



# Evaluation of Osteoarthritis in Dogs Treated with Tibial Tuberosity Advancement using a Porous Titanium Scaffold

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## ABSTRACT

**Background:** The aim of this study is to (1) evaluate the impact of tibial tuberosity advancement (TTA) with porous titanium scaffold implants on the progression of osteoarthritis (OA) and to (2) determine whether these advances are indicative of limb function as determined by gait analysis. Osteoarthritis is a common degenerative joint disease affecting dogs with cranial cruciate ligament (CCL) ruptures, which in many cases worsen after surgery. Utilizing TTA with a porous titanium scaffold, we analyzed the effects of this material on the progression of OA, employing radiographic imaging and gait analysis as assessment tools.

**Methods:** Twenty-one dogs diagnosed with CCL ruptures underwent TTA using a porous titanium scaffold implant. Radiographs were taken for each dog preoperatively and at multiple intervals postoperatively to assess the degree of OA progression using standard scoring metrics. In addition, objective gait analysis was performed to quantify the improvement in limb function over time postoperatively, focusing on parameters such as GAIT4 Dog® lameness score (GLS) and total pressure index percentage (TPI%).

**Result:** This study demonstrated a variable, generally positive trend in postoperative functional recovery but not in the management of OA progression. Radiographic analysis showed slowed OA progression in the majority of cases. The porous titanium scaffold appeared to support biomechanical stability and gradual bone adaptation, but not to potentially reduce the potential for osteoarthritis progression. The findings suggest that the TTA technique with a porous titanium scaffold may be useful in improving limb function in dogs with anterior cruciate ligament (ACL) ruptures, but there is continued progression of osteoarthritis.

**Key words:** Cranial cruciate ligament (CCL) rupture, Osteoarthritis progression, Porous titanium scaffold, Radiographic assessment, Tibial tuberosity advancement (TTA).

## INTRODUCTION

Cranial cruciate ligament rupture (CrCLR) is a common cause of hind limb lameness in dogs, whose main role is in the stability of the stifle joint by preventing cranial tibial drawer movement and limiting hyperextension of the joint and excessive internal tibial rotation (Danielson *et al.*, 2016; Comerford *et al.*, 2011; De Rooster *et al.*, 2006). Instability of the stifle joint following rupture of the cranial cruciate ligament (CrCLR) appears to predispose the limb to subsequent osteoarthritic changes and damage to the medial meniscus (Krupkova *et al.*, 2018; Spinella *et al.*, 2021; De Bruin *et al.*, 2007). Many surgical procedures have been described for the treatment of cruciate ligament (CCL) ruptures in dogs that aim to neutralize cranial tibial thrust during weight bearing (Wemmers *et al.*, 2022; Hussain *et al.*, 2018). Presence and progression of radiographic changes of OA in the stifle joint of the CCL-deficient dog has been reported after conservative treatment (Boyd *et al.*, 2007; De Bruin *et al.*, 2007) and after extracapsular or intracapsular substitution techniques (Mölsä *et al.*, 2014; Ledecy *et al.*, 2014; Rafla *et al.*, 2025) tibial plateau leveling osteotomy (TPLO) (Hurley *et al.*, 2007; Moore *et al.*, 2020) and tibial tuberosity advancement (TTA) (Morgan *et al.*, 2010). Since the introduction of TTA, various modifications have been described such as the rapid TTA, the modified maquet procedure and the newer 'porous scaffold' implants (Aragosa *et al.*, 2022; Bernardi-Villavicencio *et al.*, 2020; Della *et al.*, 2021). A considerable

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number of studies have been conducted that explored the most suitable postoperative assessment strategies for TTA, including functional force plate analysis, radiographic assessment of osteoarthritis progression and comprehensive assessment of postoperative complications (Voss *et al.*, 2008; Pinna *et al.*, 2019; Wolf *et al.*, 2012; Guadalupi *et al.*, 2023; Miller *et al.*, 2023). Radiographic and arthroscopic evaluations demonstrate progression of osteoarthritic changes despite surgical intervention (Muir, 2017). On the one hand, radiographic studies demonstrate that osteoarthritis (OA) persists in the muscle treated with stabilization, even in cases that are otherwise uncomplicated. For instance, Tibial Plateau Leveling Osteotomy (TPLO) cases exhibited elevated OA scores up to 36 months

following surgery, despite enhanced weight-bearing (Hurley *et al.*, 2007; Shimada *et al.*, 2020). Conversely, objective gait analysis (e.g. force plate or pressure-sensitive walkway measurements) offers insights into functional recovery; however, there are few studies that have connected these functional outcomes with parallel quantification of OA progression. A study evaluating pressure-sensitive gait performance in dogs with osteoarthritis (OA) found significant overlap between healthy and OA-affected dogs in gait symmetry indices, highlighting the complexity of linking structural disease to functional deficits. (Brønneiche *et al.*, 2020). Advances in functional evaluation methods and biomaterial engineering have facilitated the development of porous titanium (Sodhi *et al.*, 2021) scaffold implants for TTA, with the objective of improving osseointegration and reducing implant-related complications (Vani *et al.*, 2021). The aim of this study was to reveal the evolution of radiographic osteoarthritic changes in the stifle joint of dogs treated with porous titanium TTA and to establish the relationship between these structural changes and objective gait parameters over a 6-month postoperative period with serial assessments (preoperative, 1, 3 and 6-month follow-up).

## MATERIALS AND METHODS

The medical records of dogs that underwent tibial tuberosity advancement (TTA) with a porous titanium scaffold at the department of surgical clinic (DiMePRE-J) of the University of Bari Aldo Moro were retrospectively evaluated between January 2022 and July 2025. Of these, the current study includes the ankles that underwent radiographic evaluation and pressure-sensitive walkway (PSW) system from the preoperative period to 6 months postoperatively with the consent of the dog owners. The inclusion criteria for this study were only if standard radiographic follow-up: 1. Availability of the mediolateral and craniocaudal projection was available; 2. Availability of pressure-sensitive walkway (PSW) data were available at all time points, obtained preoperatively (T0) and at postoperative examinations at 1, 3 and 6 months postoperatively (T0, T1, T3 and T6). Furthermore in the absence of implant failure or complications and in the absence of any suspicion of a meniscal tear as indicated by a tibial compression test performed under axial load over the full range of motion of the joint. Dogs were excluded from the study if they showed incorrect or incomplete radiographic positioning, or if the radiographs were of insufficient quality for the purpose of assessing the presence of osteoarthritis. Exclusion criteria also included the presence of other concomitant orthopaedic, neurological or neoplastic diseases; the occurrence of major surgical complications, such as subsequent meniscal tear, contralateral hindlimb lameness within 6 months of surgery and the use of anti-inflammatory drugs during the follow up period. Also, X-rays that were not available 1, 3 and 6 months postoperatively were excluded.

All dogs were evaluated by 3 board-certified veterinary surgeons preoperatively. Since this study is not experimental in nature and is not randomized, ethics committee approval was not necessary. Preoperative planning included a radiographic assessment under general anesthesia. Standard mediolateral radiographs of the affected hind limb with cruciate ligament rupture were obtained at approximately 135° of flexion to determine the required degree of tibial tuberosity advancement. Advancement measurements were performed using both the joint tangent method and the tibial plateau angle-based method with dedicated DICOM planning software. Selection of porous titanium (Ti6Al4V) cages was made according to patient size. The porous titanium scaffold used for the TTA procedures was a commercially available titanium implant designed for veterinary orthopedic applications. They were manufactured and developed by “Biosurgex, European Union Trademark; Product Category Medical Devices, Pharmaceutical Products”. The porous cage is in the form of a highly porous wedge synthesized by Electron Beam Melting (EBM) of Ti6Al4V (Titanium-Aluminum-Vanadium alloy) powder with a particle size of 45-65 µm. These implants had controlled pore geometry and mechanical properties designed to encourage bone growth and ensure stable osseointegration. A variety of cage, plate and screw dimensions were available to ensure optimal intraoperative compliance. After owner consent and induction of general anesthesia, surgery was performed using dedicated TTA instruments. A medial approach was made to the proximal tibia and a Maquet hole was created in the distal tibial tuberosity. Using a positioning guide, an osteotomy of the tibial tuberosity was performed. The osteotomized segment was carefully advanced to the predetermined advancement distance, after which the selected porous titanium cage was inserted into the osteotomy gap. Fixation was achieved with a contoured titanium plate and cortical screws placed along the cranial aspect of the tibial tuberosity and proximal tibial diaphysis. The surgical procedure was completed with a layered closure and postoperative radiographs were obtained to verify cage positioning and advancement. Preoperative and immediate postoperative mediolateral and craniocaudal radiographs of the affected joint were obtained as well radiographs 1, 3 and 6 months after TTA. The assessment of signs and progression of osteoarthritis in the patellar joints was conducted by three independent observers with different experience at different time points. The worst osteoarthritis score assessed by each radiologist was selected for the statistical analysis. The assessment of osteoarthritis considering the presence of osteophytosis and subchondral sclerosis was achieved at 12 specific anatomical sites of the stifle joint (Fig 1) by applying a method modified from that suggested by Wessely in 2017 (Wessely *et al.*, 2017). Anatomical sites related to the tibial tuberosity, were eliminated from the analysis as they were considered non-evaluable during TTA. According to this

method, Wessely assigned a score from 1 to 4 for each location depending on the severity of typical osteoarthritis findings: 1 = normal radiographic appearance, no signs of osteopathy; 2 = mild osteophytosis and/or mild sclerosis; 3 = moderate osteophytosis and moderate sclerosis; 4 = pronounced osteophytes and severe sclerosis. The scoring system for each grade at osteoarthritis is shown in Table 1. For each radiographic examination, a global osteoarthritis (OA) score (Innes *et al.*, 2004; Wessely *et al.*, 2017) score was calculated by summing the individual scores assigned to all 12 anatomical sites, resulting in a total score ranging from 0 to 48 at each assessment time point. The osteoarthritis (OA) score as determined by each radiologist was averaged for each patient and used for statistical analysis. Based on the total radiographic OA score (0-48), dogs were divided into Four OA severity groups as follows: Group A, no or minimal OA (0-12 points); Group B, mild OA (13-24 points); Group C, moderate OA (25-36 points); and Group D, severe OA (37-48 points). Dogs were categorized into four osteoarthritis severity groups based on the total radiographic OA score (range 0-44): Group A: no or minimal OA (0-11 points), Group B: mild OA (12-22 points), Group C: moderate OA (23-33 points) and Group D: severe OA (34-44 points). This categorization is reflective of the distribution of radiographic changes and follows a proportional division of the scoring scale; consistent with the approaches previously published approaches for classifying multifocal osteoarthritis (Innes *et al.*, 2004; DeLuke *et al.* 2012; Hurley *et al.*, 2007; Wessely *et al.*, 2017).

Gait analysis was performed using a pressure-sensitive gait system (GAIT4Dog®, CIR Systems Inc., Sparta, NJ,

USA) combined with dedicated quadruped analysis software (GAITFour®, version 4.9Wr). Standardization required head-up and central positioning on the mat, with a minimum of four valid gaits (*i.e.*  $\geq 4$  gait cycles) demonstrating consistent speed. For each dog, pressure variables (GAIT4Dog® lameness score and total pressure index, TPI%) were recorded for each pelvic limb (unilateral CrCLR managed with porous TTA) and for the contralateral limb, which was clinically normal and were expressed as a percentage of body weight. Gait tests were performed at four time points: preoperatively (T0) and at 1 month (T1), 3 months (T2) and 6 months (T3) postoperatively. The GAIT4Dog® Lameness Score (GLS) is a method of determining the relative loading of the limbs during stance. A score of 100 represents symmetrical loading; values  $<100$  indicate reduced loading (lameness) and values  $>100$  indicate compensatory overload of the contralateral limb. The total pressure index percentage (TPI%) is a measurement of the distribution of weight across all limbs (expected physiological distribution): 30% for thoracic limbs, 20% for pelvic limbs.

#### Statistical evaluation of the data

The data collected were statistically analyzed by using MedCalc statistical software version 14 (MedCalc Software bvba, Ostend, Belgium). A comprehensive set of descriptive statistics was derived for each variable, with the mean value expressed as  $\pm$  standard deviation (SD). The normality of distribution was assessed using the Kolmogorov-Smirnov test. For data sets exhibiting normal distribution, a repeated-measures analysis of variance (ANOVA) was conducted to compare the preoperative and postoperative data collected

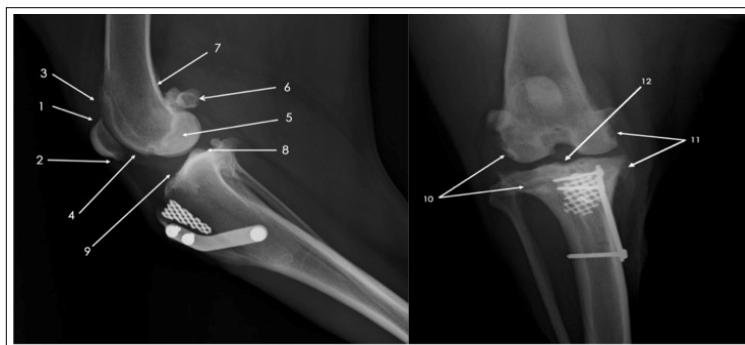


**Fig 1:** 1) Anatomic locations for osteoarthritis assessment on mediolateral and craniocaudal radiographic imaging, patellar apex, 2) patellar base, 3) proximal trochlear ridge, 4) distal trochlear ridge, 5) femoral condyle, 6) sesamoid bones 7) popliteal surface of the femur 8) caudal aspect of the tibial plateau 9) central aspect of the tibial plateau 10) Lateral tibial and femoral condyles, 11) Medial tibial and femoral condyles, 12) Intercondylar notch.

**Table 1:** Osteoarthritis grading system and corresponding radiographic changes.

| Grade | Severity | Changes                                                         |
|-------|----------|-----------------------------------------------------------------|
| 1     | No       | Radiographically normal/no evidence of sclerosis or osteophytes |
| 2     | Mild     | Mild osteophytes and/or mild sclerosis                          |
| 3     | Moderate | Moderate osteophytes and moderate sclerosis                     |
| 4     | Severe   | Marked osteophytes and severe sclerosis                         |

at one, three and six months post-surgery, followed by post-hoc Tukey HSD tests to identify pairwise differences. For variables that did not meet the requirements of normality, non-parametric testing (Kruskal-Wallis test with pairwise post-hoc comparisons) was applied. The gait analysis parameters derived from the pressure-sensitive walkway including GAIT4 Dog® lameness score (GLS) and the total pressure index percentage (TPI%) were subjected to a repeated-measures analysis of variance ANOVA to evaluate differences across time points. When deemed appropriate, paired evaluations between observations were performed using paired t-tests. The level of statistical significance was set at  $p < 0.05$  for all tests.

## RESULTS AND DISCUSSION

Twenty-one stifle joints satisfied the inclusion criteria for the study and a total of 56 X-ray images were collected. Thirty-five stifle joints were excluded from the study due to missing data or failure to reach the 6-month follow-up for radiographic review and gait analysis after surgery. Of the 21 stifle joints examined, one was a bilateral surgical stifle, while 20 were unilateral stifles. The breeds most frequently represented included mixed breed dogs ( $n = 6$ ), american staffordshire terriers ( $n = 2$ ), labrador retrievers ( $n = 3$ ), cane corsos ( $n = 2$ ), border collies ( $n = 1$ ), boxers ( $n = 1$ ), german shepherd dogs ( $n = 1$ ), golden retrievers ( $n = 3$ ) and rottweilers ( $n = 2$ ). The population comprised seven intact males and two neutered males, eight spayed females and four neutered females. The canines included

in the present study had a mean age of  $5.2 \pm 3.3$  years and a mean weight of  $36.8 \pm 17.9$  kg at the time of surgery. The TTA procedure was performed on 8 right and 13 stifle joints. A radiographic analysis of osteoarthritis (OA) based on 21 stifle joint assessments demonstrated a significant increase in global OA score over time. In comparison with the initial baseline (T0), mean global OA scores were found to be significantly elevated at both T3 and T6 ( $P < 0.001$ ). The mean global OA score increased from  $14.8 \pm 1.5$  (range: 0-29) at T0 to  $19.8 \pm 5.6$  (range 0-31) at T6. No cases of severe OA were recorded at any time point. The number of stifle joints in the groups according to the OA score intervals is listed in Table 2. The OA scores were found to be statistically significant ( $P < 0.001$ ) between the groups. Further analysis revealed that the trajectories of OA progression differed between the groups. In Group A and Group C, there was no statistically significant progression over time in any pairwise comparison ( $P > 0.05$ ). In contrast, Group B demonstrated significant OA progression from T0 to T3 and T6 ( $P < 0.001$ ) (Table 2).

No significant differences were identified between the groups with regard to gender, age and body weight distribution. The progression of osteopathy was assessed, revealing that 11 out of 21 stifle joints (52.4%) retained the same osteopathy stage throughout the follow-up period. 9 out of 21 joints (42.9%) increased osteopathy stage by one. It is noteworthy that one joint demonstrated a decrease in osteophyte score (Fig 2).

As a result of the analysis conducted during the study, it was found that there was a significant increase in the osteophyte score at the sixth month compared to the initial baseline score ( $P < 0.05$ ) (Fig 3).

An analysis of individual anatomical sites showed that osteopathy was already evident preoperatively (T0) at the patellar apex, proximal trochlear crest, distal trochlear crest and medial femoral and tibial condyles. It is important to note that the patellar apex consistently demonstrated the highest postoperative OA among all anatomical sites. Of the 21 cases that met the inclusion criteria for radiographic images, four were excluded from the study because they did not reach the 6-month follow-up for postoperative gait analysis, did not return for follow-up, or did not have complete clinical examinations. In the outcome

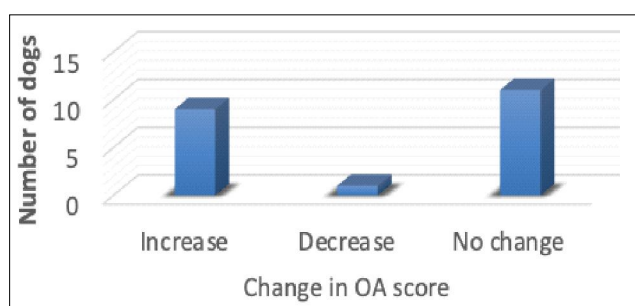


**Fig 2:** Change in osteophyte score before intervention up to six months.

**Table 2:** Statistical details of OA results in groups.

| Sample  | Nr of dogs | OA score mean $\pm$ SD (range) | OA score mean $\pm$ SD (range) | OA score mean $\pm$ SD (range) | OA score mean $\pm$ SD (range) |
|---------|------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|
|         |            | T0                             | T1                             | T3                             | T6                             |
| Group A | $n = 5$    | $5.9 \pm 1.4$ (0-11)           | $6.1 \pm 1.7$ (0-11)           | $8.2 \pm 2.5$ (0-17)           | $9.1 \pm 3.4$ (0-22)           |
| Group B | $n = 13$   | $16.2 \pm 1.8$ (12-22)         | $16.2 \pm 1.8$ (12-22)         | $18.1 \pm 1.9$ (13-27)         | $19.8 \pm 1.8$ (13-27)*        |
| Group C | $n = 3$    | $24.1 \pm 2.8$ (23-29)         | $24.1 \pm 2.8$ (23-29)         | $25.2 \pm 2.9$ (23-29)         | $27.2 \pm 2.8$ (24-31)         |
| Group D | $n = 0$    | N/A                            | N/A                            | N/A                            | N/A                            |

T0: Preoperative; T1, T3 and T6 months postoperative; N/A: Not applicable.

\*Statistically significant.

analyses for the pressure measurement parameters, a statistically significant difference in GAIT4Dog® lameness score (GLS) was observed between the treated limb (Tr, treated limb) and the control limb (Cl, contralateral limb) at each time point. It is worth noting that no statistically significant difference was detected in the GAIT4Dog® lameness score (GLS) between the treated limb at T0 and at T1 ( $p = 0.697$ ). However, in contrast at T0, the treated limb displayed a significantly different GLS compared to the control limb where GLS values for the treated limb changed significantly from T0 to the follow-up

assessments, with significant changes observed between T0 and T2 ( $p = 0.006$ ) and between T0 and T3 ( $p < 0.001$ ) (Table 3).

Similarly, for the parameter total pressure index % (TPI%), a statistically significant difference was recorded between the treated limb (Tr) and the control limb (Cl) for each time point. And in this evaluation parameter, statistical analysis did not show a statistically significant difference in TPI% between the treated limb (Tr) at T0 and the treated limb (Tr) at T1 ( $p = 0.658$ ), but statistically significant differences were found between the treated limb (Tr) at T0 and at T2 ( $p = 0.006$ ) and between the treated limb (Tr) at T0 and at T3 ( $p < 0.001$ ) (Table 4).

The clinical outcomes of TTA in the treatment of CrCLR in dogs are well documented (Hoffmann *et al.*, 2006, p. 219; Stein and Schmoekel, 2008; Lafaver *et al.*, 2007). In this study, we evaluated the radiographic progression of osteoarthritis (Fig 4) as well as functional outcome via gait analysis in dogs treated with tibial Tuberosity advancement (TTA) using a porous titanium implant over a six-month follow-up period. Although by radiographic assessment the majority of dogs exhibited signs of OA by month six (84% minimal to mild OA; 9% moderate OA; 4.8% showed reduced osteoarthritis), none progressed to severe OA.

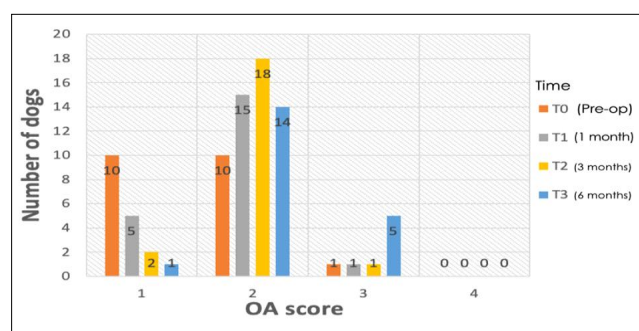


Fig 3: Osteophyte results during the 6-month study period.

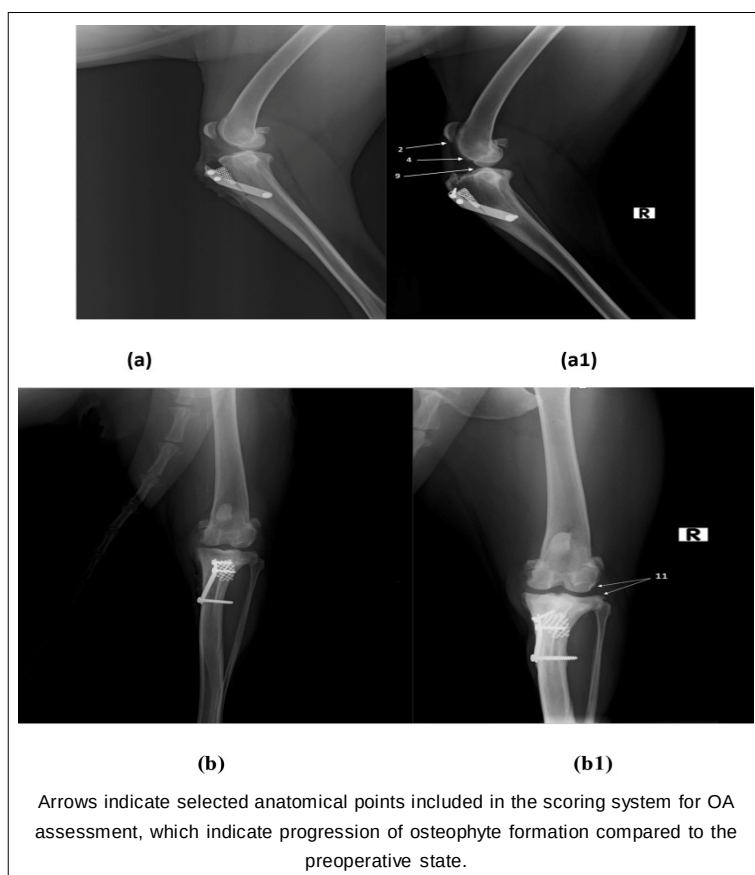


Fig 4: Representative case (mediolateral and craniocaudal radiographs) demonstrating radiographic progression of osteoarthritis before (a, b) and 6 months after TTA surgery (a1, b1) with a porous titanium implant.

It is important to note that, despite the apparent radiographic improvement, gait function as measured with the GAITFour®Dog pressure-sensitive walkway system improved significantly from the preoperative day to six months postoperatively, approaching normal parameters. Previous studies on the clinical utility of TTA consistently assess postoperative complications, limb function and osteoarthritis progression (MacDonald *et al.* 2013; Aragosa *et al.*, 2022; Bernardi-Villavicencio *et al.*, 2020; Hans *et al.*, 2017). Peak vertical force (PVF) measured using a force plate is widely accepted as a reliable and objective metric for comparing the force generation capacity of normal and abnormal limbs in dogs (McLaughlin, 2001; Voss *et al.*, 2007). In our study, the GLS and TPI% of the pressure-sensitive walkway system increased postoperatively in comparison with the preoperative period. This finding indicates that weight-bearing, lameness and gait ability recovered rapidly from the first month and were approaching normal by the sixth month. A similar clinical benefit has been reported in dogs treated with TPLO, reaching levels comparable to those of healthy dogs six months after surgery (Krotscheck *et al.*, 2016; Kim *et al.*, 2009; Della *et al.*, 2021). Consequently, these results are consistent with our findings that functional recovery continues even in the presence of radiographic progression of OA. Although it is well established that OA progresses after TPLO and TTA, some studies suggest that stabilization techniques may not completely prevent the long-term effects of secondary OA on weight-bearing function. Previous studies using force plates system have not found any significant association between OA severity scores (OAS) and weight-bearing functionality (Gordon *et al.*, 2003; Shimada *et al.*, 2020; Brown *et al.*, 2013; Wong and Govendir, 2022). Our findings support the conclusions of previous reports, in which it was demonstrated that

radiographic OA progressed in most cases, while the functional improvement in the treated limb during this time was significant. Similarly, Morgan *et al.* (2010) reported that OA progressed in more than half of the limbs of dogs treated with TTA, however ground reaction forces improved and also showed no correlation with OA outcomes. This finding is consistent with current research, which further supports the idea that radiographic degeneration does not serve as a direct predictor of functional impairment in dogs treated with porous titanium TTA. It is noteworthy that recent studies using pressure-sensitive walkway system also support our observations. Guadalupi *et al.* (2023) and Lascelles *et al.* (2006) demonstrated significant functional improvements in the treated limb starting 90 days after TTA. Objective gait analysis using force plate gait analysis has been validated as reliable for quantifying changes in gait (Voss *et al.*, 2008) and similar biomechanical improvements have also been consistently documented. Our outcome data provide validation of these findings up to six months, demonstrating sustained functional benefits even in cases of continued progression of OA. In all radiographic evaluations of dogs, the patellar apex was identified as the most frequent site of early osteophyte formation at the time point of the day of the procedure (T0). This finding is consistent with the results of earlier studies which demonstrated that CCL-deficient stifle joints often frequently exhibit periarticular osteophytes at the patellar apex and trochlear crests prior to stabilization (Shimada *et al.*, 2020; Gilbert *et al.*, 2019; Pinna *et al.*, 2019). These changes are probably the consequence of a combination of mechanisms including increased patellar tendon tension and enthesopathy following CCL rupture, altered patellofemoral contact mechanics with cranial displacement of contact pressures and osteophyte formation at cranial capsular attachment sites predisposed

**Table 3:** Analysis of GAIT4Dog® lameness scores (GLS) between the treated limb (treated limb, Tr) and the control limb (Cl, contralateral limb) for each time point.

| Sample                                     | No of dogs | Mean GLS (GAIT4Dog®lameness scores) |             |             |             |
|--------------------------------------------|------------|-------------------------------------|-------------|-------------|-------------|
|                                            |            | T0                                  | T1          | T2          | T3          |
| Treated limb (Tr)                          | 17         | 61.6±25.24                          | 69.7±8.89   | 81.1±7.83   | 93.1±11.31  |
| Control limb (Cl),<br>(contralateral limb) |            | 116.8±21.92                         | 110.2±10.72 | 110.1±11.94 | 109.8±11.19 |
| p-value                                    |            | p<0.001                             | p<0.001     | p<0.001     | p = 0.024   |

**Table 4:** Analysis of total pressure index % (TPI%) between the treated limb (treated limb, Tr) and the control limb (Cl, contralateral limb) for each time point.

| Sample                                     | No of dogs | Mean TPI % (Total pressure index %) |           |           |             |
|--------------------------------------------|------------|-------------------------------------|-----------|-----------|-------------|
|                                            |            | T0                                  | T1        | T2        | T3          |
| Treated limb (Tr)                          | 17         | 12.7±4.56                           | 13.8±2.1  | 15.8±1.91 | 18.1±2.15   |
| Control limb (Cl),<br>(contralateral limb) |            | 22.9±4.52                           | 22.5±2.25 | 21.9±2.38 | 21.7±2.18   |
| p-value                                    |            | (p<0.001)                           | (p<0.001) | (p<0.001) | (p = 0.024) |

to chronic instability and synovitis (Kim *et al.*, 2017; Gilbert *et al.*, 2019; Sample *et al.*, 2017). It has been observed that other anatomical regions including the patellar apex and the proximal trochlear tuberosity also exhibit earlier and more pronounced OA changes, which are likely indicative of localized redistribution of biomechanical stress following advancement of the tibial tuberosity (Medeiros *et al.*, 2018; Guerrero *et al.*, 2011; Pinna *et al.*, 2019). The TTA technique facilitates the reconstruction of articular forces with a view to neutralizing the cranial tibial tuberosity. This suggests that alterations in patellar tendon force vectors may be a factor in including changes in these regions (McCartney *et al.*, 2019; Apelt *et al.*, 2007; Boudrieau, 2009). Of interest during radiographic evaluation was the observation that one dog demonstrated a decrease in OA score from day 0 to subsequent evaluations. It is important to note that true reversal of OA is rare. However this finding suggests that in certain cases, postoperative stabilization may prevent or even reduce radiographic degenerative changes. This may be achieved by addressing reduced mechanical overload or improving joint motion. Similar improvement or minimal stabilization has been observed after TTA and TPLO in several studies (Moore *et al.*, 2020; Innes *et al.*, 2004). Therefore, the results of this study indicate that radiographic progression of OA alone should not be used as an indicator of functional outcome after CrCL repair with TTA. This is followed by objective gait analysis which remains essential, as subjective clinical assessment often underestimates recovery (Guadalupi *et al.*, 2023; Della *et al.*, 2021; Bøddeker *et al.*, 2012). The porous titanium TTA technique appears clinically to be effective, allowing functional recovery to near-normal levels despite the presence of radiographic degeneration (Lafaver *et al.*, 2007; Aragosa *et al.*, 2022; Miller *et al.*, 2023). However, the study has several limitations, where the six-month follow-up period may be too short to fully characterize the chronic progression of OA. Furthermore, radiographic imaging has been observed to underestimate the extent of cartilage degeneration. Thus, advanced imaging techniques such as CT and MRI have been shown to provide a more detailed comprehensive assessment of the condition (Hayashi *et al.*, 2018; Li *et al.*, 2016). Also, pressure-sensitive walkways mainly measure vertical forces and lack the multidimensional detail available with force plate analysis (Della *et al.*, 2021; Bøddeker *et al.*, 2012; Clark and Comerford, 2023; Drüen *et al.*, 2010; Bockstahler *et al.*, 2007). Therefore, future studies should include long-term follow-up (12-36 months), combined kinetic and kinematic analysis of gait and advanced imaging (CT/MRI) for a more accurate structural assessment.

## CONCLUSION

In our study confirmed that OA progressed over time after TTA with porous titanium implants to treat CrCLR joints. However, the increase in OAS after surgery was considered to have only a minor effect on weight-bearing function or lameness, which was improved from the preoperative

period. Thus, CrCLR cases with different conditions could achieve lameness recovery after TTA with porous titanium implants. The progression of OA may be a risk factor for a lower quality of life even if weight-bearing function is recovered after TTA. Therefore, these data suggest that TTA with porous titanium implants may be the preferred treatment in the early stages of cruciate ligament rupture disease in dogs.

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## Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

## Informed consent

The study did not entail any experimental procedures, as the surgical techniques and equipment utilized are commonly employed in contemporary veterinary orthopedic practice. According to the national regulations of the country in which the study was conducted, ethical committee approval was not required for retrospective clinical investigations of this type.

## Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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