of >50-70% of the length of the patella is necessary, consideration should be given to concurrent femoral shortening by 0.8 times the amount of TT distalisation.

- There are 2 main indications for femoral shortening:

    - surgical treatment of patella alta where the intent is to distalise the patella within the trochlea and the distalisation is >50-70% of the proximodistal length of the patella

    - proximal tibial osteotomies and ostectomies that result in “major” distalisation of the tibial tuberosity >50-70% of the proximodistal length of the patella

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