Force plate gait analysis to assess limb function after tibial tuberosity advancement in dogs with cranial cruciate ligament disease

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Summary
Objective: To assess functional outcome in dogs with cranial cruciate ligament (CrCL) disease after tibial tuberosity advancement (TTA) using force plate gait analysis, and to evaluate parameters potentially influencing outcome. Study design: Prospective clinical study. Animals: Consecutive clinical patients (n = 37) with CrCL-deficient stifles (n = 40). Methods: The stifle joints were examined arthroscopically prior to TTA. Meniscal release was not performed if the medial meniscus was intact. Open medial arthrotomy and partial meniscectomy were performed in the presence of meniscal tears. Vertical ground reaction forces were measured preoperatively and at follow-up examinations four to 16 months postoperatively (mean: 5.9 months). The ground reaction forces of a group of 65 healthy dogs were used for the comparison. The potential effects of clinical parameters on functional outcome were evaluated statistically. Results: Complete CrCL rupture was identified in 28 joints, and partial CrCL rupture in 12 joints. The medial meniscus was damaged in 21 stifles. Vertical ground reaction forces were significantly higher at follow-up (P < 0.01), but remained significantly lower than those of control dogs (P < 0.01). Complications were identified in 25% of joints, and the dogs with complications had significantly lower peak vertical forces at follow-up than the dogs without complications (P = 0.04). Other clinical parameters did not influence outcome. Conclusions: Tibial tuberosity advancement significantly improved limb function in dogs with CrCL disease, but did not result in complete return to function. Complications adversely affected functional outcome. Clinical significance: A return to a function of approximately 90% of normal can be expected in dogs with CrCL disease undergoing TTA.

Keywords
Stifle, tibial tuberosity advancement, cranial cruciate ligament, force plate gait analysis, function

Introduction
The tibial tuberosity advancement (TTA) technique for the treatment of cranial cruciate ligament (CrCL) deficient stifle joints was first introduced in 2002 (1). The TTA procedure is based on the theory that the angle between the tibia plateau and the patellar ligament influences the production of tibio-femoral shear forces during limb loading, and that there is no shear force component if the angle between the tibial plateau and the patellar ligament is 90° (2). The angle between the tibial plateau and the patellar ligament is dependent on the degree of stifle joint flexion (3). In an extended stifle joint, this angle is larger than 90°, resulting in a cranially directed shear force. With progressive flexion of the stifle joint, it gets continuously smaller until it is less than 90°, which then results in a caudally directed shear force (3). With TTA, the tibial tuberosity is advanced cranially in order to achieve a perpendicular angle between the patellar ligament and the tibial plateau with the stifle joint in extension (2–4). A special tension band plate and a cage placed into the tibial osteotomy gap are used in order to maintain advancement. The plates are available in seven different sizes, and the cages come in four different widths and different lengths, thus allowing adjustment of the necessary degree of advancement of the tibial tuberosity in different sizes of dogs. The implants and surgical technique have been described (4).

The effectiveness of TTA in reducing or eliminating cranial shear forces in the CrCL deficient stifle has been documented in experimental settings (5, 6), and two reports on clinical outcome after TTA have recently been published (4, 7). These retrospective descriptive studies have reported a good clinical outcome, based on the assessment of owner satisfaction (4, 7). Eighty-three percent of owners reported a marked improvement or a return to full function in one of the studies (4), and 90% of owners judged clinical outcome as ‘good’ or ‘excellent’ in the other report (7). Clinical outcome after tibial plateau levelling osteotomy (TPLO) has also been evaluated in several studies involving large numbers of dogs, and similarly good clinical outcomes and owner satisfaction were reported (8–11).

Force plate gait analysis provides a more objective method of evaluation of limb function than clinical gait examination or assessment of owner satisfaction. It has been used to assess limb function after TPLO (12, 13), but to our knowledge has not yet been performed after TTA. Force plate results indicated a return to full function in six dogs with experimental transection of the CrCL after TPLO in one study (12). However, in another study where a large number of clinical patients with CrCL disease were evaluated, TPLO resulted in a significant improvement of vertical ground reaction forces compared to preoperatively, but the patients did not return to full function in comparison to a control group (13).

The aim of this prospective clinical study was to objectively assess functional outcome in clinical patients with CrCL rupture undergoing TTA using force plate gait analysis, as well as to evaluate factors that could have influenced outcome. The authors hypothesized that TTA would improve limb function in clinical patients with CrCL disease.
Materials and methods

Inclusion criteria

This prospective study comprised 40 TTA procedures performed in consecutive clinical patients with CrCL disease between May 2003 and December 2004. The dogs needed to weigh 15 kg or more, have hind limb lameness, and have a diagnosis of partial or complete CrCL rupture as a cause for that lameness in order to be enrolled in the study. The owners of the dogs had to sign a consent form from the university prior to enrollment, which included an agreement to bring their dogs back for follow-up examinations at four to six months after surgery. Clinical orthopaedic examinations, radiographs of both stifle joints, and force plate gait analysis preoperatively and at follow-up, were required for all of the dogs.

Preoperative evaluation

Complete physical and orthopaedic examinations, radiographs of both stifle joints, and force plate gait analysis were performed preoperatively. The clinical orthopaedic examination was performed to diagnose CrCL rupture, as well as to rule out concurrent orthopaedic problems. The patients were assigned as having either partial or complete CrCL rupture status, based upon the absence or presence of passive laxity of the stifle joint.

Mediolateral and caudocranial radiographs of both stifle joints were obtained under general anaesthesia. The mediolateral radiographs were performed with the stifle joint in extension in order to allow for preoperative planning. The radiographs of both the affected and the contralateral stifle joints were evaluated for the presence of osteoarthritis. Those joints with radiographic signs of bony changes, joint effusion, or joint capsule thickening were considered to be abnormal. In the absence of any other pathological findings, these radiographic findings were considered to be suggestive of CrCL disease, even if the stifle joints were palpably stable.

Other regions of the skeletal system were also radiographed when indicated by clinical examination findings. Orthopaedic abnormalities involving the affected hind limb or the spine were noted, and the patients were assigned to have, or not to have, concurrent orthopaedic problems potentially affecting the limb undergoing the TTA procedure.

Surgical procedure

Preoperative planning was performed on mediolateral radiographs that had been taken with the stifle joint in extension, as previously described (4). Briefly, this planning involved the assessment of the amount of advancement of the tibial tuberosity necessary in order to achieve a perpendicular angle between the patellar ligament and the tibial plateau.

Arthroscopy was performed in all of the dogs prior to TTA by a single surgeon (D. M. Damur). The arthroscopy involved systematic exploration of the joint in order to confirm the clinical diagnosis of a complete or partial rupture of the CrCL, to diagnose or rule out meniscal lesions, and to inspect the surface of the articular cartilage. The grade of cartilage lesion in the femoropatellar joint was subjectively determined and graded according to a modified Outerbridge grading scale (14). Grade 0 was absence of arthroscopically visible cartilage lesions, grade I was chondromalacia, grade II was fibrillation, and grade III was fissuring of the cartilage.

In cases with intact menisci, TTA was performed immediately after the arthroscopy. In those dogs with medial meniscal lesions, a partial medial meniscectomy was performed via an open craniomedial arthrotomy prior to the TTA procedure. The medial meniscus was not released in any of the cases, and neither partially, nor completely ruptured CrCL were removed or debrided.

Tibial tuberosity advancement was performed as previously described (4), with the exception that cancellous bone graft obtained from the proximal tibial metaphysis, directly through the osteotomy site was transferred into the osteotomy gap. Implants and specialized instruments were used to stabilize the osteotomy (Kyon, Zurich, Switzerland). Care was taken to cover the implants with the medial fascia of the thigh during wound closure. All of the TTA procedures were conducted by a single surgeon (P. M. Montavon).

Postoperatively, the wound was covered with a sterile wound dressing. A bandage was not applied. Postoperative radiographs were performed to evaluate the osteotomy and positioning of the implants. The owners were advised to restrict exercise of their dogs and to keep them on a leash for six weeks. No postoperative rehabilitation program was applied.

Follow-up examination

Follow-up examinations were planned at four to six months postoperatively. This time frame was not adhered to by all of the owners, despite them having signed a consent form prior to enrollment in the study. The time of follow-up examinations therefore ranged from four to 16 months post TTA, with a mean of 5.9 months. Two groups were formed in order to evaluate any possible bias caused by the different lengths of follow-up time. One group included the dogs that were evaluated between four and six months after surgery, and the other group included those dogs with follow-up examinations between six and 16 months postoperatively. The follow-up examinations included a complete clinical orthopaedic examination, mediolateral and caudocranial radiographs of both stifle joints, and force plate gait analysis. Complications occurring during the postoperative period or diagnosed on follow-up radiographs were noted and treated if necessary.

Force plate gait analysis

Force plate gait analysis was conducted prior to surgery and at follow-up examinations four to 16 months after TTA (mean: 5.9 months). The enrollment of the dogs with bilateral CrCL disease and concurrent orthopaedic problems in the study prevented a comparison of the ground reaction forces.
(GRF) between the paired hind limbs. Ground reaction forces were therefore additionally collected from a group of healthy dogs (n=65) that did not have any apparent orthopaedic problems. This control group of dogs was breed- and body weight-matched to the TTA patients in order to minimize bias from inter-dog variation.

A force plate (OR6–7, Advanced Medical Technologies Inc., Watertown, MA, USA) that was embedded in an 8.0 m run-way, and specialized computer software (Acquire 7.3, Sharon Software, Inc., De-Witt, MI, USA) were used to obtain GRF of the hind limbs. The dogs were allowed to explore the environment before the measurements were started. The dogs were trotted across the force platform at a velocity of 1.85 to 2.15 m/s, with an acceleration/deceleration of less than ± 0.5 m/s. Velocity and acceleration were measured with three photoelectric cells placed 1.5 m apart. Peak vertical forces (PVF) and vertical impulses (VI) of at least five valid trials within the required velocity and acceleration/deceleration ranges were recorded for each hind limb. Peak vertical forces were expressed in percent of body weight (%BW) and VI in percent of body weight times seconds (%BW x sec.) Peak vertical force and VI were defined as being zero in the dogs that did not use the affected leg at a trot.

A hind limb symmetry index (SI) was calculated in the dogs with unilateral CrCL disease at the time of the follow-up examination (n=14), using the equation: SI= [(PVFnormal limb – PVFoperated limb) / ((PVFnormal limb + PVFoperated limb) x 0.5)] x 100 (15). An SI of 0 would indicate perfect gait symmetry. Based on the results of a previous study, an SI greater than six indicated lameness (16).

Statistical analysis

Data were analyzed using statistical software (StatView 5.1, SAS Inc., Wangen bei Dübendorf, Switzerland). Normality of the data was tested (StatView 5.1) prior to the parametric testing. A paired t-test was used in order to make a comparison between pre- and post-operative PVF and VI (n=40). An unpaired t-test was used to compare PVF and VI of the operated hind limbs (n=40) with those of the control group of dogs (n=65). The relationship between functional outcome (represented by PVF) and breed, presence or absence of meniscal tears, partial or complete CrCL rupture, grade of cartilage lesions, presence or absence of concurrent orthopaedic problems, presence or absence of complications, and presence or absence of revision surgery was evaluated by means of analysis of variance (ANOVA). Linear regression analysis was used for the evaluation of the relationship between functional outcome (represented by PVF) and body weight. P values < 0.05 were considered to be significant.

Results

Clinical results

Thirty-seven dogs with 40 TTA procedures were enrolled in the study. The ages of the dogs ranged from three to 11 years (mean: 6.6 years), and the female-to-male ratio was 3:2. The body weights ranged from 21.4 to 53.3 kg (mean: 34.2 kg). Fourteen different breeds were included, and Golden Retrievers, mixed-breed dogs, Bernese Mountain Dogs, and Rottweilers were the most common. The control group of healthy dogs (n=65) consisted of dogs between one and 12 years old (mean: 4.9 years) with a female-to-male ratio of approximately 1:1, and body weights ranging from 20.2 to 49.5 kg (mean: 34.4 kg). The control group comprised 15 different dog breeds, which were not statistically different from the breeds in the TTA-group.

Complete CrCL rupture was identified in 28 out of 40 stifles. Twelve dogs had partial CrCL rupture. The medial meniscus was damaged in 21 out of 40 stifles, thus necessitating partial meniscectomy. All of the dogs with meniscal injury had a complete CrCL rupture except for two dogs with partial CrCL rupture. Six of the dogs did not show any arthroscopically visible cartilage lesion in the femoropatellar joint. Chondromalacia of the femoropatellar joint was seen in 22 stifles (grade 1), fibrillation in eight stifles (grade II), and fissuring in four stifles (grade III).

Sixteen dogs had evidence of CrCL pathology in the contralateral stifle joint at the time of admission. This included two dogs that had previously undergone CrCL surgery of the contralateral limb. Extracapsular stabilization had been performed in one dog and intracapsular stabilization in the other. The other 14 dogs had clinical and radiographical findings indicative of contralateral CrCL disease. The changes in these dogs were minor and did not require any surgical intervention during the study period, with the exception of the three dogs in the study that underwent bilateral TTA. Two of these dogs had a complete, and one had a partial rupture of the CrCL in the opposite limb. Twenty-three out of the 37 dogs had clinical examination and radiographic findings suggestive of contralateral CrCL disease at the final follow-up examination, meaning that seven dogs started to develop pathological findings in the opposite stifle joint during the study period.

One or more concomitant orthopaedic problems of the spine or the affected leg were diagnosed in 15 dogs. These conditions included: lumbosacral spondylolysis (n=2), a healed lumbar fracture (n=1), hip dysplasia, coxarthrosis, or both (n=9), avulsion fracture of the lesser trochanter of the femur (n=2), and osteoarthrosis of the talocrural or intertarsal joints (n=4). These concurrent conditions were deemed to be of less clinical significance than the CrCL disease.

Postoperative complications occurred in ten stifle joints (25%), and included: implant or fixation failure in four cases, a fissure fracture of the tibia in one case, infections in two cases, confirmed late medial meniscal tears in two cases, and unsatisfactory limb function without diagnosis in one dog.

Five of these patients (12.5%) underwent revision surgery; two of the dogs with implant failure were revised because of breakage of the plate prongs and subsequent displacement of the tibial tuberosity, and three patients underwent second-look arthroscopy or arthrotomy. This included the two dogs in which a late meniscal tear was diagnosed, and the dog in which an underlying cause for the unsatisfactory limb function could not be found. Both of the dogs with late meniscal tears had complete CrCL rupture at the time of the original surgery.
The following five complications were managed conservatively; one dog had partial loss of advancement due to a fracture of the tibial tuberosity through the most proximal prong hole and breakage of that prong, which were only detected two months after surgery. Partial loss of tibial tuberosity advancement also occurred in another dog where the cage twisted within the osteotomy gap. This complication was also only noted on follow-up radiographs. An old-generation cage, which is not on the market anymore, was used in this case. One dog suffered a fissure fracture in the proximal tibia several days after surgery, which was treated conservatively with a splinted bandage. Wound dehiscence and periarticular infection was encountered in one case, and septic arthritis in another. The open wound was treated with a bandage and systemic antibiotics. The septic arthritis resolved after systemic antimicrobial treatment and repeated needle arthrocentesis and irrigation of the joint.

**Table 1** Preoperative mean peak vertical forces for the dogs with and without meniscal lesions, and for the dogs with complete and partial rupture of the CrCL. The patients with a complete cranial cruciate ligament rupture had significantly lower peak vertical forces compared to the dogs with partial rupture (bold).

<table>
<thead>
<tr>
<th></th>
<th>Preoperative PVF in %BW (n = number of stifles)</th>
<th>Preoperative VI in %BW x sec (n = number of stifles)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>mean ± standard error SE</td>
<td>mean ± standard error SE</td>
</tr>
<tr>
<td><strong>Meniscal status</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meniscal tear (n=21)</td>
<td>27.2 ± 4.40</td>
<td>1.0 ± 0.48</td>
</tr>
<tr>
<td>Meniscus intact (n=19)</td>
<td>34.9 ± 5.73</td>
<td>4.2 ± 0.96</td>
</tr>
<tr>
<td><strong>CrCL status</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complete rupture (n=28)</td>
<td>25.2 ± 3.79</td>
<td>8.5 ± 0.48</td>
</tr>
<tr>
<td>Partial rupture (n=12)</td>
<td>44.0 ± 6.79</td>
<td>10.9 ± 1.18</td>
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</tbody>
</table>

**Force plate results**

The preoperative PVF values ranged from 0 to 64.6 %BW (mean: 30.8 %BW) and preoperative VI values ranged from 0 to 9.4 %BW x sec (mean: 4.2 %BW x sec). The preoperative PVF data are further summarized in Table 1. The dogs with complete CrCL ruptures had significantly lower PVF before surgery compared to the dogs with partial CrCL ruptures (P<0.01). The patients with meniscal lesions had lower PVF than those dogs with intact menisci, but this difference was not significant.

The PVF values at follow-up were between 49.4 and 85.2 %BW (mean: 64.9 %BW), and VI were 6.4 to 10.9 %BW x sec (mean: 8.5 %BW x sec). The PVF of the control group of dogs were in the range of 57.7 to 85.4 %BW (mean: 71.8 %BW), and their VI were between 8.0 and 11.6 %BW x sec (mean: 9.9 %BW x sec). Both PVF and VI were significantly higher at follow-up examination compared to preoperatively (P<0.01) (Fig. 1). All but one dog had improved. However, PVF and VI remained significantly lower compared to those of the control group of dogs (P<0.01). They reached approximately 90% of those of the control dogs. The symmetry index (SI) of the 14 dogs with unilateral CrCL disease at follow-up was < 6 in five of the dogs (35.7 %), which indicates normal gait symmetry. The SI was > 6 in nine dogs (64.3 %), showing residual lameness.

Force plate results did not differ between the limbs (n=29) with follow-up examinations conducted between four and six months postoperatively (mean: PVF 64.9 %BW, mean: VI 8.4 %BW x sec), and the limbs (n=11) with follow-up examinations performed between six and 16 months after surgery (mean: PVF 64.7 %BW, mean: VI 8.6 %BW x sec).
Relationships of the evaluated parameters with the follow-up force plate results are summarized in Table 2. A relationship was not found between PVF at follow-up and breed, body weight, presence or absence of meniscal tears, partial or complete CrCL rupture, grade of cartilage lesions, and presence of concurrent orthopaedic problems. However, the group of dogs with grade III cartilage lesions had the lowest PVF. The dogs that suffered complications had significantly lower PVF at follow-up compared to those dogs without any complications (P=0.04). The dogs with complications that underwent revision surgery did not have statistically different limb function compared to the dogs without revision surgeries.

Table 2 Mean peak vertical forces of the dogs at follow-up separated into groups according to the different criteria evaluated. Neither the status of the meniscus, the CrCL, nor the cartilage at the time of surgery was associated with outcome. The dogs that had complications had significantly lower peak vertical forces at follow-up than the dogs without complications (bold), but the dogs out of the complication group that had revision surgeries had similar outcomes to the patients without revision surgeries.

<table>
<thead>
<tr>
<th>Complication Type</th>
<th>Follow-up PVF in %BW (n=number of stifles)</th>
<th>mean ± standard error SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meniscal status</td>
<td></td>
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<tr>
<td>Meniscal tear</td>
<td>66.2 ± 1.58 (n=21)</td>
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<tr>
<td>Meniscal intact</td>
<td>63.4 ± 1.74 (n=19)</td>
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<tr>
<td>CrCL status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complete rupture</td>
<td>65.3 ± 1.60 (n=28)</td>
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<tr>
<td>Partial rupture</td>
<td>63.8 ± 1.26 (n=12)</td>
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<tr>
<td>Cartilage status</td>
<td></td>
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<tr>
<td>Grade 0 (n=6)</td>
<td>65.4 ± 0.89</td>
<td></td>
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<tr>
<td>Grade I (n=22)</td>
<td>64.5 ± 1.66</td>
<td></td>
</tr>
<tr>
<td>Grade II (n=8)</td>
<td>67.2 ± 3.57</td>
<td></td>
</tr>
<tr>
<td>Grade III (n=4)</td>
<td>61.6 ± 1.66</td>
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<tr>
<td>Complications</td>
<td></td>
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<tr>
<td>Complication</td>
<td>60.7 ± 3.12 (n=10)</td>
<td></td>
</tr>
<tr>
<td>No complication</td>
<td>66.2 ± 1.89 (n=30)</td>
<td></td>
</tr>
<tr>
<td>Revision surgeries</td>
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<tr>
<td>Revision surgery</td>
<td>65.8 ± 5.02 (n=5)</td>
<td></td>
</tr>
<tr>
<td>No revision surgery</td>
<td>64.7 ± 1.18 (n=35)</td>
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</tbody>
</table>

Discussion

Vertical GRF were significantly higher after TTA compared to preoperatively. However, they remained significant lower than those of the control group of dogs, which suggests that dogs do not return to full function after TTA. The same result was reached when only looking at the 14 dogs with unilateral CrCL disease: one third of those dogs regained full function, and two thirds had residual lameness based on calculation of a symmetry index between the paired limbs. Overall, a function of approximately 90% of normal can probably be expected, based on comparison of follow-up PVF to those of a weight- and breed-matched control group of dogs. Body weight of dogs, breed, complete or partial CrCL rupture, and the absence or presence of meniscal lesions at the time of surgery did not influence the PVF that was measured at follow-up. Also, the time to follow-up examination was not related to limb function because the dogs with follow-ups between four and six months had similar GRF compared to the dogs with follow-ups between six and 16 months. Although the number of dogs in the late follow-up group was rather small (n=11) it seems that an early return of limb function can be expected after TTA.

A direct comparison of force plate results of the present study with existing literature is difficult due to differences in methodology, the types of dogs evaluated, and the normal variability in GRF. Most of the studies that used the trotting gait for evaluation of techniques for treatment of CrCL disease were performed on experimental dogs (12, 17, 18). In dogs with experimental transsection of the CrCL, a return to full function was achieved after extracapsular stabilization and after TPLO, whereas fibular head transposition and intracapsular stabilization were not able to restore full limb function (12, 17, 18). Although a return to full function was also described in one report on clinical patients treated with extracapsular stabilization (19), another study on clinical patients only reported a PVF of 55% BW and VI of 7.5 %BW x sec six months after extracapsular stabilization (20), which is clearly less than what would be expected in healthy dogs.

Limb function was compared at a walking gait after extracapsular and intracapsular stabilization, and after TPLO in a large clinical study comprising 131 Labrador Retrievers (13). Similar to the studies performed at trotting velocity, extracapsular stabilization and TPLO resulted in a better limb function than intracapsular stabilization, and there were not any significant differences in outcome between extracapsular stabilization and TPLO (13). Both techniques resulted in significant improvement of limb function as compared to preoperative values, but as in the present study, PVF remained significantly lower in all of the treatment groups in comparison to a group of normal dogs (13). Also, similar to the present study, only 10 to 15% of dogs returned to completely normal function after either technique (13). In another clinical study that was performed at walking velocity, extracapsular stabilization resulted in a return to full function, but only if an intensive rehabilitation program was instituted after surgery (21). In summary, vertical limb loading six months after TTA seems to be comparable to that achieved after TPLO and extracapsular stabilization, but further studies using the same gait for obtaining GRF, comparable patient material, and the same postoperative treatment protocol are needed to directly compare functional outcome between those techniques.

The occurrence of complications was the only factor in the present study to have a significant relationship with the functional outcome after TTA. The dogs with complications had lower PVF at follow-up compared to the dogs without any complications. The type and incidence of complications that were encountered in the present study were quite similar to that described in another report on TTA (4). A high complication rate of 57% was encountered after TTA in a third study (7). However, most of these complications were minor and the authors included general complications that were not necessarily related to the surgical technique. We did not differentiate between major or minor complications, but the com-
plications seen in the 10 dogs can be classified as major. The complications seen were also comparable to that reported after TPLO, although a slightly lower number of cases required revision surgery after TPLO than after TTA (8, 9, 11). Interestingly, the dogs with complications that underwent revision surgery (two cases with implant failure, three cases with second-look arthroscopy or arthroscopy) did not have a worse outcome than patients without revision surgery in the present study. When interpreting the overall complication rate, it should be taken into consideration that this study comprised dogs that were operated on during the late development phase of the implants and the technique. Due to improved implants and techniques over the last few years it should be possible to lower the complication rate.

Cartilage lesions in the femoropatellar joint were found in 85% of our patients. The degree of retropatellar cartilage changes did not significantly influence outcome in the patients of the present report, but patients with grade III lesions had the lowest PVF at follow-up (Table 2). This result has to be interpreted with caution though. Whilst it seems reasonable that severe femoropatellar cartilage pathology could negatively influence stifle joint function, the classification of the cartilage changes was only based on subjective arthroscopic evaluation, and only four dogs had severe grade III lesions. A theoretical effect of advancing the tibial tuberosity on stifle biomechanics, besides eliminating cranial tibial subluxation, is reduction of retropatellar pressure (2). Retropatellar pain is a common clinical finding in humans with stifle osteoarthritis, and advancement of the tibial tuberosity (Maquet procedure) has been used in order to reduce retropatellar pressure in affected people (22). Although clinical results of this technique were variable, a reduction in pain was observed in up to 80% of patients (23, 24). Further studies are required to evaluate the effect of TTA on retropatellar pressure, and a potential effect of cartilage lesions in the femoropatellar joint on pain and clinical limb function.

Late meniscal tears remain an unresolved problem after surgery for CrCL disease in dogs. The incidence of subsequent meniscal tears after TTA was 10% in dogs with initially intact menisci after TTA when open arthrotomy, but no meniscal release, were performed (7). Other authors found a 20% rate of late meniscal injuries after TTA with open arthrotomy and no meniscal release, and they therefore suggested routinely releasing the meniscus during TTA (4). The release of the medial meniscus does reduce the incidence of late meniscal tears after TPLO (10) but it also disturbs load transmission through the meniscus, and as such increases instability and cartilage loading (25, 26). Meniscal release was not performed for these reasons in the present study. Late meniscal tears were confirmed in two of the dogs in the study (5%), or in 10% of the dogs with initially intact menisci, as previously described (4). Both of the dogs were Bernese Mountain Dogs. Not all of the dogs with suboptimal limb function underwent second-look arthroscopy, hence the true incidence of late meniscal tears could have been higher than that confirmed. The choice of performing a meniscal release with TTA should be made based on outweighing the potential negative effects of a meniscal release, and the risk of a subsequent meniscal tear.

The inclusion of dogs with evidence of CrCL disease of the contralateral limb can be considered to be a drawback of the study. Although ground reaction forces of the operated limb were not compared to those of the contralateral limb but to a control group of dogs, load redistribution to other limbs could theoretically have affected our results. Load redistribution to other limbs has been described to occur with lameness in one study (27), but was not confirmed in another study (28). Overall, load redistribution therefore does not seem to cause marked changes in PVF of other limbs. Additionally, with the exception of the three dogs that underwent bilateral TTA, the changes in the contralateral stifle joint were usually mild, and were considered minor enough not to require surgery. Also, the inclusion of dogs with concurrent orthopaedic problems could possibly have affected force plate results. However, the differences between the dogs with and without concurrent problems of the affected limbs were not significant.

Conclusion

Tibial tuberosity advancement significantly improves vertical limb loading in dogs with CrCL deficient stifles. Although the dogs do not return to full limb function, a function of approximately 90% of normal can be expected. The complication rate was 25%, and the presence of complications was the only factor to have a negative effect on outcome as measured using force plate gait analysis.

References


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