Clinical Applications of Demineralized Bone Matrix: A Retrospective and Case-Matched Study of Seventy-Five Dogs

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Objectives—To evaluate the outcome in dogs treated with demineralized bone matrix (DBM) as an adjunct to orthopedic procedures.

Study Design—Retrospective and case-match study.

Animals—Dogs (n = 75).

Methods—Medical records (1999–2006) and radiographs of dogs that had orthopedic procedures (comminuted fractures, tibial plateau leveling osteotomy [TPLO] where correction for tibial rotation created an osteotomy gap, arthrodeses, open corrective osteotomies) where DBM was used were reviewed for signalment, quantity of DBM implanted, duration of exercise restriction, radiographic healing, and complications. Dogs that had TPLO and correction of tibial torsion (n = 15), or arthrodesis (n = 16) were compared with case-matched controls. Data were analyzed using Kruskal–Wallis test, ANOVA, Tukey’s HSD test, and logistic regression analysis.

Results—Mean (± SD) healing time for orthopedic surgeries with DBM augmentation were 15 ± 6.97 (weeks) and complication rate was 19% (14 dogs). Dogs with a TPLO gap filled with DBM were allowed to return to normal exercise 2 weeks earlier than dogs with a well-apposed TPLO site. Radiographic healing, duration of exercise restriction, and timing of destabilization were similar in dogs undergoing carpal and tarsal arthrodesis whether they received DBM, autogenous graft, or both.

Conclusions—DBM can be used to treat uncomplicated bone defects associated with comminuted fracture repairs, open osteotomies, and arthrodeses in dogs. Under these circumstances, clinicians might expect similar clinical outcomes without the possibility of side effects associated with the harvest of autogenous cancellous bone.

Clinical Relevance—DBM is safe for use in dogs.

INTRODUCTION

Autogenous cancellous bone graft is used in dogs with bone defects, with fractures with a low mechanical and/or biological assessment score, delayed unions, nonunions, or arthrodeses. Autogenous cancellous bone is the most effective material for promoting rapid healing, and is considered the “gold standard” when evaluating bone-graft substitutes. Cancellous bone autograft contains osteoinductive factors, offers a scaffold for osteoprogenitor cells, and provides viable cells without stimulating immune reactions or causing disease transmission.1,2 Although complications have been reported after harvesting of autograft in dogs, their incidence remains unknown.3 In humans, morbidity associated with the collection of autogenous bone approaches 25%, with major complications occurring in 3–4% of patients.4,5 Complications include pain, sepsis, stress fractures, intraoperative blood loss, increased surgical time, and limited supply.1,3,5,6

Concerns with limited availability and associated complications have prompted the search for bone-graft sub-
ststitutes. One strategy is to identify a single purified molecule, which could ultimately be confirmed as the agent of choice for clinical promotion of bone healing and regeneration, for example, bone morphogenic protein (BMP). 7 More than 13 BMPs have been identified. 8–19 Synthetic agents do not carry any risk of disease but do not contain the optimal mixture of growth factors naturally present in bone-derived products. Because osteoinductive proteins are water soluble and readily diffusible, they must be combined with a biocompatible carrier to be effective. However, combination with bovine-derived collagen may affect its future as a delivery system for growth factors in man. 20–23 Although rh-BMP2 has recently been clinically used in dogs, the cost of these preparations remains prohibitive. 24, 25

Another strategy is to identify an optimal mixture of bone-growth agents, either concocted from purified agents, or generated biologically as the product of a tissue or a cultured cell, such as demineralized bone matrix (DBM). DBM is the most common source of partially purified bone-inducing factors used in human patients. 26–29 The allogenic bone is chemically sterilized (typically combined with demineralization process) rather than irradiated to preserve osteoinductive properties. 30 DBM provides osteoconduction with the collagen network naturally present in bone, and osteoinduction by the inherent BMPs liberated during demineralization. The processing of commercial canine DBM allograft including the removal of the peristium, cartilage, and bone marrow, and freezing have been shown to reduce immune reactions. 31 Commercial preparations (such as Grafton, Osteotech [Eatontown, New Jersey, USA]; Osteofil, Sofamor Danek Group Inc. [Memphis, Tennessee, USA]; Opteform, Exactech Inc. [Gainesville, Florida, USA]; DynaGraft, GenSci Regeneration Sciences [Toronto, Ontario, Canada]) differ in manufacturing process and carrier, which, along with their natural origin results in a somewhat variable efficacy. 30, 32 DBM is available for human use in a variety of forms including fibers, flex, moldable gel, putty, as well as an injectable version. Because DBM lacks structural properties, it should only be used as a gap filler in nonweight bearing areas. Frozen canine DBM has been commercialized in the United States in 1 and 3 mL units since 1996 and is now available as a freeze-dried product.

Use of DBM as a substitute or adjunct for autogenous cancellous bone graft has been evaluated experimentally in dogs and clinically in cats and horses. 33, 34 Frenkel et al. 35 showed that DBM gel enhanced spinal fusion compared with decortication or autograft alone in 7 dogs. DBM promoted complete closure of 15 mm diameter defects in the parietal bone of rabbits by 12 weeks and was more effective than calcium sulfate, poloxamer gel, or calcium phosphate cement. 36 DBM bone from either the tibia or calvaria induced similar bone formation when compared with autograft in calvarial defects in 40 growing puppies. 37 Unstable radial ostectomies in 6 beagle dogs progressed to nonunion, whereas bone healing occurred comparably when DBM or autogenous bone graft was inserted in the ostectomy gaps. 38

Our objectives were to review the use of DBM as a gap filler in dogs that had orthopedic surgery. We hypothesized that healing of DBM grafted defects would be similar to (1) that of defects (comminuted fractures, open corrective ostotomies, and arthrodeses) grafted with autogenous bone or; (2) well apposed osteotomies (tibial plateau leveling ostotomies [TPLOs]).

MATERIALS AND METHODS

DBM

The allograft we used consisted of cancellous chips mixed with DBM (Fine mix, Veterinary Transplant Services, Kent, WA). This graft is manufactured from bone aseptically harvested from animals euthanatized for reasons unrelated to tissue transplantation (trauma or aggression) after owner consent. This bone graft combines demineralized cortical bone powder (particle size 125–1180 μm) and mineralized cancellous bone chips (particle size 125–1260 μm). Bone powder is demineralized by exposure to 0.6 N hydrochloric acid and buffered back to a slightly acidic pH. Demineralized bone powder and cancellous chips from the same batch are combined in a 50:50 ratio, before microbial culture and freezing.

Inclusion Criteria

Medical records (1999–2006) of all dogs treated with DBM were reviewed. Dogs were included if DBM was used instead of autogenous graft to treat bone defects associated with comminuted fractures, TPLO in which correction for tibial rotation caused an osteotomy gap, arthrodesis, or open corrective ostotomies; and if clinical and radiographic follow-up had been performed at our hospital. Dogs with osteomyelitis, delayed union, nonunion, or neoplasia were excluded from the study.

Signalment, diagnosis, indication, quantity of DBM used (1, 2, 3, 4, 5, or 6 mL), time when radiographic union occurred, and number and type of complications were obtained from the medical record. Time at which the clinician recommended a gradual return to normal exercise was noted. Complications were defined as any undesirable outcome secondary to the surgical procedure.

Two subsets of dogs that had been treated by standardized procedures—(1) TPLO with tibial rotation correction and (2) carpal or tarsal arthrodesis—were identified from this population. Case-matched control animals were identified for each group of dogs.

Case-Matched Study

TPLO Group. Dogs included in this group had TPLO with correction of tibial torsion and DBM was used to fill the
ostectomy gap.\(^{39}\) The degree of tibial torsion was estimated based on a combination of radiographs and computed tomodiagram of the tibia. Correction was performed if the internal torsion of the tibia was estimated to be ≥ 10°. Control dogs had TPLO without correction of tibial torsion and had good apposition of the osteotomy site so bone grafting was not warranted. Dogs were matched based on age, body weight, and breed. Whenever possible, the contralateral limb was used as the match. In cases where the contralateral limb was used, tibial torsion was either absent or estimated to be < 10°, and therefore not corrected.

TPLOs were stabilized with a 6 hole, 3.5 mm TPLO plate (Slocum Enterprises Inc., Eugene, OR). A soft padded bandage with a lateral splint or modified Robert Jones bandage was placed for 24-48 hours postoperatively to reduce swelling. Postoperative pain management included the administration of opioids and either carprofen or deracoxib for 7–10 days postoperatively.

Outcome measures included radiographic bone healing and duration of postoperative exercise restriction. A recommendation to return to normal exercise was based on complete orthopedic examination and subjective evaluation of radiographs by a surgeon. This recommendation was made when dogs were not lame at a walk, had regained normal pain-free range of motion of the knee, were not painful on palpation of the surgical site, and had radiographic evidence of a callus subjectively bridging most of the osteotomy. At this point, owners were instructed to return to preinjury schedule of walks on a leash and add supervised off-leash exercise 5–10 minutes, 3 times daily for 1 week. Duration of off-leash exercise was increased to 15 minutes, 3 times per week the following week. By the 3rd week, dogs were allowed to return to their preinjury exercise regimen. Owners were contacted by phone 3 weeks later to verify that dogs effectively returned to their preoperative level of activity and did not have any complications.

The time at which this recommendation was made scored as 1 = if the recommendation was made within 6 weeks after surgery; 2 = if the recommendation was made > 6 weeks but <12 weeks after surgery; 3 = for recommendations made at 12 weeks; and 4 = when gradual return to normal exercise was not recommended until >12 weeks after surgery. A scoring system was also used to grade radiographic evidence of bone union on lateral and craniocaudal projections obtained at 6-week intervals: grade 1 = healing osteotomy with little bone activity; 2 = presence of bridging callus across the osteotomy; and 3 = healed osteotomy (radiographic union) where at least 50% of the radiolucent osteotomy line was no longer visible (Fig 1). All radiographs were scored by a board-certified radiologist unaware of the study groups.

**Arthrodesis Group.** Dogs in this group had carpal or tarsal arthrodesis using either an external fixator or dynamic compression plate for stabilization of the arthrodesis and DBM (Group 1) or a combination of DBM and autogenous cancellous bone (Group 2). If a bone plate was used, external coaptation in the form of a splint was provided. Control dogs were treated with carpal or tarsal arthrodesis and autogenous cancellous bone. Dogs were matched based on the treated joint (carpus or tarsus), method of fixation (external fixator or bone plate), age, and body weight.

Outcome measures included the time for removal of the external fixator or splint, time at which gradual return to exercise was recommended, and radiographic evidence of bone formation across the joint. Time to external fixator or splint removal and time to return to function was translated into a scoring system where 1 = ≤ 6 weeks; 2 = >6 to ≤12 weeks; and 3 = >12 weeks, which was commonly around 18 weeks.

Radiographs obtained immediately after surgery and at 4–6-week intervals were graded by a board-certified radiologist unaware of group assignment. A score was assigned based on the widest joint space measured between tarsal/carpal bones on lateral, dorsopalmar/plantar, and oblique projections. A score of 0 = presence of a gap>3 mm; 1 = 3 mm gap; 2 = gap>2 up to 3 mm; 3 = 1–2 mm; 4 = <1 mm; and 5 = no joint space visible (radiographic union, Fig 2).

**Statistical Analysis**

Data for the retrospective study, including signalment, body weight, and quantity of DBM used was analyzed using software (Systat 11, Systat Inc., Richmond, CA) and expressed as a mean ± SD. Because discrete quantities of DBM were used (1, 2, 3, 4, 6 mL), and 57 of 75 dogs received 1 mL,
the Kruskal–Wallis test was used to compare the frequency distributions of the quantities of DBM used between each of the treatments indications. ANOVA and Tukey’s HSD test were used to determine if significant differences between healing times existed. ANOVA and logistic regression analysis were used to compare complication rates among the 4 orthopedic treatments. Radiographic healing scores, time to return to function, and removal of external fixation or splint (if applicable) for the case-match studies were analyzed using Proc Regress in SUDDAN 9.0 (Research Triangle Institute, Research Triangle Park, NC). For all analyses, \( P \leq .05 \) was considered significant.

**RESULTS**

**Retrospective Study**

**Signalment.** Seventy-five dogs met the criteria for inclusion. Mean (± SD) age of dogs treated with DBM was 4.7 ± 3.8 years (minimum, 3 months; maximum, 16 years). Thirty-three dogs were female (44%; 6 intact, 27 spayed) and 42 dogs were male (56%; 12 intact, 30 castrated). The most common breeds included mixed breed (20); Labrador Retriever (8); Shetland Sheepdog and Pitbull (3 each); and Siberian Husky, Rottweiler, Maltese, Golden Retriever, German Shorthair Pointer, American Eskimo, and Bull Mastiff (2 each).

**Indications for DBM.** Uses included fracture repair (n = 33), TPLO (15), arthrodesis (20), and corrective osteotomy (7). All fractures were closed, comminuted, and involved the diaphysis of the humerus (n = 5; 15%), radius/ulna (9; 27%), femur (14; 42%), tibia/fibula (4; 12%), or metatarsals (1; 3%). Fractures were repaired using open reduction and internal fixation (29; 88%) or external skeletal fixation (4; 12%). Indications for arthrodesis included traumatic luxations (7; 35%), hyperextension injuries (7; 35%), degenerative joint disease (3; 15%) including 2 previous shearing wounds and 1 pre-
vious radial carpal bone fracture, valgus deformity (1; 5%), repair of a failed arthrodesis (1; 5%), and primary treatment of a shearing wound (1; 5%).

**DBM Used.** Mean amount of DBM used was 1.5 ± 0.99 mL (minimum, 1 mL; maximum, 6 mL). Fifty-seven of 75 dogs (76%) received 1 mL, 1 dog received 2 mL (1%), 15 dogs received 3 mL (20%), 1 dog received 4 mL (1%), and 1 dog received 6 mL (1%). Fractures were treated with an average of 1.68 ± 1.41 mL of DBM (minimum, 1 mL; maximum, 6 mL). TPLOs were treated with an average of 1.27 ± 0.7 mL DBM (minimum, 1 mL; maximum, 3 mL), arthrodeses were treated with an average of 1.35 ± 0.88 mL DBM (minimum, 1 mL; maximum, 4 mL), and corrective osteotomies were treated with an average of 1.57 ± 0.98 mL DBM (minimum, 1 mL; maximum, 3 mL). There was no significant difference in the quantity of DBM used for each orthopedic procedure (*P* > .43), although there was a bimodal distribution where patients were usually treated with either 1 or 3 mL DBM.

**Complications.** The overall complication rate was 18.7% (14 of 75 dogs). Eight of 33 dogs with fractures had complications including a loose screw (1), delayed union (2), nonunion (3), and implant failure (2). Of these, 4 were not clinically consequential, and 4 (12%) required additional surgery, including grafting a delayed union and, nonunion, and repair of 2 failures. One of the dogs with delayed union went on to heal without additional therapy, 1 dog with nonunion was not clinically affected (showed no pain or lameness with normal function), and no additional therapy was recommended, and 1 dog with nonunion was presumed to have osteosarcoma and all were considered to have nonconsequential complications because no additional therapy was recommended.

Two of 15 dogs that had TPLO (13%) had complications including osteomyelitis and tibial tuberosity avulsion (1) and fibular fracture (1). Three of 20 dogs treated by arthrodesis had complications (15%) including osteomyelitis (1), nonunion (1), and fracture at a pin site (1). The arthrodesis diagnosed as a nonunion reached a radiographic score of 4, but no further progression of healing was noted during follow-up. There were no complications recorded for dogs with corrective osteotomies. Complication rate was not affected by the indication for DBM (fracture, corrective osteotomy, TPLO, or arthrodesis, *P* > .9). Complications that could possibly be related to use of DBM, including delayed union, nonunion, and osteomyelitis, occurred in 10.7% (8/75) of all cases including 6% (1/15) of TPLOs, 10% (2/20) of arthrodeses, and 13% (5/33) of fractures.

**Follow-Up Duration.** Mean follow-up was 14.5 ± 8.04 weeks (minimum, 2 weeks; maximum, 40 weeks). Return to normal activity was recommended at an overall mean of 15.6 ± 7.2 weeks (minimum, 8 weeks; maximum, 36 weeks). All dogs effectively returned to their preinjury activity without complication thereafter. Dogs were allowed to return to their preinjury activity at 15.0 ± 4.19 weeks (minimum, 12 weeks; maximum, 24 weeks) after fracture repair, 9.0 ± 2.58 weeks (minimum, 8 weeks; maximum, 12 weeks) after corrective osteotomy, and 11.4 ± 1.89 weeks (minimum, 6 weeks; maximum, 18 weeks) after TPLO. Exercise restriction was longer after arthrodeses (22.3 ± 10.09 weeks; minimum, 12 weeks; maximum, 36 weeks) than TPLO, fractures, or corrective osteotomies (*P* < .01).

**Radiographic Evidence of Healing.** Mean time to radiographic union was 15 ± 6.97 weeks (minimum, 8 weeks; maximum, 36 weeks). Time to radiographic union for fractures was 13.56 ± 2.40 weeks (minimum, 12 weeks; maximum, 16 weeks). Time to radiographic union for TPLO was 12.8 ± 1.78 weeks (minimum, 12 weeks; maximum, 18 weeks). Time to radiographic union for dogs treated by arthrodesis was 27.3 ± 11.72 weeks (minimum, 14 weeks; maximum, 36 weeks). Time to radiographic union for dogs treated by corrective osteotomy was 10 ± 2 weeks (minimum, 8 weeks; maximum, 12 weeks).

**TPLO Case-Matched Study.**

Fifteen dogs (7 spayed females, 6 castrated males, 2 intact males) had simultaneous TPLO, correction of tibial torsion, and DBM implantation at the osteotomy gap. Mean age was 5.33 ± 3.15 years (minimum 2 years, maximum 12 years) and mean body weight was 43.24 ± 14.74 kg (minimum, 18.64 kg; maximum, 69.10 kg). The contralateral limb was used as a match in 9 dogs and 6 other dogs were identified as case-matched controls. One dog and its control had previously undergone extracapsular repair of their CCL disease. In both cases, a K-wire was implanted in the tibial crest to prevent tibial crest fracture. Dogs treated with DBM (11.4 ± 1.89 weeks after TPLO and DBM) were allowed to return to exercise faster than dogs that did not receive DBM (13.69 ± 5.87 weeks; *P* < .01). Mean radiographic healing score at 6 and 12 weeks was 1.57 ± 0.76 and 2.88 ± 0.3, respectively, for dogs treated with DBM. Mean radiographic bone healing score at 6 and 12 weeks for controls was 1.71 ± 0.72 and 2.69 ± 0.75, respectively. There was no difference between the radiographic healing scores at 6 weeks (*P* > .9) or 12 weeks (*P* > .4) in the groups.

**Arthrodesis Case-Matched Study.**

Of 20 dogs treated by arthrodesis, 16 suitable case-matched controls of dogs treated with arthrodesis and cancellous autograft were identified.
Group 1. This group was 8 dogs treated by arthrodesis and DBM (4 tarsal arthrodeses, 4 carpal arthrodeses). All carpi and 3 of the tarsi in this group were stabilized with bone plates whereas an external fixator was used to stabilize 1 tarsal arthrodesis. Implants were similar in size within matched pairs. Mean age of this group was 5.1 ± 4.3 years (range, 1–14 years) and mean body weight was 23.6 ± 10.7 kg (range, 5.5–36.4 kg). Time to external fixator or splint removal ($P = .11$), duration of exercise restriction ($P = .35$), or radiographic healing scores at 6 weeks ($P = .37$), 12 weeks ($P = .71$), or 18 weeks ($P = .31$) did not differ between matched pairs.

External coaptation was removed at 11.9 ± 6.2 weeks in dogs treated with DBM compared with 9.5 ± 3.5 weeks in the group implanted with autograft. Dogs were allowed to return to normal activity after 18.5 ± 7.6 weeks in the DBM group and 18.6 ± 6.4 weeks in the autograft group. All arthrodeses had a radiographic score of 0 immediately after surgery. Mean radiographic healing score at 6 weeks was 2.5 ± 1.3 for the DBM-treated group and 2.0 ± 1.3 for the autograft group; 3.8 ± 0.7 for the DBM-treated group and 3.6 ± 1.1 for the autograft group at 12 weeks; and 4.2 ± 0.4 for the DBM-treated group and 4.2 ± 0.4 for the control group at 18 weeks.

Group 2. This group was 8 dogs grafted with DBM combined with autogenous cancellous bone (5 carpal and 3 tarsal arthrodeses). Two tarsal and all carpal arthrodeses were stabilized with bone plates, whereas an external fixator was used in 1 tarsal arthrodesis. Mean age was 5 ± 2.0 years (range, 2–7 years) and mean weight was 28.0 ± 11.0 kg (range, 3.6–40.0 kg). There was no significant difference between case matches in time to external fixator or splint removal ($P = .73$), exercise restriction ($P = .73$), or radiographic scores at 6 weeks ($P = .81$), 12 weeks ($P = .68$), or 18 weeks ($P = .26$). External coaptation was removed at 11.4 ± 2.5 weeks in dogs treated with a mixture of DBM and autograft compared with 11.0 ± 5.5 weeks in dogs treated with autogenous cancellous graft. Return to normal exercise was recommended 20 ± 8.9 weeks after surgery in dogs treated with DBM and autograft, compared with 21.3 ± 12.9 weeks in dogs treated with autograft alone. Mean radiographic healing scores at 6, 12, and 18 weeks were 2.3 ± 0.9, 3.7 ± 0.5, and 4.0 ± 0 for dogs treated with DBM and autogenous bone compared with 2.4 ± 1.4, 3.5 ± 1.2, 4.3 ± 0.5 for the autograft group.

**DISCUSSION**

Our principal findings were as follows: (1) overall healing time and complication rate in uncomplicated orthopedic surgeries augmented with DBM were 15 ± 6.97 weeks and 18.75% (14 of 75 dogs); (2) dogs undergoing TPLO and correction of tibial torsion, and DBM treatment of the osteotomy gap were allowed to return to normal activity about 2 weeks earlier than dogs with a well-apposed TPLO site; and (3) radiographic healing, duration of exercise restriction, and timing of destabilization were similar in dogs undergoing carpal and tarsal arthrodesis whether they received DBM, autogenous graft, or both.

Fractures vary tremendously in their severity, which can affect the methods available for fixation and the biological environment of the fracture. Trauma associated with fractures may cause reduced blood supply to bony fragments, and the process of internal fixation may further compromise the blood supply to the bony fragments, which can affect healing and may predispose to infection. The variability of mechanical and biologic characteristics of fractures prevented their inclusion in a case-matched study. Similarly, corrective osteotomies were not included in the case-match study because they vary in location, severity, and fixation technique. However, the sample size of this retrospective study allows some comparison of complication rates and healing times with previous reports. Reported healing time for fractures in dogs varies from 10 to 15 weeks, with ranges from 4 to 27 weeks. Although all fractures in our study were severe enough to prompt the surgeon to use a bone graft, mean healing time was 15.6 weeks, which is comparable to previous reports.

The percentage of complications after fracture repair and DBM implantation (24%) is comparable to published reports for fracture fixation where DBM was not used (21–33%). Similarly, the type and frequency of complications in dogs with fractures treated with DBM do not appear to differ from previously reported complications of fracture healing. The type and rate (2/15 or 13%) of complications after TPLO and DBM were also similar to previous reports of complications after TPLO. Complications have been reported in 18–28% of TPLOs and include intra-articular screw or pin placement, hemorrhage, dehiscence, infection, patellar tendon swelling, tibial tuberosity avulsion, osteomyelitis, loose implants, broken screws, fibula fracture, patella fracture, draining tracts, and septic arthritis.

The retrospective nature of our study and the lack of control group for the fractures did not allow us to specifically identify complications caused by DBM. However, DBM is an allograft and could potentially act as foreign material, inhibiting normal healing, and lead to delayed or nonunion. Its allogenic origin, manufacturing process, and storage may also raise concerns of contamination and carriage of micro-organisms into the fracture, causing osteomyelitis. Complications potentially related to DBM, including infection, delayed healing, and
nonunion were diagnosed in 13% (5/33) of fractures, 10% (2/20) arthrodeses, 6% (1/15) of TPLO, and none of the corrective osteotomy cases. Similar complications are reported in 10–19% of fractures, 6–7% of TPLOs, and 16–22% of arthrodeses where DBM was not used.40–48 Based on these values, DBM did not appear to increase the rate of complications in dogs that had uncomplicated orthopedic procedures.

Arthrodesis and TPLOs are procedures that are more standardized than fracture repairs and are therefore appealing as clinical models to study bone healing. These records were reviewed in a case-matched study to control variables that may affect bone healing such as weight, age, and type of fixation. The value of our study remains limited by the size of the population, especially in the arthrodesis group, where DBM was augmented with autograft in half of the cases. The control group consisted of dogs treated with a quantity of autograft that could not be accurately determined based on our retrospective review of their records. However, the goal of graft therapy is to fill bony defects. The quantity of graft placed in each dog was most likely similar because postoperative gaps were identical in all dogs. In addition, all dogs were matched to case controls based on their body weights; implants and joint spaces were therefore similar in size and most likely filled with the same quantity of graft material. A subjective scale of 0–3 has previously been proposed to evaluate radiographic healing of arthrodeses.49 To improve the objectivity of this assessment, our scoring system was based on the widest gap between carpal/tarsal bones. This measurement was based on 3 radiographic projections, to minimize the impact of radiographic positioning.

The control group in our TPLO case-matched study should ideally have included dogs with simultaneous correction of tibial torsion and an osteotomy gap filled with autogenous graft. We were not able to identify such a population in our hospital and substituted for dogs with a good apposition of the TPLO site and no graft. Although these cases differed from their match by 2 variables (gap, DBM), they do represent standard TPLOs and can therefore act as a reference. Nine of 15 dogs in this group acted as their own match, eliminating inter-individual variations.

Radiographic scores of bone healing did not differ between case matches undergoing TPLO or arthrodesis. Although the healing time for TPLOs has not been specifically reported previously, our clinical impression is that most heal between 6 and 12 weeks. Our results confirm this impression, as TPLOs healed on average in 11.4 weeks. The only difference identified in this study was that dogs with a TPLO gap treated with DBM were allowed to resume normal exercise faster than dogs with a well-apposed osteotomy, suggesting that DBM palliates the delayed healing that may be expected from a gap at the osteotomy site. This finding did not correlate with radiographic scores, reflecting the fact that clinicians do not establish postoperative exercise regimen based solely on radiographs. For example, the exercise restriction was lifted in those dogs whose exercise had not been restricted by their owners and had no evidence of complication on physical and radiographic examinations. The discrepancy between radiographic scores and return to normal exercise also illustrates the subjectivity of the measures of outcome in our study and the lack of consensus regarding radiographic assessment of bone healing.50 The radiographic scores reported in our study were assigned by a board-certified radiologist unaware of the clinical status of the dog, whereas return to exercise was recommended by the attending surgeon subjectively reviewing both radiographs and physical findings.

Although limited by their retrospective nature and subjective measures of outcome, our results support the use of DBM to treat bone defects in dogs that have uncomplicated orthopedic procedures such as comminuted fracture repairs, open osteotomies, and arthrodeses. Under these circumstances, clinicians might expect similar clinical outcomes without the possibility of side effects associated with the harvest of autogenous cancellous bone. The results of our retrospective study justify a prospective, randomized clinical trial evaluating the outcome of DBM use in uncomplicated orthopedic procedures in which more objective measures of outcome could be collected including force-plate analysis, advanced imaging, densitometry, or ultrasound.51 In addition, future studies are warranted to evaluate the effects of DBM in cases where bone healing is compromised by infection or by a potential lack of viable cells (nonunions, limb spare procedures).

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REFERENCES


