Correlation of radiographic changes after tibial tuberosity advancement in dogs with cranial cruciate-deficient stifles with functional outcome


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Radiographic Changes after Tibial Tuberosity Advancement (TTA) in Dogs with Cranial Cruciate Deficient Stifles and their Correlation with Functional Outcome

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Introduction

Partial and complete rupture of the cranial cruciate ligament (CrCL) occurs frequently in dogs and results in instability and secondary osteoarthritis (OA) (1-8). The presence and progression of radiographic changes of OA in the stifle joint of the CrCL-deficient dog has been reported after conservative treatment (4,9), and following extracapsular or intracapsular substitution techniques (7,10-15), TPLO (15-19), and TTA (20). The radiographic features examined included the present and progressive changes in soft tissues and bone. Soft tissue changes have included joint effusion/capsular thickening, lateral and medial soft tissue thickening, intra-articular osseous fragments, and meniscal mineralization (14,18). Bony changes included osteophytosis and enthesophytosis, subchondral sclerosis, subchondral cyst formation, and joint space narrowing (7,14,15,18,21), generally placing emphasis on presence and growth of marginal osteophytes. Patellar ligament thickening and patellar tendinosis have also been evaluated and noted after TPLO (19,22,23).

Surgical techniques that change the geometry of the proximal tibia, such as tibial plateau leveling osteotomy (TPLO) and tibial tuberosity advancement (TTA) were developed with the intent to restore functional stability of the stifle, prevent deterioration of the medial meniscus, and reduce the degree of secondary OA in the stifle joint with CrCL rupture (24). The initial hope that progression of OA could be minimized using these techniques has not been realized. While progression of OA was found to be smaller in dogs undergoing TPLO as compared to extracapsular stabilization in one study (15), in general, the progression of OA has been observed after both TPLO and TTA (16-20). The radiographic progression of OA after TTA has not been reported in detail up to date, nor is it known whether certain clinical factors correlate with the development of degenerative changes.

Outcome after surgery for CrCL disease can be assessed based on the radiographic appearance of the progression of osteoarthritis of the stifle joint and by evaluating functional outcome, which is probably the clinically more relevant outcome measure. While radiographic changes have been used as a standard clinical
tool to evaluate progression of the degenerative disease (7,18,25), their identification does not necessarily relate
directly to clinical functional outcome (10,17). Several studies have reported or suggested a lack of significant
correlation between the radiographic appearance of OA and clinical evaluation of limb function (5,7,9,18,26).
Postoperative clinical status of patients has been judged using lameness evaluation by a clinician, or by an
owner’s assessment at various periods of time following surgery in previous studies (18,20,27,28). This type of
assessment is subjective and may not necessarily reflect the effective functional outcome. Force plate gait
analysis is a more objective method to classify gait, and has been used to demonstrate clinical effectiveness of
several techniques for treatment of dogs with CrCL disease (29-32).

The goal of this prospective study was to record the presence and progression of both bony and soft
tissue radiographic changes occurring after TTA, and to evaluate potential risk factors for progression of OA
after surgery. The influence of the level and progression of radiographic OA on functional outcome of the dogs
as determined by force plate gait analysis was also examined. The authors hypothesized that severity and
progression of stifle OA would not be an indicator for functional outcome as determined by vertical ground
reaction force parameters.

Materials and Methods

Dogs and clinical evaluation

The study comprised 35 dogs with a body weight of 20 kg or more with a partial or complete CrCL rupture that
underwent 38 TTA procedures between May 2003 and December 2004. These dogs were part of the population
of an earlier study of consecutive patients with CrCL disease that had been treated with TTA (32). Two out of
the original 37 dogs were discarded due to incomplete radiographic studies. All dogs underwent arthroscopic
examination of the stifle before surgery. Synovial membrane biopsies were taken at the beginning of the
arthroscopy from the medial joint capsule using 2.7 mm arthroscopic spoon forceps (Dr. Fritz Instruments,
Tuttlingen, Germany). Samples were stained with hematoxylin and eosin and were examined with a light microscope. The retropatellar fat pad was partially removed to increase visibility. The intraarticular structures were explored for partial or complete CrCL tears, meniscal lesions, and to grade cartilage lesions in the femoropatellar joint according to a modified Outerbridge grading scale (33). Dogs with meniscal lesions underwent a medial parapatellar arthrotomy for partial meniscectomy. A TTA procedure was then performed as described previously (32,34).

**Radiographic evaluation**

Mediolateral and caudocranial radiographs were evaluated on a presurgical study, an immediate postoperative study, and a final follow-up study planned at 4 to 6 months after surgery. Mediolateral views were obtained with the stifle joint in extension of between 120 to 135 degrees. The caudocranial radiographs were made with the central x-ray beam at 15-degree proximal/distal angle. Pre- and postoperative studies were made on anesthetized dogs, and follow-up studies radiographic studies on sedate dogs. Radiographic exposure was controlled by of use of a digital system. Hard copies were made of each exposure for examination. Evaluations concerning the degree and progression of OA and soft tissue changes were made by a board certified radiologist, who was aware of signalment of the dogs and the time of follow-up, but was unaware of the intra-operative findings and the functional outcome of the patients.

New bone production, including both enthesophytes and osteophytes, were noted at the specific anatomic locations. The presence of new bone production was recorded at 11 specific sites: apical patella, basilar patella, trochlear groove just proximal to the patella, lateral femoral trochlear groove, medial femoral trochlear groove, medial femoral condyle and epicondyle, lateral femoral condyle and epicondyle, intercondylar fossa, medial tibial plateau, lateral tibial plateau, and caudal tibial plateau. New bone production at a specific site was graded 0 when not identified, and 1 to 3 when present, based on the amount of new bone, as indicated by bone density
in addition to the thickness of the new bone. A total score of 0 indicated no evidence of new bone production within the joint, while 33 indicated extensive new bone at all 11 sites. Three groups were formed with scores of 0-3, 4-10, and >10 (Table 1).

For evaluation, the score of the bony changes on the preoperative study was compared with the score of the final study. For statistical analysis, the data were treated individually as well as being divided in a manner that separated those with no progression, minimal progression (increase in score of 1 to 4), those with moderate progression (increase in score of >5 to 10), and those with marked progression in the new bone production during the study (increase in score of >10) (Table 1).

Soft tissue changes included joint effusion/capsular thickening, lateral and medial soft tissue thickening, intra-articular osseous fragments, and meniscal mineralization. The changes were scored normal or excessive. Detection of joint capsule distention and joint effusion was based on the caudal distention of the joint capsule as seen on the lateral view or displacement of the collateral ligaments as seen on the caudocranial view. Detection of joint capsule distention and joint effusion was also determined as excessive if the retropatellar fat pad was less than 1cm in width, when measured at its widest site on a mediolateral view. For statistical analysis five groups were formed (Table 1). In group 1, findings were negative on preoperative and postoperative studies, in group 2, findings were negative on preoperative studies and positive on postoperative studies, in group 3, findings were positive on preoperative studies and positive unchanged on postoperative studies, in group 4, findings were positive on preoperative studies and positive and progressive on postoperative studies, and group 5, findings were positive on preoperative studies and positive but regressive on postoperative studies.

**Force plate gait analysis**

Force plate gait analysis (Force plate OR6-7 from Advanced Medical Technologies Inc., Watertown, MA 02472 USA) was conducted preoperatively and at the final follow-up examination at trotting velocity, as
reported earlier (32). Trial velocity was 2.0 m/s (± 0.15 m/s), with an acceleration/deceleration smaller than ± 0.5 m/s². Peak vertical forces (PVF) and vertical impulses (VI) of five valid trials were recorded for each hind limb and were expressed in percent of bodyweight (%BW for PVF; %BW s for VI). Peak vertical forces and VI were defined to be zero in dogs not using the affected leg at a trotting gait.

Statistical analysis

Results from descriptive statistics are reported as means ± one standard error. Data were analyzed using statistical software (StatView 5.1, SAS Inc., Wangen bei Dübendorf, Switzerland). Normality test (StatView 5.1) was applied prior to parametric test if used.

Preoperative radiographic scores were compared between dogs with partial and complete ligament ruptures, between dogs with and without meniscal lesions, and between the different grades of cartilage lesions seen during arthroscopy using factorial analysis of variance (ANOVA).

The influence of partial or complete CrCL rupture, presence of meniscal lesions, grade of cartilage lesions at the time of surgery, and presence of complications and revision surgery on progression of OA was examined using ANOVA for the absolute bony radiographic scores, and Chi Square test for the progression categories of both bony and soft tissue lesions. Linear regression analysis was applied to describe the relationship between body weight and progression of OA.

Radiographic OA scores were compared with functional outcome as represented by PVF, and VI at follow-up. Linear regression analysis evaluated the relationship between the bony OA scores determined on both the preoperative and the follow-up radiographs, and the PVF and VI at follow-up. Linear regression analysis was also used to evaluate the relationship between the progression of bony OA changes and the PVF and VI at follow-up. Additionally, ANOVA was applied for evaluation of bony progression categories and PVF and VI at follow-up, and for the soft tissue change categories and PVF and VI at follow-up. A post-hoc
Bonferroni Dunn test was used for further evaluation if significant differences were found between groups.

Significance was set at $P \leq 0.05$.

**Results**

**Clinical results**

Thirty-five dogs with 38 TTA procedures were enrolled in the study. Body weights ranged from 21.4 to 53.3 kg (mean 33.7 kg ± 1.19). Complete CrCL rupture was identified in 28 of the 38 stifles, and partial rupture in ten stifles. Meniscal lesions were found in 21 stifles and were subsequently treated by partial meniscectomy.

Femoropatellar cartilage lesion were seen in 32 out of 38 stifle joints and were graded as (33): chondromalacia in 20 stifles (grade 1), fibrillation in eight stifles (grade 2), and fissuring in four stifles (grade 3). Postoperative complications occurred in ten operated joints. Revision surgery was performed in five of these, including a second look arthroscopy or arthrotomy in three, and revision of implants in two stifles. Thirty-three synovial membrane biopsies were considered suitable for histologic examination: a predominance of lymphoplasmacellular infiltrates was found in 20 biopsies (60.6%), and unspecific synovitis with villous hypertrophy and/or hyperemia in 10 cases (30.3%). Three biopsies (9.1%) contained normal synovial tissue.

The follow-up radiographic study and the force plate analysis were conducted between four and 16 months (mean 5.9 months) after TTA.

**Radiographical results**

The bony changes noted on the preoperative study produced scores between 0 and 3 in 13 joints, between 4 and 10 in 18 joints, and over 10 in seven joints (mean of 6.16 ± 0.93). The bony changes noted on the follow-up study produced scores between 0 and 3 in 7 joints, between 4 and 10 in 16 joints, and over 10 in 15 joints (mean of 9.63 ± 1.06). No progression of new bone over the study period was noted in 17 joints (Figure 1),

Komentar [tg2]: We need SD here (you said in statistical evaluation that data is presented as mean ± sd. Also add it in the abstract)
progression between 1 to 4 points in nine joints, progression between 5 to 10 points in 11 joints (Figure 2), and progression of over 10 points in one joint. Mean progression of new bone production was 3.34 ± 0.73. Results are further summarized in table 1.

The following basic patterns were noted on the final radiographic study; (1) new bone production around the femoropatellar joint, in particular, the abaxial surfaces of the trochlea, the femur just proximal to the trochlea, and the distal apex of the patella, (2) enthesophytes at the attachment of the collateral ligaments on the femoral epicondyles and the periarticular area of the tibia plateau, (3) new bone from the epicondylar region extending toward the abaxial surfaces of the trochlear notch, and (4) minimal new bone at the intercondylar fossa. The femoropatellar joint was principally involved in eleven joints. The pattern of new bone formation was both femoropatellar and femorotibial in 16 joints. The change was primarily femorotibial in three joints. In eight joints, changes of OA were not sufficiently prominent to place the joint into a distinct pattern (total score 3 or less).

Soft tissue changes, in particular joint effusion or capsular thickening was a less evident radiographic feature than the bony change, but was considered present in 29 joints prior to surgery, and in 33 joints following surgery. Progressive degree of soft tissue change was determined in ten joints, while 19 had similar scores both pre- and postoperatively (Table 1).

Force plate results

Preoperative PVF ranged from 0 to 64.6 %BW (mean 31.5 %BW ± 3.67) and preoperative VI from 0 to 10.9 %BW s (mean 6.3 %BW s ± 0.35). Peak vertical forces at follow-up were between 49.4 %BW and 85.2 %BW (mean 65.0 %BW ± 1.27) and VI ranged from 6.4 to 11.6 %BW s (mean 9.37 %BW s ± 0.12). One-way analysis of variance revealed no difference in ground reaction forces of 26 limbs that had a follow-up between 4 and 6 months, and 11 limbs that had a follow-up between 6 and 16 months.
Statistical results

Preoperative bony radiographic OA scores were significantly greater in dogs with meniscal lesions compared to dogs without \( (P = 0.04) \), but did not differ between dogs with partial or complete CrCL ruptures, and between the different grades of cartilage lesions.

Both the bony radiographic OA scores at follow-up, and the progression of bony radiographic scores did not depend on presence of partial or complete CrCL rupture, presence or absence of meniscal lesion, presence or absence of surgical complications, or revision surgery. The grade of cartilage lesion at the time of surgery was statistically associated with progression of bony OA scores \( (P < 0.01; \text{Figure 3}) \). Dogs with grade III cartilage lesion had a significantly higher progression of OA scores as compared to dogs with grade I \( (P = 0.001) \), and dogs with grade II \( (P = 0.0013) \) cartilage lesions (Bonferroni/Dunn test, significance at \( P < 0.0083 \)).

None of the parameters tested was statistically associated with presence and progression of radiographic soft tissue changes.

Neither the preoperative radiographic bony OA scores, nor the bony OA scores at follow-up examinations, nor the progression of bony scores throughout the study period, nor the categories of soft tissue changes were associated with functional outcome represented by PVF and VI at the final follow-up examination.

Discussion

Progression of radiographic changes indicative of OA in the stifle joint of the dog has been reported after conservative treatment \( (4,9,35-37) \), extracapsular or intracapsular substitution techniques \( (7,8,10-14) \), and recently also following TPLO and TTA \( (15-20) \). It seems that both after TPLO \( (16,18) \) and after TTA \( (20) \).
approximately half of the patients develops progressive OA. This was similar in the present study, where OA
did progress in 55% of stifles during the given follow-up time.

Preoperative radiographic OA scores were significantly greater in dogs with meniscal lesion than in dogs
with intact menisci in the present study. High radiographic scores usually indicate chronic disease and it is
possible that meniscal lesions were more common in chronic cases because they had more time to develop. It is
also possible that the presence of meniscal lesions had resulted in a faster progression of OA in the affected
stifles. Preoperative radiographic scores did not differ between dogs with partial and complete CrCL rupture.
This is somewhat surprising, because when assuming that CrCL disease in large-breed dogs is degenerative in
origin one would expect a higher degree of OA in dogs with complete ligament rupture. However, some of the
cases with complete CrCL rupture in this study only had no or only minimal signs of OA at presentation, which
suggests an acute, and possibly traumatic CrCL rupture in these dogs.

Meniscal release and caudal pole hemimeniscectomy have recently been described to result in changes of
pressure distribution and in increased stresses within the medial compartment of the stifle joint (39), which was
suggested to be a potential risk factor for development of OA in affected stifle joints. In the present study we
did not observe statistically significant differences in the degree of progression of OA between dogs with
meniscal lesions that were treated by partial meniscectomy and dogs with intact menisci. There was also no
difference between dogs with partial or complete CrCL rupture concerning progression of OA. These findings
could of course be different in studies with longer follow-up times.

Radiographic scoring systems may not necessarily reflect the true severity of OA. The radiographic
features identified in OA have classically included new bone production, bone lysis, bone sclerosis, and soft
tissue changes (7,14,15,36,37). Thus, scoring systems have been used in a varied of ways. Usually each
determinant within the system has been assigned an equal value with the score dependent upon the severity of
the change. Scores were then totaled for an accumulative global score. This was done without consideration of
the ease in detection of the determinant in the OA or whether the determinants should in fact have equal value.

An unexpected decrease in score for example could be the result of remodeling or maturation of osteophytes that gave the impression of decreased level of osteophytosis (14) or the result of the use of soft tissue parameters that were more evident postoperatively than later in the study (14,15). In addition, radiographic studies are compromised by morphologic distortion, geometric magnification, and superimposition of bony changes.

In this study, no attempt was made to produce a global score for soft tissue changes and bony changes to indicate the level of OA because of the lack of knowledge of appropriate weighing of individual features. For the present study we chose to use a combination of scoring systems (7,14,15,36,37). It is admitted that the score indicating the level of OA was biased toward features that were more prominent on the radiograph. For stifle OA, this was radiodense osteophytosis. Subchondral sclerosis in the tibial plateau was not evaluated in the present study because this evaluation has been shown to have a large intra- or inter-observer variability (14). Changes in the fabellae were also not included because of the assumption that these changes were age dependent and their association with stifle OA was questionable (2). Notch stenosis was described as an important feature of stifle OA in one study (7) while a similar pattern was not seen in this study, probably because of a younger age of the population or a more acute presentation.

The soft tissue changes were recorded separately from the bony changes in this study. Statistical evaluation showed no correlation with clinical outcome or with other parameters. Joint effusion/capsular thickening were usually present at the time of surgery and often failed to resolve. TTA, as well as TPLO, only provides functional stability of the stifle joint during weight bearing, and capsular thickening is probably an attempt of the body to stabilize the joint. In addition, synovial inflammation and/or proliferation may add to the radiographically visible soft tissue silhouette. Synovial membrane biopsies could not be taken at the time of follow-up in our clinical patients, so the degree of synovial inflammation during the course of the disease
remains unknown. However, lymphoplasmacellular synovitis, as seen in 60.6% of the preoperative synovial
membrane biopsies indicates a chronic inflammatory process that may not resolve after treatment. A similar
incidence of lymphoplasmacellular synovitis (47%) has been described previously (40). Type and degree of
synovial membrane pathology were not associated with the degree of CrCL degeneration in that study (40). The
type of surgery also can have an effect on radiographic appearance of effusion, for example when placement of
an intraarticular fascial graft disrupts the anatomy of the infra-patellar fat pad and the cranial femorotibial joint
space (14). The advancement of the tibial tuberosity during TTA may create more intracapsular volume, which
could add to the radiographic signs of cranial joint effusion/capsular thickening. Additionally, removal of the
infra-patellar fat pad during arthroscopy decreases the size of the fat pad, and may also create a radiographical
appearance of joint effusion/capsular thickening.

The grade of cartilage lesion seen at the time of surgery was the only factor having an influence on
progression of bony OA changes in this study. Dogs with severe cartilage changes at the time of surgery seem
to have a higher probability of suffering from progression of OA as indicated by bony changes. Cartilage injury
is not seen on radiographs, thus preventing prognostic information from the preoperative films. Weight-bearing
radiographic studies might assist in the determination of cartilage injury, but these are difficult to perform and
to evaluate accurately, and are not used regularly in small animal surgery. Weight-bearing radiographs show a
decrease of the joint space caused by thinning of the cartilage layer in human patients. However, the articular
cartilage has been described to increase in thickness after experimental transection of the CrCL in dogs (38),
thus also questioning the value of weight-bearing radiographs in this species. **The presence or absence of**
meniscectomies could possibly also cause variability in the width of the medial aspect of the joint space.

Much emphasis is placed on presence and degree of osteophytosis in evaluation of the clinical status of
the joint in canine medicine (5,7,9,10,16,17,36,41). The presence and progression of OA has been suggested as
a true test of the value of the treatment of injured CrCL (7), and thus, control of OA has been listed as one of
the primary surgical goals of repair of CrCL injury (9). However, the achievement of this goal has not been
proven and many reports have noted progression of OA after stabilization despite an acceptable clinical
outcome (5,7,8,10,11,13,18,27). The value of treatment on clinical status of patients has usually been judged
from a lameness evaluation by a clinician or by a client questionnaire or owner’s assessment at various periods
of time following surgery (19,20,21,28). Force plate analysis is a more objective method to evaluate limb
function, and has been used in evaluation of treatment in cruciate ligament deficiency dogs (29-32). The marked
increase in PVF and VI at follow-up compared to preoperative values demonstrated the clinical effectiveness of
TTA in this study. The comparison of force plate results versus the presence and progression of patterns of new
bone formation and soft tissue changes all failed to show significance. Thus, the study continues to support the
contention that the presence or progression of OA as determined on radiographs has little influence on the
clinical status of the joint.

Comparison of progression of OA in the stifle joint between studies has been made difficult because of
an inability to compare the material studied because of differences in age, size, athletic activity, the level of
meniscal injury, whether the injury to the CCL was partial or complete or whether the dogs were an
experimental model with complete sectioning of the CrCL. The nature of the surgical or non-surgical
treatment, type of arthrotomy (17), resulting joint stability, and experience of the surgeon additionally play a
role in the appearance and progression of OA in the dog with CrCL disease (2). Placement of dogs within
groups with comparing treatment modalities has often not been in a random manner when considering the
above. In addition, the assumption that the radiographic progression of OA may not be linear in presentation
(14,15) makes comparison between most clinical studies appear impossible and questions the value of the use
of OA as a measurement of the assumed value of a treatment. One study suggested that the progression of OA
was greater from entry to the study to 7 months postoperative than from 7 months to 13 months postoperative
(14).
The addition of magnetic resonance imaging (MRI) as a technique for evaluation of OA results in the advantages of tomographic sectioning that facilitates the detection of new bone production particularly in the center of the joint including femoral intercondylar fossa, the central tibial plateau and intra-axial margin of the femoral condyle. In addition, the evaluation of cartilage thickness, joint effusion, synovitis, subchondral sclerosis, meniscal disease, and ligament disease are more accurately evaluated (37). The knowledge that 72% of men and 67% of women with normal radiographic evaluation of the knee have osteophytosis when examined by MR certainly shows the increased value of that technique, but also questions osteophytosis as an indicator of OA if found in such a high percentage of patients (42).

Complications were encountered in ten dogs, out of which five required revision surgery. This is a high percentage of major complications requiring revision surgery in comparison to other reports on TTA (20, 43). The study was conducted during a time period where implants still were under development, but they have been improved since. The occurrence of complications or the necessity of revision surgery was not associated statistically with a higher progression of OA, although a trend (p=0.08) was present for dogs undergoing revision surgery to have a higher progression of OA. A second arthroscopy or arthrotomy causes an inflammatory process in the stifle joint and may activate degenerative joint changes.

In summary, limb function as determined by force plate analysis, improved markedly after TTA. Osteoarthritis as determined by bony changes progressed in 55% of the patients. The degree of radiographically visible OA, and the progression of bone and soft tissues changes after TTA did not correlate with functional outcome. The progression of new bone formation was higher in dogs with severe cartilage lesions at the time of surgery. Other risk factors for progression of stifle OA could not be determined.

References


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Table 1. Summary of radiographic results regarding new bone production in 35 dogs with 38 CrCL deficient stifles that underwent TTA; preoperative scores, scores at follow-up examination (mean 173 days postoperative), progression of scores of new bone production from preoperative to follow-up, primary localization of those bony changes, and progression of soft tissue changes from preoperative to follow-up. The numbers indicate the number of stifle joints within each category.

Figure 1. Immediate postoperative (a,b) and 5 months follow-up (c,d) radiographs of a 9 year-old mixed-breed dog with a unilateral complete CrCL rupture and medial meniscal lesion. This dog was classified to have no progression of new bone production.
Figure 2. Immediate postoperative (a,b) and 4 months follow-up (c,d) radiographs of a 5 year-old Boxer with a complete CrCL rupture without meniscal lesion. This dog had a 10-point progression of radiographic scores indicating new bone production.

Figure 3. Diagram showing the relation between progression of bony OA scores and grades of cartilage lesions as determined during arthroscopy. Dogs with grade III cartilage lesions (4 dogs) had significantly greater progression of OA scores (P<0.01) as compared to dogs with grade I (20 dogs), grade II (8 dogs), and no cartilage lesions (6 dogs).