The Effect of Increasing Gap Width on Localized Densitometric Changes Within Tibial Ostectomies in a Canine Model

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Abstract. Dual-energy X-ray absorptiometry (DXA) was used to quantitate the localized densitometric changes that occur early (0-16 weeks) in a tibial ostectomy model of three different gap widths in 15 dogs. Dogs were divided into three equal groups. A 5-mm (group 1), 15-mm (group 2), or 25-mm (group 3) unilateral tibial ostectomy was performed and stabilized with a unilateral external skeletal fixator in each dog. DXA of the gap tissue was performed at 0, 14, 30, 60, 90, and 120 days after surgery. Regions of interest (ROIs) included the entire gap (groups 1, 2, 3) and ROIs within the gap a defined distance from the proximal or distal cortical bone ends: 0-2.5 mm (groups 1, 2, 3); 2.5-5.0 mm (groups 2, 3), 5.0-7.5 mm (groups 2, 3), 7.5-10.0 mm (group 3), and 10.0-12.5 mm (group 3). Bone mineral density (BMD) significantly changed over time in all three groups (P < 0.0001). The BMD of the 5-mm gap increased over the 4-month study period and reached normal middiaphysial tibial BMD by 90 days after surgery. The BMD of the 15-mm gap also increased after surgery but reached a plateau at a BMD of —0.45 g/cm² (48% of middiaphyseal BMD) at 60 days after surgery. The BMD of the 25-mm gap increased to a small extent during the first 30 days after surgery and then gradually decreased during the study period. Overall, the 5-mm gap had the highest BMD, followed by the 15-mm gap and the 25-mm gap (P < 0.0001).

Key words: Dual-energy X-ray absorptiometry — Bone mineral density — Fracture healing — Nonunion — Delayed union

The measurement of fracture site bone mineral density (BMD) with dual-energy X-ray absorptiometry (DXA) has the capability of providing clinicians with precise quantitative information concerning the local environment in bone [1-4]. This information may allow detection of derangements in the fracture gap ossification process far sooner than is evidenced by radiography, allowing earlier treatment of the fracture than would occur by relying on current methodologies. Early treatment to enhance ossification of the gap, either by altering stability or by providing osteoinductive or osteoconductive elements, should shorten the time to union and limit the morbidity in patients with abnormally healing fractures. The radiography and histomorphometry of delayed union and nonunion has been reported, but the detailed densitometric changes that occur over time during abnormal bone healing has not been defined [5-8].

Experiments examining the local densitometric changes that occur in fracture gaps of various widths may provide a better understanding of normal and abnormal fracture healing and serve as a foundation for discrimination between these conditions. Therefore, the purpose of this study was to determine the local densitometric changes that occur early (0-16 weeks) in a tibial ostectomy canine model of three different gap widths, the smallest width resulting in union and the largest resulting in atrophic nonunion.

Materials and Methods

Animal Model

Fifteen adult, mixed-breed dogs were used for this experiment. Dogs are an accepted model for evaluating bone healing [9-12]. Maturity was confirmed by radiographic examination for closure of the proximal tibial and distal femoral physes. All animal experimentation was reviewed and approved by the Institutional Animal Use and Care Committee.

The surgical procedure was performed on the right hindlimb of each dog. All dogs were given prophylactic antimicrobial therapy (cefazolin, 60 mg/kg, I.V.) administered once immediately before surgery. Dogs were premedicated with acepromazine (0.06 mg/kg, S.Q.), induced with thiampyl (16 mg/kg, I.V.), and maintained on halothane and oxygen. Dogs were placed in right lateral recency, and the limb was aseptically prepared and draped for surgery. A 5-cm skin incision extending down to but not including the periosteum was made over the medial diaphysis of the tibia. Dogs were divided into three equal groups and a middiaphysial transverse ostectomy was made with an oscillating saw, and a 5-mm (group 1), 15-mm (group 2), or 25-mm (group 3) section of bone was removed (Model 1370, Stryker Corp., Kalamazoo, MI). The ostectomy was stabilized using a small Orthofix unilateral external fixator (EBI Medical Systems, Inc., Fairfield, NJ). The incision was closed in three layers in routine fashion.

Craniocaudal and mediolateral radiographs were taken immediately after surgery to evaluate ostectomy reduction and pin placement, and then monthly until euthanasia. Dogs were allowed to freely ambulate during the study period. Dogs were euthanatized 120 days after surgery.

Densitometry

DXA was performed immediately after surgery at 14, 30, 60, 90, and 120 days. The scan was performed on a device using a dual-energy X-ray source (70 kVp, 140 kVp) with point resolution of 0.11 mm and overall resolution of 3.0 mm (QDR 1000, Hologic, Inc.,
Data Analysis

The effect of gap width, proximity to the cortical bone ends, relationship to the proximal or distal cortical bone end, and time were evaluated using repeated measures analysis of variance (ANOVA). If ANOVA revealed significant differences between any of the parameters examined, this relationship was evaluated with a post-hoc test (Duncan’s multiple range test).

All differences were considered significant at a probability level of 95% (P < 0.05). All statistical analyses were performed with commercially available software (SAS Institute, Inc., Cary, NC).

Results

By 4 months after surgery, radiographs revealed that bones with a 5-mm gap had united, bones with a 25-mm gap had developed atrophic nonunions, and bones with a 15-mm gap were significantly delayed in healing and appeared to be developing into atrophic nonunions. Implants did not loosen during the time course of the study. Subsequently, the distance between the bone ends did not change during the 4-month study.

BMD was significantly affected by time in all three groups (P < 0.0001). BMD of the 5-mm gap increased over the 4-month study period and had reached normal mid-diaphyseal tibial BMD values by 90 days after surgery (Table 1). BMD of the 15-mm gap also increased over time but reached a plateau at a BMD value of ~0.45 g/cm² (48% of mid-diaphyseal tibial BMD) at 60 days after surgery. BMD of the 25-mm gap increased to a small extent during the first 30 days after surgery but then gradually decreased during the study period. Overall, the 5-mm gap had the highest BMD, followed by the 15-mm gap and the 25-mm gap (P < 0.0001).

BMD was not affected by whether or not an ROI was in the proximal or distal aspect of the fracture gap (P > 0.05). BMD was significantly affected by an ROIs relationship to the cortical bone ends (Fig. 2). All ROIs in the 5-mm gap were within 0–2.5 mm of the cortical bone ends and the BMD of these ROIs progressively increased during the study period, reaching mid-diaphyseal values by 90 days after surgery (Table 2).

In the 15-mm gap, the BMD of the ROIs 0–2.5 mm from the cortical bone ends increased the quickest (P < 0.05) when compared with the 2.5–5.0 mm and 5.0–7.5 mm ROIs, although the BMD of the 0–2.5 mm ROIs plateaued at 0.42–0.53 g/cm² beginning 30 days after surgery (Fig. 2; Table 2).

There were no significant differences between the BMD of the 2.5–5.0 mm ROIs and the 5.0–7.5 mm ROIs for the 15-mm gap (P > 0.05).

In the 25-mm gap, the BMD of the 0–2.5 mm ROIs increased the most rapidly and was significantly greater at all time periods than the 2.5–5.0 mm, 5.0–7.5 mm, 7.5–10.0 mm, and 10.0–12.5 mm ROIs (P < 0.05), although the BMD increased only until 60 days, peaking at 0.30 g/cm², and then gradually decreased (Fig. 2; Table 2). For the 25-mm gap, there were no significant differences between the BMDs of the other ROIs at any time after surgery except at 30 days (P > 0.05). At 30 days, the BMD of the 7.5–10.0 mm and 10.0–12.5 mm ROIs were significantly less than the BMD of the 0–2.5 mm, 2.5–5.0 mm, and 5.0–7.5 mm ROIs (P < 0.05) (Fig. 2). The BMD of the midgap ROIs (7.5–10.0 mm, 10.0–12.5 mm) peaked at 30 days at a lower value (0.08–0.10 g/cm²) than the BMD of the 2.5–5.0 mm and 5.0–7.5 mm ROIs which also peaked at 30 days but at 0.18–0.20 g/cm².

Radiographic and histologic analysis of the 5-mm gap specimens revealed union of the gap in all specimens at 4 months (Fig. 3). The gap had filled with bone and was bridged by both medullary and periosteal callus. In three