Comparison of Healing of the Osteotomy Gap after Tibial Tuberosity Advancement with and without Use of an Autogenous Cancellous Bone Graft

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Objective: To evaluate and compare healing, with and without the use of bone graft, of the gap created during tibial tuberosity advancement (TTA).
Study Design: Prospective study and case series.
Animals: Dogs treated with TTA (n = 67).
Methods: Prospective study: Mediolateral radiographic projections (6 weeks and 4 months) after TTA without use of bone graft (group I, n = 14) were compared with radiographs of consecutive TTA in which the gap was filled with autologous cancellous bone graft (group II, n = 14). Two scoring techniques (A, B) were used. Score A was used to grade the overall osteotomy healing (0 = no healing, 4 = healed osteotomy). Score B evaluated, independently of each other, healing in 3 sites: proximal to the cage (B1), between cage and plate (B2), and distal to the plate (B3). Case series: nongrafted TTA (4–25 weeks, n = 39) were evaluated for healing (Score A). Data was analyzed using t-tests and ANOVA. Significance was set at $P \leq .05$.
Results: Prospective study: Score A, B2, and B3 showed no difference in healing between groups at 6.8 weeks and 4.2 months. Score B1 revealed, in both rechecks, a significantly higher density in group II. Case series: Radiographs at 11.59 ± 5.99 weeks scored 3.3 (2–4). No healing related complications were observed.
Conclusion: The osteotomy gap created during TTA healed within expected time regardless of bone graft use.

Tibial tuberosity advancement (TTA) was developed to restore dynamic stability in cranial cruciate ligament (CCL) deficient stifles.[1,2] Stability is accomplished by osteotomy of the tibial tuberosity in the frontal plane with advancement of the insertion of the patellar ligament.[1,2] By changing the angle between patellar tendon and tibial plateau to 90° during the stance phase of the gait, shear forces are eliminated and the stifle is rendered dynamically stable.[1] In vitro experimental studies validated the mechanics of TTA,[3–6] and clinical reports showed satisfactory function after surgery.[7–10]

In the original technique description, advancement of the patellar tendon was achieved by using cages of different sizes as spacers between the tibial tuberosity and the tibial metaphysis.[7–12] The gap created with the advancement of the tibial tuberosity varied from 3 to 12 mm depending on cage size. As initially recommended, the opening wedge was filled with autogenous cancellous bone graft taken from the tibial metaphysis, caudal to the osteotomy.[2,7,8,11,12] Other reported options are to harvest the graft from the distal aspect of the femur[9,10]; to use allograft[10]; xenograft[13]; to position a block of tricalcium phospate[2]; or to fill the defect with nanohydroxyapatite.[14] We are unaware of studies prospectively evaluating healing of the gap created by TTA.

Use of autogenous cancellous bone graft increases operative time and morbidity.[15–23] Adding commercially available allograft is convenient,[10] but increases the cost, ~US$200/patient.[19] Nanohydroxyapatite paste (Ostium®; Heraeus Kulzer Inc., Armonk, NY) increase costs ~US$100/dog.[19] Healing seems to occur regardless of the grafting material used[7–10,13,14] and use of bone graft to stimulate healing of the TTA gap may not be needed based on previous clinical reports.[2,14] Eliminating this additional

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surgical procedure may decrease the cost and morbidity of TTA.

We hypothesized that healing of the gap created during TTA will occur in absence of any grafting material in a clinically acceptable time range. To address this we conducted 2 studies. In the 1st study, we used radiography to evaluate and compare healing of the osteotomy gap with, and without, use of fresh autogenous cancellous bone graft taken from the proximal aspect of the tibia. Our null hypothesis was that radiographically determined healing would not differ between grafted and nongrafted TTAs. In 2nd study, healing in a larger group of nongrafted dogs was evaluated. We hypothesized that this group of dogs would heal without complications in a time range reported previously as normal for TTA healing.[7–10]

MATERIALS AND METHODS

All owners signed a consent form allowing all documentation regarding their dog to be used for scientific research and publication. The study had 2 components, a pilot study to test our null hypothesis, and a 2nd study in which all the dogs operated after conclusion of the pilot study, and that had at least 1 radiographic recheck were evaluated.

In the pilot study, 14 TTA were performed in 14 client-owned dogs representing 6 different large breeds. TTA was performed without harvesting bone graft from the proximal aspect of the tibia and without filling the opening gap with any grafting material (group I). Care was taken to preserve the original blood hematoma at the osteotomy site. All dogs were skeletally mature and had complete or partial CCL rupture. Data retrieved from medical records included breed, body weight, age, gender, TTA cage size, and time of radiographic examinations. Follow-up mediolateral radiographs taken at ~6 weeks and ~4 months postoperatively were evaluated.

A control group of 14 TTA performed in 11 client-owned dogs representing 8 different large breeds were grafted with autogenous cancellous bone graft obtained from the tibial metaphysis, caudal to the osteotomy (group II).[7,8]

Two radiologists independently evaluated progression of healing unaware of the TTA procedure details, using 2 different scoring techniques (A, B). Score A validated in another study,[9] uses 5 possible scores: 0 = no bone healing; 1 = early bone production without bridging between the tibial tuberosity and the shaft of the tibia; 2 = bridging bone formation at 1 site; 3 = bridging bone at 2 sites; and 4 = bridging bone at 3 sites. The sites were defined as the region of osteotomy proximal to the cage, between the cage, and the plate, and distal to the plate (Fig 1). Score B score evaluated, independently of each other, bone healing in the same 3 sites: B1 = the region proximal to the cage; B2 = the region between the cage and the plate; and B3 = the anatomic region distal to the plate. A 0–3 scale was used in each region: 0 = no bone healing; 1 = density of callus less than normal; 2 = density of callus equaling density of original bone; and 3 = density of callus higher than original bone. Original bone density was defined as bone density in the tibial shaft ~1 cm caudal to the osteotomy site and distally from where graft was harvested in group II (Fig 2).

Figure 1 Six weeks follow-up radiograph of a nongrafted tibial tuberosity advancement. Score A evaluates healing of the osteotomy at the areas proximal to the cage, between plate and cage, and distal to the cage (arrows). Score 0 = no bone healing in any area; 1 = early bone production without bridging between the tibial tuberosity and the shaft of the tibia; 2 = bridging bone formation at 1 site; 3 = bridging bone at 2 sites; and 4 = bridging bone at all 3 sites.

In the 2nd study, after completion of the pilot study, all dogs that had TTA performed (December 2007–January 2009) did not have a bone graft and had at least 1 follow-up radiographic examination to evaluate healing. Two radiologists independently, and unaware of the time interval after surgery evaluated the radiographs using scoring method A. Data retrieved from medical records included breed, body weight, age, gender, TTA cage size, and time of radiographic examination.

Statistical Analysis

In the pilot study, group variables were compared. To evaluate the 2nd study, an absolute risk score was made with a residual analysis to assess temporal healing and to correlate healing with age, body weight, and TTA cage size. Data was analyzed using software (StatView 5.1, SAS Institute

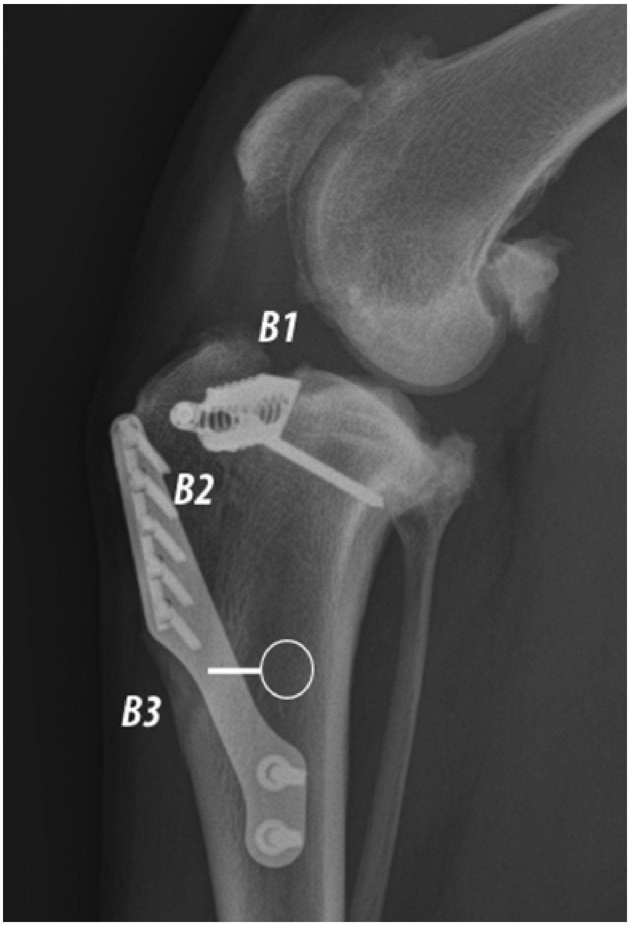

Figure 2 Ten weeks radiograph of a nongrafted tibial tuberosity advancement . Score B evaluated, independently of each other, bone healing in 3 sites described in Fig 1: B1, region proximal to the cage; B2, region between the cage and plate; and B3, region distal to the plate. A 0–3 scale was used for each site: 0 = no osseous healing; 1 = callus density less than normal; 2 = callus density equaling density of original bone; and 3 = callus density higher than original bone. Original bone density was defined as bone density in the tibial shaft ~1 cm caudal to the osteotomy site and distally from where graft was harvested in group II (circle with a 1 cm scale).

Inc., Wangen bei Dübendorf, Switzerland). Unpaired t-tests was used for the univariate analysis, i.e. {y f(x) = score B = f(group)}, and factorial ANOVA was used for the multivariate analysis: i.e. {y f(x) = score B f(group, time, localization)}. Statistical significance, i.e. error type 1, was set at $P \leq .05$. The power (type 2 error), was set at 0.8 if not stated otherwise. Results are presented as mean ± SD.

RESULTS

Pilot Study

Group I comprised 14 TTA in 14 large breed dogs (2 intact and 7 spayed females, 3 castrated and 2 intact males; mean weight, 30.6 ± 14.5 kg; mean age, 5.2 ± 2.6 years). Breeds were mixed breed (5 dogs), Golden Retriever (3), Bernese Mountain Dog (2), Dalmatian (2), Dogue de Bordeaux (1), Belgian Shepherd Dog (1). TTA cage size range was 3–9 mm (mean, 6.2 ± 1.2 mm). First radiographic control was performed at 6.9 ± 1.2 weeks and the 2nd control was at 4.29 ± 0.45 months.

Group II comprised 14 TTA in 11 large breed dogs (3 intact and 4 spayed females, 4 castrated males; mean weight, 33.6 ± 6.7 kg, mean age, 5.9 ± 2.6 years). Breeds were mixed breed (n = 4 dogs, 6 stifles), Hovawart (1, 2), Boxer (1), German Shepherd Dog (1), Labrador Retriever (1), Cocker Spaniel (1), Saint Bernard (1), Golden Retriever (1). TTA cage size range was 6–9 mm (mean, 7.5 ± 1.5 mm). Radiographic controls were performed at 6.8 ± 1.1 weeks and at 4.21 ± 0.55 months. No significant difference was detected in age, body weight, TTA cage size, and time of radiographic controls between groups.

At 6 weeks, score A was 3.03 ± 0.57 for group I and of 3.10 ± 0.76 for group II, and at 4 months, was 3.64 ± 0.57 for group I and 3.82 ± 0.37 for the group II (Fig 3). There was no significant difference in score A between group I and group II at either 6 weeks or at 4 months (power, 0.8). A significant difference in score A was found between 1st and 2nd follow-up ($P \leq .05$).

Score B1 at 6 weeks was 0.83 ± 0.60 for group I and 1.80 ± 0.82 for group II, and at 4 months was 1.44 ± 0.73 for group I and 2.05 ± 0.61 for group II. There was a significant difference between groups, with increased healing evident in the grafted group (P = .0015) at 6 weeks and again at 4 months (P = .024; Fig 4).

Score B2 at 6 weeks was 1.50 ± 0.49 for group I and 1.36 ± 0.39 for group II, and at 4 months, was 1.93 ± 0.65 for group I and 1.64 ± 0.27 for group II. Score B3 at 4 weeks was 1.46 ± 0.52 for group I and 1.07 ± 0.51 for group II, and at 4 months was 2.00 ± 0.48 for group I and 1.86 ± 0.65 for group II (Fig 5). There were no significant differences between groups for scores B2 and B3 at 6 weeks or at 4 months (power, 0.8). In both groups, the density of bony healing increased at all 3 sites from 6 weeks to 4 months (P = .0467; Fig 6).

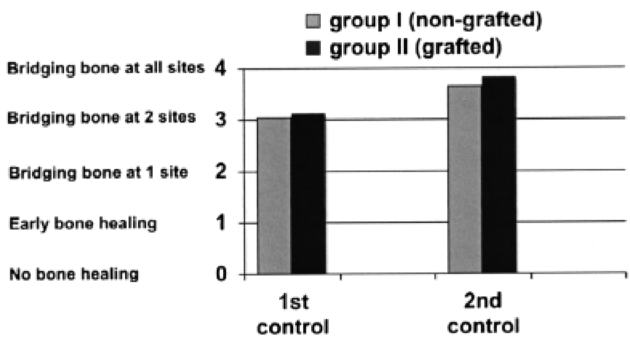

Figure 3 Chart illustrating score A results at the 1st (6.8 weeks) and 2nd (4.2 months) radiographic follow-up. No difference in healing was observed between grafted and nongrafted groups at each time, but healing progressed significantly with time.

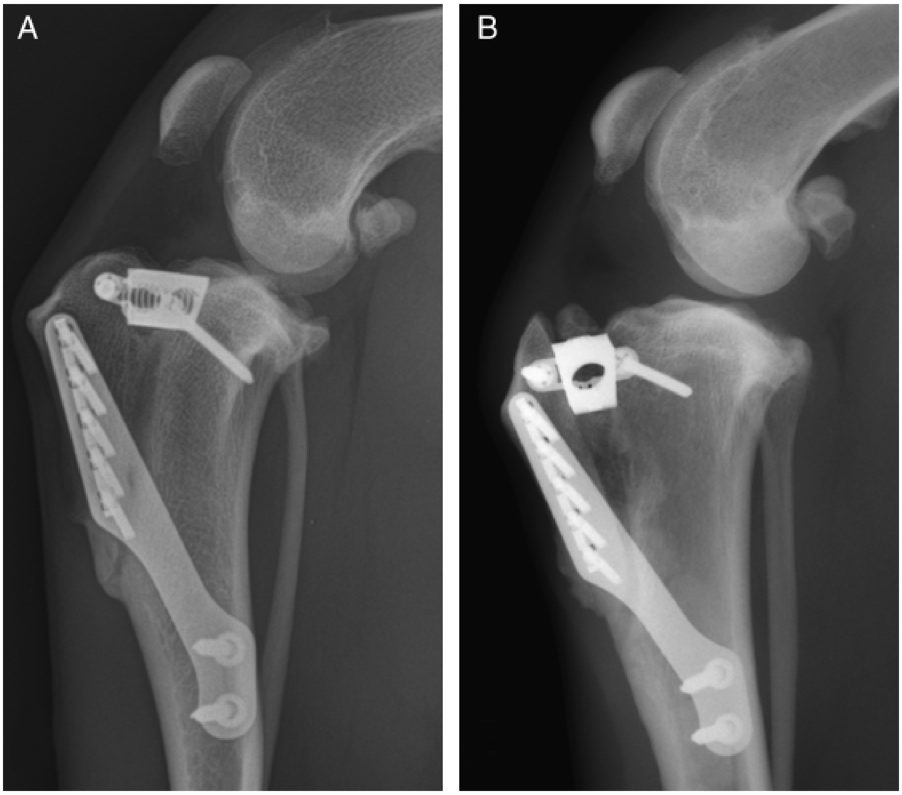

Figure 4 Initial radiographic follow-up of a group I (A) and a group II (B) dog. Less healing is observed in the area proximal to the cage in the nongrafted dog (A).

Prospective Clinical Study

Thirty-nine stifles of 39 dogs (20 spayed females, 13 castrated and 6 intact males; mean weight, 29.2 ± 11.6 kg; range, 7.3–62 kg; mean age, 5.9 ± 2.97 years; range, 1–12 years) met the inclusion criteria. Breeds were mixed breed dogs (n = 9), Labrador Retriever (3), Rottweiler (2), Border Collie (2), Beagle (2), German Boxer (2), Continental Bulldogs (2), and 1 each of White Swiss Shepherd, Australian Shepherd Dog, Kangal, Maremmano, German Shepherd Dog, Akita Inu, West Highland White Terrier, Jack Russell Terrier, Dogue de Bordeaux, Flat Coated Retriever, Golden Retriever, Vizsla, American Staffordshire Terrier, American Bulldog, Bergamasco, Doberman Pinscher, and Laika Dog. TTA cage size was 3–12 mm: 3 mm (n = 2), 6 mm (19), 9 mm (15), and 12 mm (3).

Follow-up radiographs were taken at 11.59 ± 5.99 weeks after surgery (range, 4–25 weeks). Mean healing score (Score A) was 3.3 ± 0.68 (range, 2–4). Dogs with longer follow-ups had higher healing scores by means of single score regression analysis over time ($P \leq .05$) with 89.7% stifles scoring 3 or 4 at follow-up.

Osteotomy gap healing was considered complete (grade 4) in 23 stifles (59%) at recheck. Mean follow up was 14.56 ± 5.92 weeks (range, 6–25 weeks). Twelve stifles (31%) scored 3, and 4 stifles (10%) scored 2. Radiographs of stifles scoring 3 were taken at a mean time of 8.16 ± 3.24 weeks (range, 6–15 weeks), and those of stifles scoring 2 were taken at 5 ± 1.15 weeks (range, 4–6 weeks). No healing related complications were detected. Extent of healing was not dependent on age, body weight, and/or size of TTA cage.

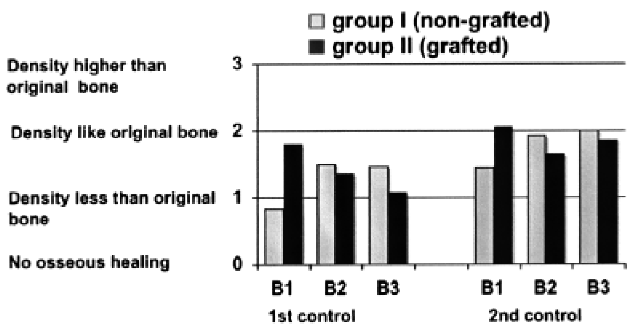

Figure 5 Chart illustrating score B results at 1st (6.8 weeks) and 2nd (4.2 months) radiographic follow-up. Site B1 had significant differences between grafted and nongrafted groups at each time. No differences were observed for sites B2 and B3. Healing progressed significantly with time.

DISCUSSION

All of the TTA procedures performed with (n = 14) and without (n = 53) fresh autogenous cancellous bone graft had acceptable healing of the gap. Partial healing of the

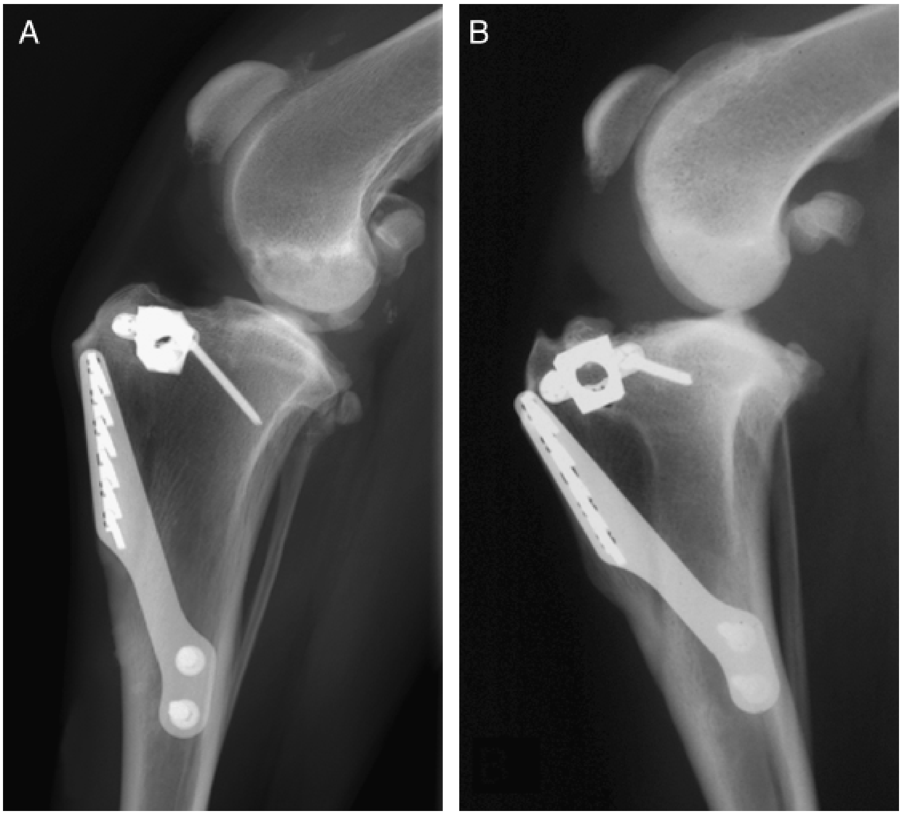

Figure 6 Radiographs (4 months) of a grafted dog (A) and a nongrafted dog (B). Score A showed no differences in healing between groups. Score B showed, except from the area proximal to the cage, no differences in healing.

gap was observed in both groups at ~6 weeks after surgery and increased with time. According to our results, after a mean of 8 weeks, the osteotomy should be healed in at least 2 sites providing enough stability to prevent implant failure. Complete healing of the osteotomy gap can be expected to occur at 3 months after surgery in most dogs.

Use of bone graft has been recommended in fractures with gaps or comminution, and in instances where fracture score is low.[15,21,24] In the initial clinical reports of the TTA technique, bone grafting was recommended because of the gap created by advancing the tibial tuberosity. We found that all osteotomy gaps healed regardless of use of a graft. It is likely that the metaphyseal location of the osteotomy with its rich blood supply and abundant cancellous bone, are major factors in gap healing with and without bone graft.[24,25] Compared with fractures, during TTA an osteotomy is performed under controlled conditions, cooling to reduce thermal necrosis, and avoiding damage to the adjacent soft tissues. These soft tissues will provide the extraosseous blood supply contributing to the healing of the gap.[24,25] Additionally, in the nongrafted dogs, care was taken to preserve the hematoma, formed immediately after osteotomy. This blood clot contributes growth factors, and stimulates angiogenesis and bone formation.[24] The osteotomized tibial tuberosity is immediately stabilized with a plate, creating optimal healing conditions. These are probably the most important reasons why no difference was found between groups.

Two scores were used to evaluate healing. Score A, validated in a previous study,[9] was used to compare healing in the pilot study, and to compare healing of our case series dogs with other reports.[7,9,10] Using this score, in the pilot study, we could not identify differences in healing between groups. Score B, used in the pilot study to evaluate bone healing in the 3 different sites of the osteotomy gap separately, showed that except from the area proximal to the cage, the osteotomy gap healed at similar times regardless of bone graft use. In the grafted group, bone graft was packed in this area and this may have enhanced healing in a location in which the retropatellar fat pad is otherwise present. The reduced healing in this area, in nongrafted dogs, did not result in any recognized clinical problems.

During development of the TTA technique, many cages were positioned in the osteotomy gap lower than what is actually recommended, leaving a larger area proximal to the cage to be filled with new bone. The current recommendation is to position the cage at 1–3 mm distal to the tibial plateau,[9,10] and less bone formation is expected to occur in this area. Our main concern was healing in the area between cage and plate (B2), where a large empty gap is present and where poor graft mineralization was reported in 3% of stifles operated with the use of allograft.[10]

No difference between treatment groups was observed at this site in our dogs.

A limitation of the pilot study is the small number of dogs. We compared healing between 2 groups of 14 dogs each, and this may be not enough to obtain conclusive results, but using a small group was justified to get early evaluation and not to expose too many patients to the risk of a nonunion at the TTA site. Both groups were not significantly different in body weight, age, and TTA cage size. These are variables that may influence bone healing, and the similitude between groups, made our results more reliable. Based on the results of the pilot study, we no longer graft TTA. Subsequent cases were radiographically evaluated and scored (score A). Healing occurred progressively with timing comparable to previous studies.[7,9,10] Complete healing occurs at ~11 weeks[9,10]; however 1 study[10] does not report how healing was evaluated making comparison difficult. We found complete healing at a mean time of 14.56 weeks, but because only 1 radiographic control was performed, the exact point of complete healing cannot be ascertained and is presumably before this time. Many of our dogs had radiographic follow-up at >16 weeks. Eliminating these dogs, yielded a mean time to complete healing of 11 weeks, which compares similarly with other reports.[9,10]

Partial healing (scores 2 and 3) was observed in our study at 5 and 8 weeks after surgery, again comparable to other studies.[7,9]

Evaluation of bone healing was performed subjectively, representing another limitation of our study. Although limited, radiography is still the most commonly used imaging tool for bone healing evaluation.[24,26] Additionally, this technique is noninvasive and widely available in clinical practice. Objective methods to evaluate bone density, such as computed tomography, have been used in veterinary medicine. We chose not to use computed tomography because of presence of metal in the scanning area and the potential presence of artifacts.

Orthogonal radiographic projections of the stifle were obtained in every dog, but only mediolateral projections were used to evaluate bone healing. The superimposition of the tibial tuberosity and caudal cortex of the tibia makes evaluation of bone healing very difficult in the craniocaudal projection. Therefore, this projection was only used to ensure absence of complications.

Nine mm cages are the most commonly used, and together with the 6 mm cages, represent about 95% of the TTA cage sizes used.[9] No 12 mm cages were used in the pilot study, and only 3 in the 2nd study. Apparently, based on our clinical experience, large advancements heal similarly to 6 and 9 mm cage advancements, but to obtain conclusive results, more cases using large size of cages may be needed.

Use of fresh autogenous cancellous bone graft increases surgical time,[21] and an additional surgical approach may be needed, increasing morbidity.[16] Other disadvantages of the use of fresh autogenous cancellous bone graft are fracture at the donor site,[16,20,22,23] postoperative bleeding,[15,16] seroma formation,[22] and infection.[21] In people, a well-known sequela of harvesting autogenous bone graft is chronic pain that may last for >6 months.[17,18] This has not be documented in animals, but additional surgical trauma and a separate approach to harvest bone graft from the distal femur[9,10,19] may cause unnecessary pain and discomfort.

Using commercially available allograft,[10,19] or another bone substitute[13,14] are reported options to avoid harvesting autograft, but these options increase the surgical costs, making them unattractive in many countries, and apparently are not necessary.

We concluded that the osteotomy gap created during TTA healed with or without bone graft at similar rates, comparable to those reported previously,[9,10] making the use of bone graft unnecessary. This reduces operative time, morbidity, and/or costs. In agreement with previous work,[9] dog age did not appear to influence bone healing at this site. Based on our results, we do not recommend use of a bone graft to fill the TTA osteotomy gap in any dog; however, we stress that care should be taken to minimize surgical trauma and thermal necrosis, and the surgically induced blood clot should be retained. We also advise that dogs should have restricted activity for the 1st 6 weeks postoperatively until the 1st follow-up radiographic examination is performed. If incomplete bone healing is observed, a gradual increase in the dog's activity for 2–3 weeks is recommended before allowing return to normal activity.

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