EX VIVO BIOMECHANICS OF A BILATERAL TYPE I/BILATERAL INTERDENTAL PIN AND ACRYLIC EXTERNAL FIXATOR APPLIED TO THE CANINE MANDIBLE

by

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(ABSTRACT)

Bilateral mandibular ostectomies were performed between premolars 3 and 4 in 10 adult canine specimens. A type I external fixator incorporating a full interdental pin was placed stabilizing a 0.5 cm fracture gap. Four different pin configurations were tested in dorsoventral bending five separate times on each of the ten mandibles: 1) intact mandibular bodies with fixator; 2) ostectomized mandibular bodies and complete fixator; 3) ostectomized mandibular bodies with the caudal pins of the rostral fragment cut; 4) ostectomized mandibular bodies with all pins of the rostral fragment cut. The full interdental pin remained intact in all configurations. Total stiffness and gap stiffness were then determined for each fixation geometry on a materials testing machine.

The mean total stiffness(Nm/rads) for the four configurations was 1) 1543.6, 2) 301.6, 3) 290.5, 4) 267.0. The mean gap stiffness(Nm/rads) for the right hemimandible was: 2) 2041.1, 3) 1763.5, 4) 1679.9. The mean gap stiffness of the left hemimandible was: 2) 2110.8, 3)1880.1, 4)1861.1. There was no gap stiffness for the first configuration since a fracture gap was not present.

Two-way ANOVA was performed on the gap stiffness and the total stiffness. There was a significant decrease in total stiffness between intact mandibles and ostectomized mandibles regardless of external fixator configuration. However, there was not a significant difference in total stiffness or gap stiffness among the different external fixator configurations applied to ostectomized mandible. External fixator configurations with only the full interdental pin engaging the rostral fragment were as stiff as configurations which had two or four additional pins in the rostral fragment for the applied loads. External fixators for rostral mandibular fractures may be rigidly secured with rostral fragment implants applied extracortically avoiding iatrogenic trauma to teeth and tooth roots.

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Dedication

I would like to dedicate this manuscript to my wonderful and supportive wife Anne and to both of our families**.**

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To my mentors at the college; faculty and staff for their support and guidance.

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LITERATURE REVIEW

Purpose

The purpose of this study was to determine the total stiffness, and the gap stiffness of an external fixation system in a canine mandibular fracture gap model incorporating a full interdental pin as the only point of rostral fixation in a bilateral type I external fixator.

Clinical Significance

This modification of a type I external fixator should provide enough stiffness to promote bony healing without jeopardizing the integrity of the dental structures of the rostral mandible.

Bone Healing

Bone tissue changes, following a fracture are a complex series of events that should culminate in a healed fracture. There is a gradual increase in the stiffness and strength at the fracture site due to the maturation of growing callus. There are three phases of bone healing that overlap: inflammatory phase, repair phase, and remodeling phase.

The inflammatory phase begins immediately after the fracture occurs and lasts for approximately 3 weeks. The inflammatory process is triggered by the trauma to the soft tissue, periosteum, and medullary contents. The development of necrotic debris and the arrival of acute phase proteins such as interleukin-1 and interleukin-6 further propagate the inflammatory phase. Platelets release platelet derived growth factors and epidermal growth factors that are necessary for the healing process and potentiate the formation of fibrous tissue and cartilage.[1-4] The first mass that develops at the fracture site is the hematoma. The exact role of the fracture hematoma is uncertain; however, it provides a scaffold the first population of cells such as granulocytes, and macrophages to localize at the fracture site. In addition to their angiogenic properties, these inflammatory cells also ingest debris and remove bacteria. Osteoclasts will be present within the first several days of fracture repair in order to clear debris and resorb bone.[1,2] The fracture begins to develop some minimal stability once the hematoma transforms into granulation tissue during the first 3-5 days following the injury.

With a few days, the hematoma begins to change into fibrous tissue. This stage of healing characterizes the reparation phase of bone healing. Macrophages, fibroblasts, and osteoprogenitor cells from the endosteum and periosteum begin to form a periosteal callus. Macrophages play a key role in fibroplasia and angiogenesis. The extraosseous vascular tissue is derived from the surrounding soft tissue. These new vessels reach a peak flow at 10 days post-injury and are independent of primary periosteal blood supply.[3,5]

The soft periosteal callus goes through a process of mineralization or chondrogenic transformation during the development of hard callus.[3,5] Cartilage producing chondroblastic cells develop from precursor cells in the hematoma. Fibrous tissue and fibrocartilage are mineralized which provides enough structural stability to allow osteod deoposition. Fibrocartilage in the callus is replaced by bone by a process similar to endochondral ossification where osteoid is deposited on the scaffold.[8] The mineralized fibrocartilage is replaced by cancellous bone by osteoblasts that produce woven bone. The principle blood supply at this stage of healing comes from the reestablishment of intramedullary vessels.[9] At this stage, the fracture should be structurally stable; however, the nature of woven bone is different from lamellar bone.

Remodeling is a long process that involves the transformation of the hard callus into lamellar bone and can take years to complete.[4,6,8] In people, remodeling may take as long as 6 to 9 years for completion.[4] Woven bone is transformed to lamellar bone around harversian systems through the removal of woven bone by osteoclasts and deposition of lamellar bone by osteoblasts. Through the generation of pizoelectricity and lines of stress in the bones the process of bone remodelling occurs. [10,11] Osteoblastic activity is increased at the concave surface of a bone that is electronegative; whereas, osteoclastic activity is increased at the convex surface which is more electropositive. Immature animals have a greater ability to remodel than adult animals. It is speculated that this is the result of a higher metabolic rate in immature animals. [12]

Bone healing can further be divided into two types: indirect or direct bone.[2,4,7,8] Healing is directly related to the fracture configuration and the stability of the fracture site. Direct bone healing occurs when there is rigid fixation and the fracture ends are in contact (contact healing) with less than a 250-500um defect.[2,9,13] With direct bone healing cartilage precursors do not develop; osteoclasts create cutting cones which cross the fracture line and lamella bone deposition occurs from the osteoblasts which populate the advancing cone of bone resorption. Direct bone healing is a slow process with the formation of minimal to no periosteal or endosteal callus and may take months to develop normal bone strength.

Indirect bone healing is characterized by the transformation of fibrocartilaginous callus to bone callus.[2,9,13] This process occurs at a faster rate than direct healing. Callus can be divided into one of three categories: anchoring, bridging or sealing callus. Anchoring callus develops at the periosteum around the fracture site several centimeters proximal and distal to the fracture. [14] Sealing callus develops at medullary surface of the fracture site and develops from endosteal proliferation. Bridging callus forms between the anchoring callus.

Complications associated with fracture healing may include delayed unions and nonunions.[4,15] Delayed union is a fracture that takes more than the expected time to heal, while a nonunion is the failure of a fracture to heal. Common causes for delayed and nonunions are fracture fixation systems that are not stable, infected fractures or fractures with decreased blood supply.[4,7,15] A common fracture scenario that creates a nonunion are pins and cerclage; this fixation system might not adequately account for the rotational stability. The result of constant motion at the fracture site prevents cartilage mineralization.[4,7,15] Instability at the fracture site can cause an abundant amount of callus (hypertrophic nonunion) without bridging callus This type of nonunion is vascular and primarily will need additional stability. Atrophic nonunions may occur when there is compromise to the blood supply or depletion of the healing components. This healing process is inactive and the bone ends will appear sclerotic. Furthermore, the fracture gap will typically be filled with fibrous tissue creating a pseudoarthrosis. [4,7,15]

Blood supply is an important component of fracture healing. If there is abundant soft tissue injury or excessive damage to the periosteal blood supply, delayed or nonunions can occur.[15] Certain bones have a higher incidence of nonunions or delayed unions including the distal radius, ulna, and femur because of surrounding soft tissue and direct blood supply.[16,17] The problem is exacerbated in certain toy breeds, due to a decreased amount of blood supply in the metaphyseal region of the radius and ulna.[16,17]

The mandible does not exhibit the same degree of nonunions and malunions that are appreciated at other bones.[29]

Bone Healing with External Skeletal Fixators

External skeletal fixation can be used to promote both direct and indirect bone healing.[2,9] The type of healing will be dependent upon the type of fracture and the configuration of the fixator. The use of external fixators for mandibular fractures will promote more indirect healing than direct. Due to the type of fixation, type I or modifications of a type I configuration, there is not enough stability to promote direct bone healing. The fracture site will be subjected to increased levels of interfragmentary strain potentiating indirect healing.[2,9]

External skeletal fixation can be used to promote the biological environment of the fracture site.[2,9] By proper placement of the external fixator pin the amount of trauma to the soft tissues and blood supply of a fracture will be reduced which promotes earlier tissue differentiation and vasuclarization. With the modification of a type I external fixator for this project, less trauma occurs at the rostral mandible to the blood supply and soft tissues. This modification carries biological fixation principles further since the interdental pin is extracortical. The utilization of biological healing principles with fracture management has been shown to decrease the amount of surgical time, surgical complications, and the incidence of delayed healing for complex comminuted fractures when compared to open reconstructive techniques.

Biomechanics

Biomechanics is a subspecialty of mechanical engineering focusing on the effects of forces on biological systems and materials used to enhance the biological system.[18] An understanding of several biomechanical principles is important to understanding the effects that forces have upon biological systems.

Force or load is equal to the acceleration of matter (F = mass x acceleration). The amount of force, the direction of the forces, and the rates of application to the material all have an effect on the outcome of the material. Forces and their affects on bones or composites can be evaluated through load-deformation curves and stress-strain curves.[18,19,20,21]

Load-deformation curves allow for the mechanical evaluation of a bone or a bone-implant composite.[18,19,20,21] The curves are valuable for obtaining information about how a bone will respond to a force and the effectiveness of implants to resist the applied forces. In particular, the slope of the curve contains information regarding the stiffness, strength, and energy absorption capacity of a material or composite.[18,19,20,21] The initial phase of a load-deformation curve is the elastic region which is where no permanent deformation occurs in the material.[18,19,20,21] This type of deformation is called elastic. Stiffness, which correlates to the elastic region of the curve, is indicated by the amount of load a material can sustain with minimal deformation. Stiffness is calculated from the slope of the curve; a steeper slope means the stiffness is greater.[18,19,20,21] (Fig 1)

When increased loads are applied to the material, permanent deformation occurs starting at the yield point occurs.[18,19,20,21] The following region is known as the nonelastic phase or plastic region. If a load is applied beyond the plastic region, the ultimate failure point is reached symbolizing ultimate failure. This is the strength of the material. Strength is defined as the amount of load needed to cause catastrophic failure. Thus, strength and stiffness are not equal.[18,19,20,21]

Stress-strain curves are normalized load-deformation curves; these curves do not includethe size and shape of the tested material as active variables.[18,19,20,21] Stresses are internal forces that are generated under an applied load. Strain is the amount of deformation from the original shape under a specific load.[18,19] There are three categories of forces for stress and strain: tension, shear, and compression. Similar to the load deformation curves, stress-strain curves can provide important information. Stiffness, also known as the elastic modulus or Young's modulus of elasticity, is determined by the slope in the elastic region and is equal to the stress divided by the strain. The strength of a material is equal to the entire area under the curve. Stress-strain curves are more suitable for testing of different materials or composites such as steel vs. titanium. In the first part of our study, load deformation curves were determined.[18,19]

Bone Mechanics

The characteristic response of bone to force (compression, bending, shear, tension, or torsion) depends on the type of bone being evaluated, the location of the bone and the structural integrity of the bone.[21] In addition, the shape of the bone, associated structures, and bone disease will dictate the mechanical response. Cortical bone has a different mechanical response than cancellous bone. These differences in the mechanical response between cortical and cancellous bone are related to the porosity or apparent density of the material, where porosity is the percentage of bone occupied by nonmineralized bone.[1,21] Cortical bone has a higher percent of inorganic component than cancellous bone, which imparts more stiffness and rigidity and a lower porosity. [1,21] Cancellous bone is composed of a higher percent of organic material that gives the bone more flexibility. [1,21] The mandible has a large percentage of cancellous bone located at each alveolus creating a potential weak spot for fractures.[57]

In this study, mandibles harvested from canine cadavers were used as the test model. This model was selected based on the potential benefits of locking the fixator apparatus to the teeth and specific placement of the implants based on tooth root landmarks. The mandibles were kept moist throughout storage and testing of the fixation devices. The biomechanical effects of autolysis should have been minimal since the mandibles were stored at -70^0C and the project was performed within hours of thawing the mandibles.

Mechanical Properties of External Skeletal Fixators

Linear external skeletal fixators neutralize bending, shear, tensile, compressive, and torsional forces.[2,9,22,24,26] The advantage of linear fixators is that they promote healing without the application of internal fixation, thus preserving the local biological environment of the fracture site.[2,9,13,26] In addition, the stiffness of the construct can be controlled by the applicator.[13] Several studies have been done evaluating the biomechanics of external skeletal fixators and the principles of construct design and application. Factors that affect the construct include: external frame geometry (a type I, II or III fixator), number of pins per fracture fragment, type of pin (smooth or threaded), the distance between the clamps, distance of the connecting bar from the bone, material characteristics of the connecting bar and technique of fixation pin placement.[2,9,13,26,29-40]

Several of these factors can be utilized to increase the stiffness of the construct: increasing the number of pins per fracture fragment, increasing the diameter of the pins, using stainless steel pins as opposed to titanium pins and decreasing the connecting bar distance to the bone. Frame stiffness can be defined by the following equation: [28]

$$K_f = 12\ ME_SI/S^3$$

Where K_f is equal to axial stiffness, M is equal to the number of pins in the fracture fragment, E_S is equal to the pin modulus, I is equal to the pin area moment, and S is equal to the distance from the side bar to the bone. This equation is important because it emphasizes the importance of the location of the connecting bar to the overall stiffness of the construct and the diameter of the pins applied.[28]

The number of pins applied to each fracture fragment will contribute to the overall stiffness and strength of the construct.[2,9,13,25,26,29-40] Typically, the greater the number of pins per fragment the better the construct will promote bony healing. Biomechanically, for a type I fixator, after the application of a fourth pin into each fracture fragment there is not a statistical difference in the strength.[27,28] Typically, four pins should be placed in each fracture fragment for a type I fixator and 2 to 4 pins for a type II or III fixator.[27,28]

Mechanical Properties of Polymethylmethacrylate

Acrylics are commonly used for the repair of fractures.[22] The versatility of the material is related to its strength and its free form.[22,41] Acrylics have been used as connecting bars for external fixation of mandibular and maxillary fractures, and in many long bone fractures. Acrylics have also been used as a primary fixation device or as an intra-oral splint for mandibular and maxillary fractures.[23,27] Several different acrylic materials have been used as connecting bars, most are methylmethacrylate compounds such as Technovit[a] or Orthodontic Resin[b].

Biomechanically, a 19-mm diameter acrylic bar has similar properties to a 4.8-mm diameter steel connecting rod.[2,13,22] Furthermore, there is an advantage to roughening the pin surface to increase the pin to acrylic interface.[2,13,22] In a recent study, pins with a roughened surface had a 40 percent higher shear strength compared to smooth pin-acrylic interface.[22,26]

Polymethylmethacrylate results from an exothermic chemical reaction of a dry powder (polymer), a liquid (monomer) and a free radical. The powder is a polymer that is composed of micronized spheres that are approximately 10-30 um in size. The chemical reaction is spontaneous and involves chain initiation, chain propagation, and chain termination.

The polymerization of polymethylmethacrylate involves three stages: dough time, working time and setting time. [19,42,43] The dough time occurs within the first 3 minutes, and the result is a material that is soft, pliable, and has the consistency of a plastic. Depending on the ambient temperature, the working time can vary in length up to the setting time of 12 to 15 minutes. The warmer the environment, the faster the material will set. The setting time can take upwards of 12 to 15 minutes and again depends on the ambient environment.

The process of polymerization is an exothermic reaction. Temperatures of 50-100 ^{o} C are produced during the polymerization phase of the reaction.[26,69] There has not been any documentation of tissue necrosis within the oral cavity due to the direct application of polymethylmethacrylate. However, thermal necrosis of sheepskin occurs with temperatures of 55 ^{o}C applied for 1 minute.[26] Thermal necrosis of rabbit bone has been documented with the application of heat at 55 ^{o}C for 1 minute.[26] Thermal conduction through pins has been demonstrated experimentally with the application of methylmethacrylate to the pins. In addition, biomechanical changes have occurred in bone when the temperature exceeds 50^{o}C.[13,22,26] The importance of the temperature effect on all fracture systems is two-fold: direct soft-tissue necrosis and bone necrosis that could result in premature implant failure due to loose pins.[13,22,26]

Thermal and mechanical necrosis are complications from acrylic based external skeletal fixation systems.[22,26,61] Necrosis of bone secondary to pin placement has resulted in a 50 percent reduction in the axial pullout strength of pins. This is related to heat build-up from the application of methylmethacrylate and microfractures at the pin to bone interface because of the lack of pre-drilling. One study has documented that Technovit and the APEF system[c] are capable of producing heats greater than 50^{o}C for longer than 1 minute. These materials could result in thermal necrosis through heat conduction from the pin. This complication can be reduced by placing the connecting bar at least 5 mm away from the skin surface to reduce the risk of thermal necrosis. Cooling the pins with saline or placing saline-soaked sponges may reduce thermal conduction.[22,26,61]

Heat dissipation occurs within the mandible due to blood supply and potentially within the teeth. The close proximity of the mandibular canal and of the blood supply to the placement of pins will promote heat dissipation. We speculate that the tooth roots within the mandible will act as a reservoir for heat pulling heat away from the cancellous bone, which would help reduce local thermal necrosis. The potential limiting factor with this thought is that the teeth may act as reservoirs or similar to porcelan and retain the heat. This could potentially reduce the overall heat dissipation within the mandible and contribute to thermal necrosis.[44]

Polymethylmethacrylate can be reinforced by the application of wire within the construct. Acrylics reinforced with wire improve resistance against compressive, bending and tension forces. Other agents that have been utilized for reinforcement have included various fibers or small glass spheres.[44]

Mandible

The mandible is a unique bone that has inherent limitations for surgical repair due to its shape. The curve of the rostral mandible, the dental structures, and the extensive musculature contribute to the complexity of this bone. Furthermore, the mandible presents other challenges for surgical repair due to the limited bone stock for implants. This bone invites a unique challenge in order to repair the fracture without jeopardizing the structures of the mandible. There are several features of the mandible that create this complexity.

Mandibular Anatomy

The descriptive terminology used within the oral cavity is relative to other anatomical structures. Terms that will be used throughout this manuscript include: labial (towards the lips), mesial (towards the rostral aspect of the dental arcade), distal (towards the caudal aspect of the dental arcade), occlusal (biting surface of the tooth) and contact (site where adjacent teeth touch).[45,46,47]

The mandible is comprised of two bones rostrally at the symphysis and caudally to the temporal bones through the temporomandibular joints. The mandibular symphysis in canines and cats is a fibrocartilage joint.[45] In humans, the symphysis is fused.[45,46] Each hemimandible is comprised of two components: the body and the ramus. The horizontal component or the body provides the necessary bone stock for the dentition. The vertical component or the ramus is made up of several structures. The coronoid process is the prominent dorsal bone of the vertical ramus. This bone is flat and relatively thin and provides attachment for several muscles. The condyloid or articular process is the transverse bony protuberance, located at the caudal aspect of the junction between the horizontal and vertical ramus. It provides the articulation with the temporal bones. The temporomandibular joint will allow for both lateral and rotational movements. In the canine, the predominant movement is rotational in a simple “hinge-like” manner.[45,48] Lateral movement is limited due to the dental inter-lock. An angular process is located at the caudal aspect of each hemimandible and serves as the attachment for the digastricus and the medial pterygoid muscles.

The mandibular canal is located in the ventral third of the horizontal ramus. The mandibular artery, vein, and nerve course through the canal and link the mandible and its dentition.[67] (Fig 2) The blood supply enters each hemimandible on the medial aspect and exits at the mental foramen.[67] The rostral mandible receives a large percentage of its blood from extraosseous sources. This is important for fixation in order to promote healing by minimizing the application of implants that may disrupt the blood supply.[67]

The musculature of the mandible is made up of the masseter, digastricus, temporal, and the lateral and medial pterygoid muscles.[46,47,48] These muscles attach to the caudal aspect of the mandible; the rostral mandible does not have large muscle groups. These muscles provide most of the force for the movement of the jaw.[47,48] The temporalis muscle is the largest muscle of the group in the dog and the cat. This muscle, due to its attachment on the condylar process, is the principle muscle involved in closing the oral cavity. The digastricus muscle inserts along the ventral aspect of the mandible and is the muscle responsible for opening the oral cavity. The muscles in this area are innervated by the trigeminal nerve except for the caudal portion of the digastricus is innervated by the facial nerve.

Bite force is the force that the mandibular muscles create through contact between the upper and the lower arcades of the teeth. The force is typically measured in pounds per square inch (psi). The force in people is roughly 250-300 psi; however, a sudden closure of the jaw can generate a focal force of 25,000 – 30,000 psi. [45,59] In canines, the measurement is more subjective, but passive forces of 150-800 psi have been noted. It is believed that canines can generate 100 times the focal bite force of humans, thus resulting in a potential force of 80,000 psi.[45,59]

Dentition comprises a large portion of the mandible. The incisor teeth and the canine teeth each occupy the rostral mandible through a single alveolus per tooth. The premolar and molar teeth have two alveoli, and the third molar has one. [47,48]

Oral Microbiology

The oral cavity is inhabited by variety of bacteria in both the cat and the dog. The local environment has a direct effect on he flora. Factors that affect the flora include diet, orthodontic procedures, trauma, and dental therapy. The natural flora of the oral cavity in the canine consists of aerobes and anaerobes. In a normal dog, *Staphylococcus aureus, Staphylococcus epidermidis*, *Pastuerella multocida,* and *Streptococcus spp*. are the most common organisms found.[49] Important anaerobes found within the oral cavity include *Bacteroides spp*., *Fusobacterium spp*., and *Veillonella spp*. The population of bacteria, particularly anaerobes, increases with oral disease such as periodontis.[50,51] This plays an important role in fracture fixation and the association of gingivitis and periodontis with fractures and nonunions.[50,51]

Bacteremia can occur in dogs following extractions and periodontal repair. Organisms have been identified in sevearal cases reports from blood cultures following these procedures.[50,51] The organisms can result in hematogenous spread to wounds or colonization in the heart.[49] The concern with fractures is the infection of the fracture site with secondary infection of the implants. This can result in delayed unions, nonunions, and premature failure of fracture implants.[15,50,51] The use of external skeletal fixation will help to preserve the local fracture environment, reduce the trauma to the blood supply, and reduce the potential for nonunions in an unfavorable environment.

Antimicrobial prophylaxis is an important arsenal to the treatment of mandibular fractures at the time of the surgical repair and at the time of implant removal. It has been stated that the improved blood supply to the oral cavity will reduce the rate of infection. In human studies, open mandibular fractures had a significantly higher infection rate when antibiotics were not used.[61] In a canine study, the findings were similar; antibiotics did appear to lower the incidence of infection. [61]

Occlusion

The normal occlusion of the canine is based on mesatocephalic breeds.[45] The occlusion and function are that of a scissor or shear bite with the maxillary incisors rostral to the mandibular incisor teeth.[45,46] Based on these breeds, there is minimal contact between the maxillary and the mandibular incisor teeth. Variations of occlusion do occur with different breeds

The anatomy of the canine oral cavity creates an occlusion that limits mediolateral translocation and creates a dental interlock. Mediolateral movement is prevented by the shearing occlusion of the mandibular molars in relation to the maxillary fourth premolar and the molars, and the dental interlock of the mandibular and maxillary canine teeth.[46,48] A load limited to bending is dictated by the hinge-like nature of the temporomandibular joint and the difficulty in translocating the mandible in a mediolateral plane. These anatomic and mechanical factors combine to minimize mediolateral movement of the mandible, concentrating bending loads to the rostral mandible.

Based on the dental interlock, bending forces were the only forces evaluated in this study. Torsional forces could occur if malocclusion occurs from the fracture fixation or the normal occlusion for the canine prior to fracture fixation. If the occlusion is addressed at the time of fixation torsional forces should be minimal.

Malocclusion is defined as any deviation from normal occlusion and can result from genetics, retained deciduous teeth, and trauma.[45,48] One study demonstrated that at least 50 percent of the malocclusions are acquired and have no genetic factor.[45] This is particularly important to the breeder in the consideration of restorative orthodontics.

Malocclusion is classified as: Class 0, I, II, III and IV.[48] Class 0 is normal or othoclusion. Class I malocclusion or neutroclusion has a normal mesial to distal relationship of the dental arcade and results in differences of individual teeth. This type of malocclusion represents the greatest proportion of malocclusions. It is characterized by missing teeth, individual tooth malpositions, and differences in tooth size. Trauma and damage to the dentition secondary to fractures are classified as a type I malocclusion. Class II malocclusion is evident in dolichocephalic breeds, such as dachsunds, and collies. This malocclusion is characterized by an “overshot” bite in which the maxillary incisors are moved rostral in relation to the mandibular incisors by at least 3/16th of an inch. This can result in the maxillary canine teeth wearing on the distal aspect of the mandibular canine teeth. In severe cases the mandibular incisor teeth can traumatize the maxillary gingiva with severe brachynathism. Class III malocclusion is characterized by an “undershot” bite in which the upper arcade is moved distal to the lower arcade. Class IV is a special malocclusion or a variation of wry mouth.

Mandibular Fractures

Mandibular fractures in dogs represent 3-6% of all fractures seen in dogs. [23,27,52] These fractures are usually secondary to trauma such as vehicular, gunshot, fall, kicks and bite wounds and occur with a higher frequency in young male dogs.[23,27,52,54] Other causes of mandibular fractures include pathologic etiologies including neoplasia, severe periodontitis, and iatrogenic tooth extractions. Similarly, in humans, 20-40% of all facial trauma cases result in mandibular fractures, most often associated with vehicular trauma.[52]

Clinically, animals with mandibular fractures may have a dropped-jaw appearance, malocclusion, or hemorrhage.[23,27,52,53.56,57] Diagnostically, a thorough oral exam under sedation or anesthesia is appropriate, as well as a complete neurological exam of the head. Radiographs are necessary to complete the diagnosis including an extraoral series with ventrodorsal, oblique, and lateral radiographs and intraoral radiographs.[52,56] The temporomandibular joint is a difficult area for radiographic interpretation. Computed tomography including the use of three-dimensional reconstructions can provide clearer information regarding fractures in this vicinity.

Pharyngostomy tubes for anesthesia are critical for the evaluation of the oral cavity prior to fixation and during fixation to enable the surgeon to have exposure to assess the wounds and the occlusion.[52,56]

The most common location for mandibular fractures in dogs is the premolar region.[52] In cats the most common location is in the symphyseal area and in people fractures predominate in the ramus or the angle of the mandible. Anecdotally, in canines the mandibular canine teeth and the symphyseal area create a relatively rigid area, similar to the root structure of the caudal premolar and molar area.

Mandibular fractures will almost inevitably involve the dentition.[45,52,57] Previous recommendations included the acute extraction of all teeth that were involved in the fracture. This was formerly based on the incidence of osteomyelitis with these types of fractures; however, with current antibiotic therapy, the incidence of osteomyelitis has decreased.[45,52,57] Current recommendations involve the salvage of teeth that do not have preexisting periodontal or endodontal disease due to the potential stability the tooth can provide to the fracture.[45,52,57] The teeth are also important in the occlusal assessment. The teeth should continue to be assessed for 6 months to a year following a mandibular fracture especially if the periapical circulation was involved. In some cases, extractions or endodontic repair will need to be considered. Following union in a human study, mandibular fractures that caused the most tooth morbidity involved the root surface from the gingiva to the apical area and subsequently affected periodontal and endodontic integrity.[45]

Many mandibular fractures are open and are frequently located rostral to the first molar. The caudal mandible has musculature that might lower the incidence of open fractures in this area.[52,61] In one canine study, 83 of 87 open fractures involved the tooth root alveolus suggesting that the weakest area of the mandible is through the alveolus.[52,61]

As with all fractures, the goal of fixation is early return to normal function. With mandibular fractures the goal includes establishing of normal dental occlusion, immediate function or feeding diversionary procedures. With mandibular fractures, the orientation of the fracture line and subsequent muscular forces may influence the choice of fixation device.

Mandibular body fractures are categorized based on the location and the direction of the fracture as either disadvantageous (unfavorable) or advantageous (favorable).[45] Disadvantageous fractures occur when the fracture line runs in a caudoventral direction.[45] These types of fractures have the propensity for distraction due to the previously described muscular attachments and are more likely to require surgery. An advantageous mandibular body fracture occurs with a caudodorsal fracture line and mechanically promotes compression due to the muscular attachments.[45]

The tension side of the mandible is the occlusal surface.[56] Bridging of this surface results in compressive forces on the ventral aspect of the mandible during closure of the jaw. This can be accomplished with the intraoral wires and acrylic splints that are attached to the teeth.[55,62] Intraoral wires and splints are appropriate for mandibular fractures in the premolar area; however, these techniques are not well sutited for caudal mandibular fractures.[45,52,55]

In dogs and cats, rostral mandibular fractures are typically separations at the symphysis because the fibrous union there is the weakest location in the mandible.. Fixation of these fractures involves an interdental wire encircling the rostral mandible.[56,60,63] This fixation is not very rigid. Healing will occur within 3 to 6 weeks since bony union is not the end point of the repair. Rostral fractures other than symphyseal fractures do occur.[56] Fractures in this area are treated conservatively with muzzles since numerous alveoli are present which compromises fixation device attachment.

Tape muzzles are the most common technique that is used to stabilize mandibular fractures.[23,27,58,63] They are useful for first aid treatment of mandibular fractures in order to prevent soft tissue damage from instability. In cases with minimal displacement or with a unilateral body fracture, this fixation technique can be suitable to promote bony healing. The oral cavity does not require the same degree of rigid fixation to promote bony healing as other long bone fractures. The muzzle should be applied to allow a 1.0cm space between the incisors so that the animal can eat. An incorrectly applied muzzle can result in malocclusion, compromise breathing, aspiration pneumonia, moist dermatitis, and weight loss.[3,27,58]

Bone plating provides rigid fixation of fractures and early return to function while preventing many of the complications associated with tape muzzles.[23,67,68] Bone plating has been shown to stabilize fractures of the mandible when the screws are placed monocortically, reducing iatrogenic trauma to the tooth roots.[23] However, bone plating can be expensive, technically challenging when applied to the rostral mandible, and not readily available to all veterinary practitioners. Plating in the rostral mandible area can be difficult because of the degree of plate contour needed. The amount of soft tissue dissection needed to apply a plate to the caudal mandible may negatively affect bone healing because of traumatized blood supply.[23,67,68]

Caudal mandibular fractures occur with less frequency than other mandibular fractures. Fractures in this area are inherently difficult to repair surgically.[45] The caudal mandible is surrounded by extensive musculature which makes exposure of the bone difficult. The cortical bone of the caudal mandible is thin and limits bone purchase of implants.[45,55] Fractures involving the temporomandibular joint are difficult to expose and it is difficult to achieve perfect articular congruity. Treatment for caudal mandibular fractures is usually conservative using tape muscles or interdental acrlyic bridges between the mandibular and maxillary canine teeth. With articular fractures of the caudal mandible, conservative management is acceptable providing reassessment for function and occlusion is done to allow consideration for a condylectomy should the problem persist.

Complications with Mandibular Fractures

The types of complications of mandibular fractures are similar in both and humans.[61] In one study 34% of canine mandibular fractures had some kind of complication, which is higher than the complication rate in humans. The most common complication was malocclusion due to the difficulty in placing appropriate fixation while maintaining occlusion.[61] Other complications include osteomyelitis, malunion, nonunions, and fixation failure.[52,61] In cases of osteomyelitis or nonunions, culture and sensitivity of the fracture site is indicated. Cancellous graft can be used for mandibular fractures or the use of an autogenous rib graft incorporated into the fracture. Grafting will sometimes need to be delayed until the infection is under control. In severe cases of infection or nonunions that have led to bone resorption, partial mandibulectomies might be indicated.

Complications with external skeletal fixators range from mild problems to complete failure of the fixation technique.[13,61] The two most common complications are premature pin loosening and local pin infection.[13,61] Premature pin loosening can result from several technical errors. Thermal necrosis of the surrounding bone can occur from pin insertion without predrilling and the application of acrylics as a connecting device.[13,69] Without predrilling, pin insertion can cause microfractures at the pin bone interface which may result in premature fixation loosening. Predrilling should be performed and should be 0.1 to 1.0 mm smaller than the transfixation pin. Furthermore, premature pin loosening due to microfractures can occur if the pin diameter exceeds 20 percent of the diameter of the bone or if the pins are placed closer than 1.5 cm from the proximal and distal fracture ends.[13,69]

Premature loosening due to local pin tract infection can be reduced by proper pin application and management techniques, such as cleaning the pin-skin interface on a regular basis, decreasing the irritation at the pin-skin interface by having a large enough opening that reduces skin tension and bandaging the apparatus to reduce the pin-skin motion.[13,61,69] Other complications during the use of external skeletal fixators have included iatrogenic bone fracture, pressure necrosis of the skin because of close proximity of connecting bar, and soft tissue structure damage by the fixation point.

Prognosis

Clinical union of the fracture varies with the location of the fracture, the type of fracture, open versus closed fractures and the involvement of teeth. Clinical union can be expected to occur within 3 to 8 weeks. Based on several studies fractures rostral to the first molar heal faster than caudal mandibular fractures. This might be because it is technically easier to provide more rigid fixation in the premolar region. In addition, since symphyseal fractures do not have a bony union healing is quicker, which may influence the results reported.

External fixation (EF) techniques, including the use of and acrylic connecting bars, have been shown to adequately stabilize fractures and experimental osteotomies of the mandible in dogs.[23,57] This technique for fracture repair is relatively simple to perform, and the equipment is readily available. This technique is well suited to the oral cavity due to the frequency of open fractures. The useof acrylic connecting bars instead of standard Kirschner systems allows for greater flexibility in transcortical pin placement because the connecting bar can be contoured. The pins are placed in different planes in order to avoid the root structures and the mandibular canal. Transfixation of lesions rostral to the first molar are not recommended due to the trauma to the sublinqual structures.

Influence of an interdental full pin on stability of an acrylic external fixator for rostral mandibular fracture.

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Summary

Bilateral mandibular ostectomies were performed between premolars 3 and 4 in 10 adult canine specimens. A type I external fixator incorporating a full interdental pin was placed stabilizing a 0.5 cm fracture gap. Four different pin configurations were tested in dorsoventral bending five separate times on each of the ten mandibles: 1) intact mandibular bodies with fixator; 2) ostectomized mandibular bodies and complete fixator; 3) ostectomized mandibular bodies with the caudal pins of the rostral fragment cut; 4) ostectomized mandibular bodies with all pins of the rostral fragment cut. The full interdental pin remained intact in all configurations. Total stiffness and gap stiffness were then determined for each fixation geometry on a materials testing machine.

There was a significant decrease in total stiffness between intact mandibles and ostectomized mandibles regardless of external fixator configuration. However, there was not a significant difference in total stiffness or gap stiffness among the different external fixator configurations applied to ostectomized mandible. External fixator configurations with only the full interdental pin engaging the rostral fragment were as stiff as configurations which had two or four additional pins in the rostral fragment for the applied loads. External fixators for rostral mandibular fractures may be rigidly secured with rostral fragment implants applied extracortically avoiding iatrogenic trauma to teeth and tooth roots.

Introduction

Mandibular fractures represent 3-6% of all fractures diagnosed in the dog, and generally result from vehicular trauma, falls, kicks, gunshots and fights. [23,52,53,54,61] The most common location for mandibular fracture in the dog is in the region supporting the premolar teeth.[52] The predilection for mandibular fractures in this area may be related to mandibular anatomy.[46] The right and left halves of the mandible are united at the strong, rough surfaced mandibular symphysis which includes incisor and canine tooth roots. This union of the horizontal components of the mandible at the symphysis occurs in the rostral premolar segment of the mandible. This premolar area may be subject to fracture based on the relative strength of the individual horizontal bony components compared with the tooth root and mandibular symphyseal bone composite, the relative weakness of the canine alveoli, location of muscle forces in relation to the rostral mandible, or a combination of these factors.(Fig 3)

Several techniques have been used to stabilize mandibular fractures, including bone plating, external coaptation with a tape muzzle, interfragmentary wire, interdental acrylic, external fixators, and combinations of these techniques.[23,40,55,61,62] The most common technique for mandibular fracture repair in dogs is by external coaptation using a tape muzzle.[52,27] Tape muzzles are utilized frequently because of their low cost, ease of application, and association with secondary bony healing. However, the tape muzzle can cause a delay in return to function, malocclusion, and a moist dermatitis.[23,27,57,58] Other complications that may occur include aspiration pneumonia, decreased range of motion, muscle atrophy from disuse, and heat prostration from a decreased ventilatory capacity.[23,27,57,58]

Bone plating provides rigid fixation of the fracture and early return to function while preventing many of the complications associated tape muzzle application. [23,67,68] Bone plating also has been shown to adequately stabilize fractures of the mandible when the screws are placed monocortically which is beneficial because of reduced iatrogenic trauma to the tooth roots.[23] However, bone plating can be expensive, technically challenging when applied to the rostral mandible, and not readily available to veterinary practitioners. Plating in the rostral mandible area can be difficult based on the degree of plate contour needed in that region while the amount of dissection for plate application in the caudal mandible may negatively affect healing due to traumatized blood supply.[23,67,68]

External fixator (EF) techniques, including the use of intrafragmentary pins and acrylic connecting bars, have been shown to adequately stabilize fractures and experimental osteotomies of the mandible in dogs.[23,57] This technique for fracture repair is relatively simple to perform, and the equipment is readily available. The most common complications are pin loosening and local osteomyelitis.[69] This technique also can result in trauma to neurovascular structures if pins are placed into the mandibular canal.[40,56] Iatrogenic trauma to the tooth roots may occur resulting in periodontal and/or endodontic complications such as pulpitis and destruction of alveolar bone jeopardizing tooth maintenance.[69]

Fractures in the mandibular premolar area may be comminuted making application of plating, EF, or interfragmentary techniques difficult. An extracortical method to engage the rostral, predominantly symphyseal component of a mandibular fracture and to include it in a bilateral type I EF would avoid iatrogenic trauma to the neurovascular structures and tooth roots which dominate this bony segment. The purpose of this study was to determine the total stiffness and gap stiffness of a full interdental pin secured extracortically to the rostral mandible as the only point of rostral fixation when included in a bilateral type I EF.

Materials and Methods

The experimental model used was the canine mandible. Ten mandibles were collected from large, mesatocephalic dogs (30-40 kg) within 12 hours of death. The animals were euthanized for reasons unrelated to this study and were free of musculoskeletal and dental abnormalities. All non-gingival soft tissues were resected from each specimen. Mandibles were wrapped in saline-soaked towels and frozen at -70^0C until the experiment was performed. When ready for external fixator application, bones were thawed at room temperature and kept moist with saline throughout the testing.[31,65] The vertical rami of each mandible were embedded in a customized aluminum testing apparatus using cement.[d] The cemented specimen and apparatus provided rigid fixation of the mandible, allowing testing in a dorsoventral direction.(Fig 4) Proper spatial orientation of the embedded mandible was checked with a leveling device at the midbody of each horizontal ramus in both longitudinal and sagittal planes. Only mandibles level in both planes were accepted thereby reducing the incidence of torque or abnormal moments during testing.

The EF was applied in a coronal plane. Four pins[e] were placed into each mandibular body, and one pin was used as a interdental, full pin to produce a modified type I EF (Fig 1). A low-speed drill[f] was used to drill 3.1 mm pilot holes at each pin location. Pins were placed based on crown and mandibular landmarks in order to avoid penetration of the mandibular canal and the tooth roots. Pins were placed interradicularly, dorsal to the mandibular canal, and bilaterally at the 1st molar and 4 th – 2 nd premolars as described previously.[23] Medium positive end-threaded pins[e] 3.2 mm in diameter were applied through the pilot holes perforating the lingual cortex. A jig was used to provide reproducibility of pin placement in a coronal plane ensuring perpendicular pin placement in the long axis of each body. A medium 3.2mm centrally threaded pin[e] was placed as a interdental, full pin caudal to the canine teeth. A figure-of-eight wire twist pattern with 18 g wire was used to secure the interdental pin around each canine tooth and improve wire interdigitation with the PMMA. Polymethylmethacrylate[a] (PMMA) [15 mls] was applied to the lingual aspect of the canine and incisor teeth resulting in an acrylic plate covering the oral portion of the interdental pin and wire in all mandibles.

One-half inch anesthetic tubing[g] was placed around the pins. The medial edge of the tubing was placed 1.0 cm from the lateral cortex of the mandible. The tubing was filled by syringe with PMMA in a liquid consistency. Tubing from a low-pressure suction device was attached to an 18-gauge needle, which perforated the most rostral aspect of the anesthetic tube. The suction device was activated during PMMA injection in order to reduce the amount of air bubbles within the PMMA. The fixator was allowed to cure at room temperature for 12 hours prior to testing.

The EF/mandibular composite was tested in a dorsoventral bending mode and was not tested to failure (Fig 2). The applied loads did not reach the yield point of the EF/mandibular composite load deformation curve so as to allow repeated tests on a single mandible. The rigidity of the intact mandibles and the EF/mandibular composite, and the load displacement response of the fragment ends were evaluated on a biomechanical testing machine[h]. Specimens were positioned so that a downward load was applied to the most rostral portion of the mandible. The loading rate was 2.0 mm/min. Each specimen was loaded to 100 N five times, with the mean value of these five tests used for statistical analysis. Load and displacement of the crosshead were recorded.

After testing the intact mandible with the composite EF [Group 1], a saw[f] was used to create a 0.5cm bilateral mandibular ostectomy between the 3rd and 4th premolars. The resulting simulated fracture gap was large enough to prevent contact during testing. This model resulted in 2 pins in each caudal body fragment and 2 pins in each rostral body fragment, bilaterally. The interdental, full pin was the most rostral pin fixed to the rostral fragment. Three EF/mandible composite configurations were tested sequentially following ostectomy: bilateral type I EF, (8 pins) + interdental pin remaining [Group 2]; bilateral type I EF with most caudal pin of rostral fragment cut, (6 pins) + interdental pin remaining [Group 3]; bilateral type I EF with both pins of rostral fragment cut, (4 pins) + interdental pin remaining [Group 4]. In this latter group, only the interdental pin engaged the rostral fragment. (Fig 5) Random testing of EF/mandible composite configurations was not performed in order to maintain the structural integrity of the connecting bar for each test.

Motion between the bone fragment ends was monitored with 2 needle-tipped extensiometers[i] secured to the ventral cortex of each mandibular body.(Figure 6) The total stiffness was determined by the applied moment divided by the angular displacement of the mandible with the following equation:

$$\text{Total stiffness} = M/\ \text{Ø}$$

M is equal to the moment applied to the rostral mandible, $M = PN$ where P is the applied load and n is the length of the mandible from the cement to bone interface to where the force was applied. Ø is equal to the L divided by N. L is the corresponding deflection difference.

The gap stiffness was determined by the applied load divided by the angular displacement at the ostectomy with the following equation:

$$\text{Gap stiffness} = M/\ \phi$$

Where: ϕ is the angular rotation of the gap face and is equal to $\tan^{-1}(G/A)$. Where G is the gap closure measured by the extensiometer and A is the distance from the mandibular centerface to the ventral cortical edge of the mandible.

Data were collected continuously and stored in a computer data file. Each of the four configurations for the 10 mandibles was identified as a specific treatment group. A total of 50 mechanical tests were conducted on each of the 4 configuration groups.

Statistical Analysis Comparisons of means for each of the 4 treatment group parameters (n=50) of total stiffness and gap stiffness were analyzed using two-way ANOVA for a randomized block design. Statistical probability of $p < 0.05$ was considered significant. If the p-value was less than 0.05, individual differences within the treatment group were identified using Fisher's Least Significant Difference test. If the p-value was greater than 0.05, all treatment groups were considered equal. When comparisons between groups were not significant, power calculations were performed to determine the percent difference which would be necessary to detect a significant difference. Statistical analysis was performed using a commercially available statistical software program[j].

Results

The intact EF/mandible composites of group 1 had significantly greater total stiffness 1544+/-315.9 Nm/rads in dorsoventral loading. The total stiffness decreased significantly with the presence of a simulated fracture gap. The total stiffness for treatment groups 2, 3, and 4 were 301.6+/-72.4 Nm/rads, 290.5 +/-70.3 Nm/rads, and 267.0+/-49.7

Nm/rads, respectively. There was no significant difference in total stiffness between the three treatment groups with a simulated fracture gap(p.0.05, power=0.8 @ δ=63%)

The gap stiffness for the right mandibular body in treatment groups 2, 3, and 4 were 2041.1+/-473.6 Nm/rads, 1763.6+/-371.9 Nm/rads, and 1679.9+/- 805.60 Nm/rads, respectively. The gap stiffness for the left mandibular body in treatment groups 2, 3, and 4 were 2110.8+/-551.1 Nm/rads, 1880.1+/-317.6 Nm/rads, 1861.1+/-851.8 Nm/rads, respectively. There was no significant difference in gap stiffness between treatment groups(p>0.05, power=0.8 @ δ=84%) or between right and left mandibular bodies of the same treatment group(p>0.05, power=0.8 @ δ=83%)

Discussion

A previous study has shown that secondary bony healing will occur in a canine bilateral mandibular osteotomy model repaired with a bilateral type I EF similar to the configuration evaluated in groups 1 and 2 of the study reported here.[23] A bilateral fracture located immediately caudal to the apical aspect of the canine tooth roots, especially if comminuted, may be particularly challenging to repair when outcome goals include maintenance of occlusion and avoidance of iatrogenic trauma to dental structures. In this study, we evaluated EF configurations which have been proven to be effective in promoting bony healing of mandibular fractures of the premolar region[1,8,19]. In addition, a configuration was evaluated which could be applied extracortically to a rostral mandibular fragment composed principally of tooth roots and the mandibular symphysis. Tests were performed to determine if this latter configuration might have similar mechanical properties as a configuration previously shown to be associated with appropriate bone healing.[23]

A simulated fracture gap model was used similar to previous studies.[23,27,31,65] This component of our model did not allow fragment end contact, requiring the applied EF to carry the entire force transferred through the bodies of the mandible. The simulated fracture gap model also reflected the clinical condition of repairing a comminuted fracture where bone end contact cannot be achieved and a buttress effect is necessary.

PMMA is an advantageous connecting bar material in the clinical setting based on its low cost, ease of application, and adaptability for use with curved bones like the mandible.[34,40,57,62] PMMA connecting bars of 19 mm diameter similar to those used in this study have been shown to have similar rigidity as 4.8 mm steel connecting bars.[22,36] The type of PMMA used in this study has been shown to have superior mechanical properties when compared to other acrylic materials.[22] A potential complication of anesthetic tubing used for connecting bar molds is the entrapment of air bubbles which may weaken the structural properties of the EF. In this study, negative pressure was applied within the tubing during PMMA injection in order to minimize the presence of air bubbles.

Positive profile, end-threaded pins were applied as described previously.[31,65] As recommended, the innermost pin was placed as close to the fragment end as possible while avoiding tooth roots. Although optimal pin distance parameters may have influenced mechanical test results, the clinical practicality of minimizing iatrogenic dental trauma was influential in pin site selection.[23,27] Therefore, dental anatomy relative to the simulated fracture gap between the 3rd and 4th premolars dictated pin positioning for all pins. Since specimens were from dogs of similar size and there were no dental spatial abnormalities, pin distances relative to the simulated fracture gap were similar and consistent among dogs.

The amount of force applied to each fixator configuration was standardized at 100 N for each test. This value was selected based on a study that evaluated the bite force of canines in which the majority of dogs had a non-aggressive, chew toy bite force of less than 200 N.[59] The bite force of dogs during prehension of food in the postoperative healing period may be expected to be less than this value based on the recommended soft consistency of the diet. The test force applied to the mandibles in this study was considered to be clinically appropriate while generating load versus displacement curves without reaching the yield point of the EF. This test force was applied to the acrylic covering the interdental, full pin equidistant between the canine teeth generating a constant bending moment along the length of the EF/mandible composite. Equidistant load positioning and level specimen orientation was supported by gap stiffness data analysis which indicated similar amounts of movement at the simulated fracture gap for both right and left mandibular bodies for each test. Single site loading at this anatomic region was clinically relevant for mandibular fractures of the premolar region. The premolar region is non-occlusal in dogs.[40] Canine and incisive occlusal forces would impart a bending load on the mandible during biting or prehension of food. A load limited to bending is dictated by the hinge-like nature of the temporomandibular joint and the difficulty in translocating the mandible in a mediolateral plane. Mediolateral movement is further prevented by the shearing occlusion of the mandibular molars in relation to the maxillary PM4 and the molars; and the dental interlock of the mandibular and maxillary canine teeth.[40] These anatomic factors likely combine to minimize mediolateral movement of the mandible, concentrating bending loads to the rostral mandible.

Mechanical tests in this study were performed in dorsoventral bending and used to determine fixation rigidity particularly as it relates to motion at the simulated fracture gap. Maximizing EF rigidity will decrease complications including pin loosening, delayed union or nonunion, and pin sepsis.[8,32,60,66] In the study reported here, the EF/mandibular total stiffness, and the simulated fracture gap stiffness were determined for the different configurations during dorsoventral bending. Our results show that the gap stiffness was significantly greater than total stiffness in bending for all configurations evaluated. Although total stiffness and gap stiffness are intimately related, minimizing motion specifically at the fracture site has a positive effect on bone healing.[8,32,60,66] Gap stiffness is a more accurate measurement since it is a focal measurement. It will be increased relative to total stiffness because less deflection will be detected.

We acknowledge that rotation of the rostral fragment could occur if one pin was securing the rostral fragment and a force was applied directly to the caudal part of the rostral fragment. This complication would be especially predictable when using a single pin in bone resulting in a circular interface. The mass of wire-reinforced acrylic engaging the interdental pin and interdigitating with the lingual surface and interdental spaces of the incisor and canine teeth likely provided a structure with a geometric advantage to resist rotational forces. In addition, a force generated in this region would be unlikely to cause rotation clinically based on the dental interlock of the mandibular and maxillary canine teeth and the soft consistency of the diet recommended in the postoperative healing period.

Based on the results of this study, the stiffness of the EF/mandible composite configurations of group 4 were equal in dorsoventral bending as those in groups 2 and 3 which had two or four additional pins in the rostral fragment. This result is unexpected based on the work of others in which at least two pins are recommended to engage each fracture fragment.[31] Research studies have shown that multiple pins in each fracture fragment increase EF rigidity and minimize rotational and torsional forces. We consider the maintenance of EF/mandible composite mechanical properties in group 4 to be related to the structural design of the metal/acrylic/bone composite of the engaged rostral fragment. Application of the interdental, full pin and acrylic as described in this study incorporates nearly all tooth and bone of the mandibular symphysis. Although not directly tested in this study, the geometric structure of this rostral fixation may have a greater mechanical advantage in resisting rotation and bending when compared with placement of 2 or 4 pins in the rostral mandibular bodies. Other factors which may have contributed to maintenance of EF rigidity by the interdental, full pin and acrylic include: a short EF length combined with a relatively large diameter connecting bar, and the bilateral design of the interdental pin. The standard deviation for gap stiffness in group 4 was substantially greater possibly related to inconsistencies in frame structure. Statistical analysis of the power of the model reported here indicated that a difference of 65-84 % between groups was required in order to detect a statistical difference. Further studies with a larger sample size may be indicated in order to detect statistically significant differences between groups.

This experimental model allowed for sequential testing and comparison of configurations while minimizing variation in specimen and configuration preparation. The group 1 EF/mandible composite configuration tested before ostectomy provided baseline data for subsequent assessment of the relative strengths and weaknesses of the tested EF configurations. The total stiffness of the intact mandible was approximately four times greater than any of the tested EF configurations. The design permitted multiple test runs without catastrophic failure of the fixator following ostectomy.[31] Failure data would have increased our confidence level in recommending the configuration evaluated in group 4. However, it tested favorably when compared with an EF configuration (group 2) similar to one which has been shown to promote bony union in a mandibular osteotomy model.[23] Therefore, we consider the configuration of group 4 a potentially useful surgical technique for comminuted rostral mandibular fractures.

Damage to teeth, tooth roots, and neurovascular structures of the mandible is often overlooked in difference to rigid application of metallic implants for repair of mandibular fractures. Iatrogenic trauma to these structures may predispose the dog to pulpitis, tooth loosening, apical abscess, local osteomyelitis, tooth death, and tooth resorption.[23] In fact, the validity of mandibular fracture repair may be questioned if the structures meant to be supported by the healed bone are sacrificed to attain bony union.[37,54] Techniques that provide for occlusal maintenance and optimal oral and dental health should be delivered. The results of the study reported here indicate that a mandibular fracture fragment rostral to the level of PM3 may be rigidly secured with implants applied extracortically as described. We have used this technique clinically in 3 dogs with comminuted fractures of the mandible. Complications were limited to transient gingivitis at the site of acrylic application. Long term follow-up has indicated appropriate bony healing and occlusal maintenance.

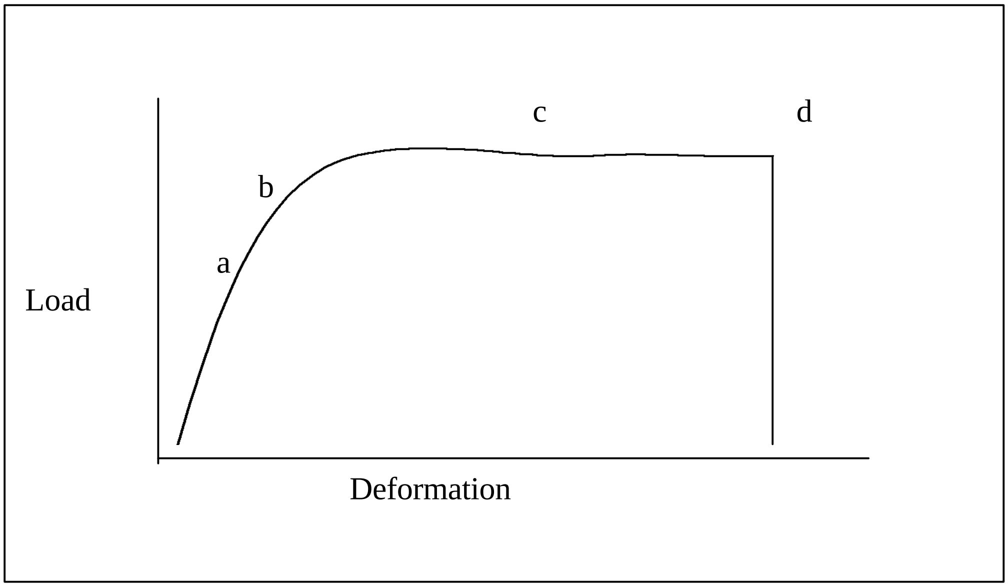

Figure 1: Load-deformation curve: a is equal to the elastic region; b is equal to the yield point; c is equal to the plastic region and d is equal to the point of catastrophic failure.

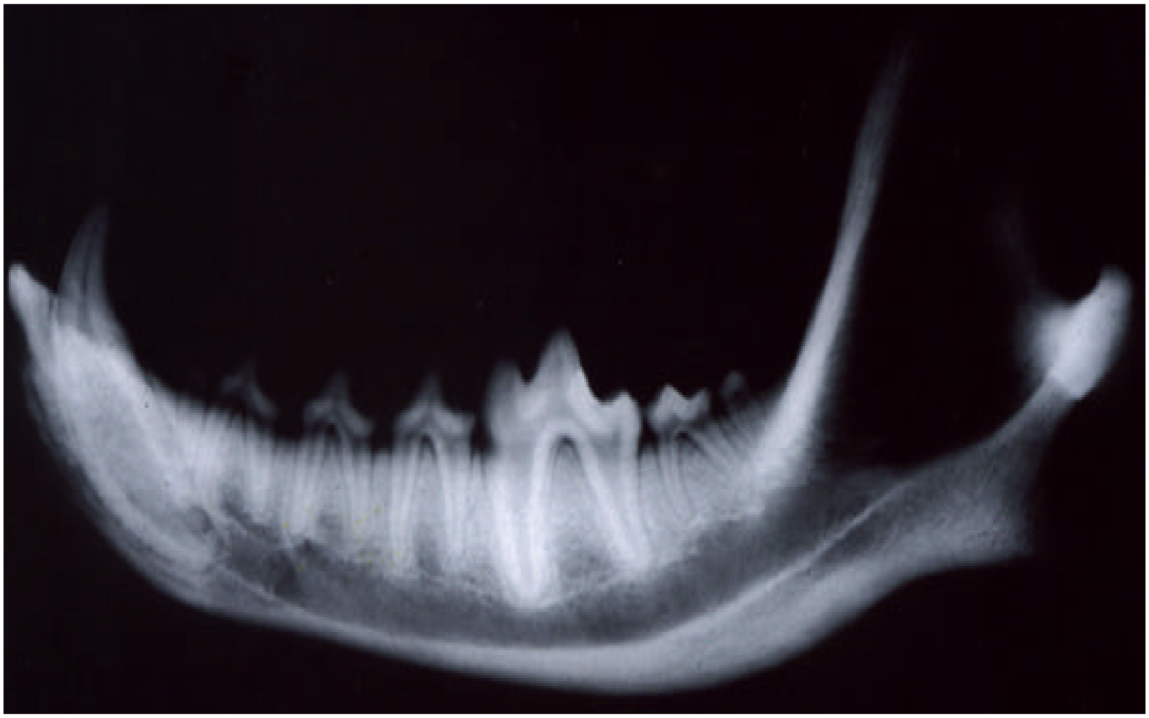

Figure 2: Lateral mandibular radiograph; not the location of the mandibular canal and the small amount of bone stock.

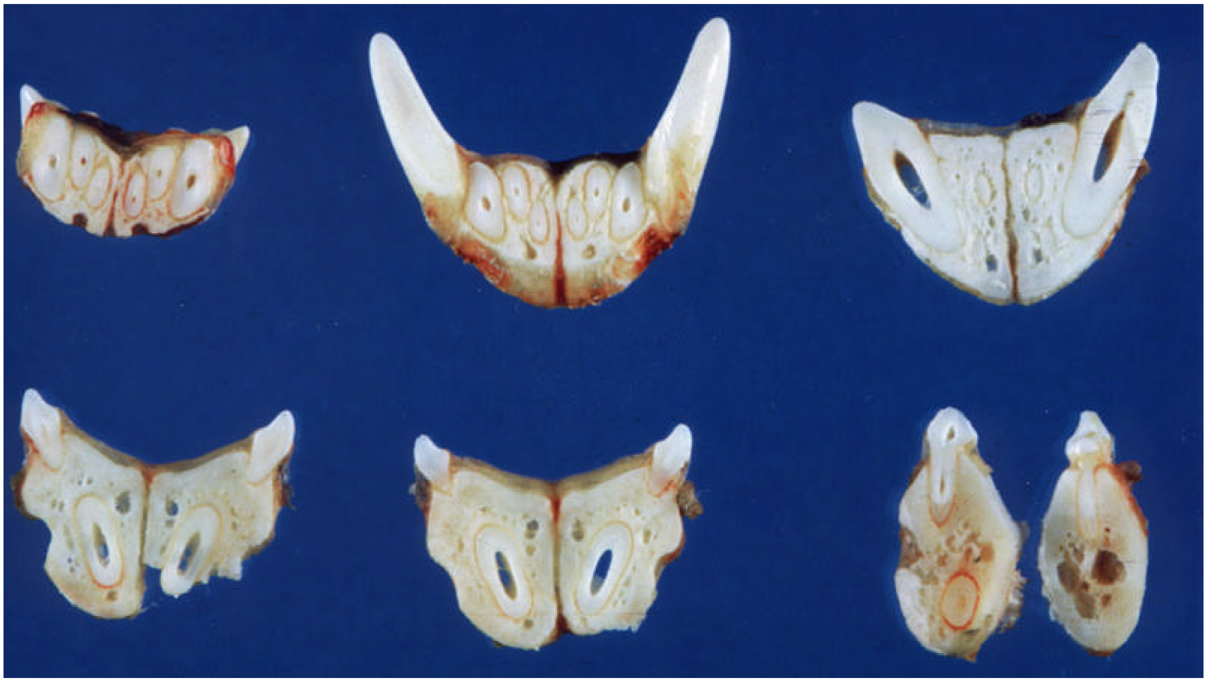

Figure 3: Cross section of the rostral mandible. Note the large percentage of the bone stock that is occupied by tooth roots.

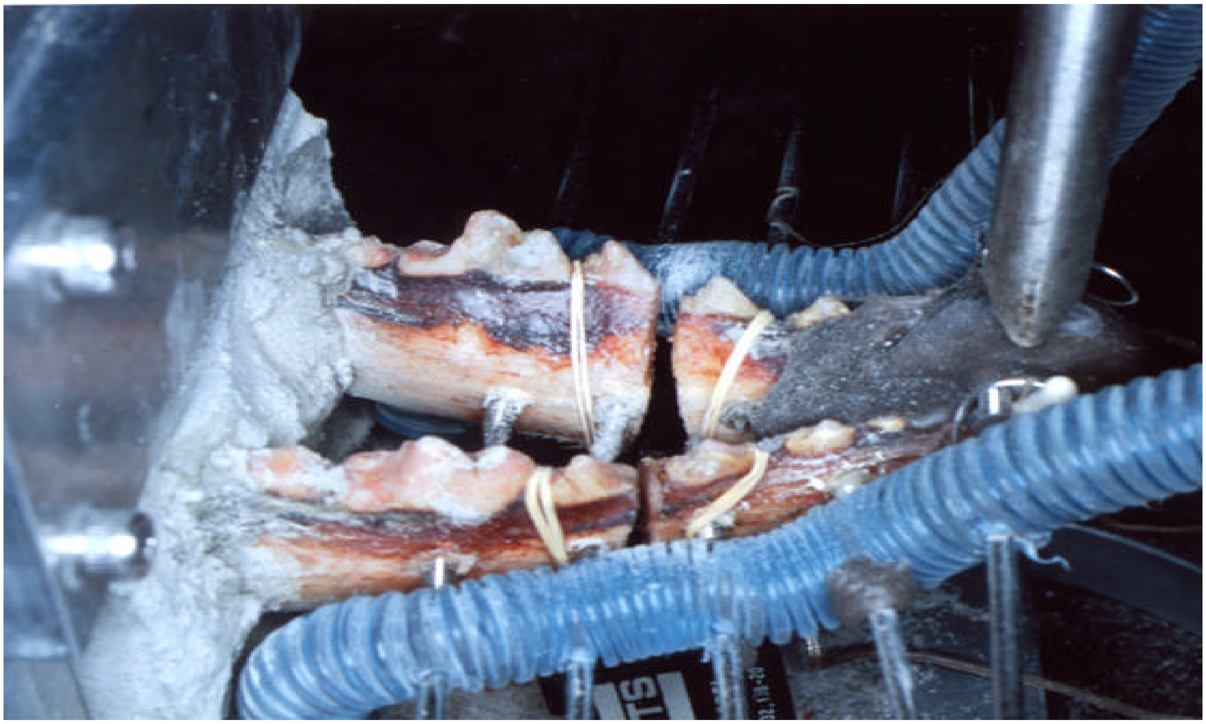

Figure 4: Dorsal view of the mandible composite: note the fracture gap and the location of the interdental pin on the distal aspect of the canine teeth.

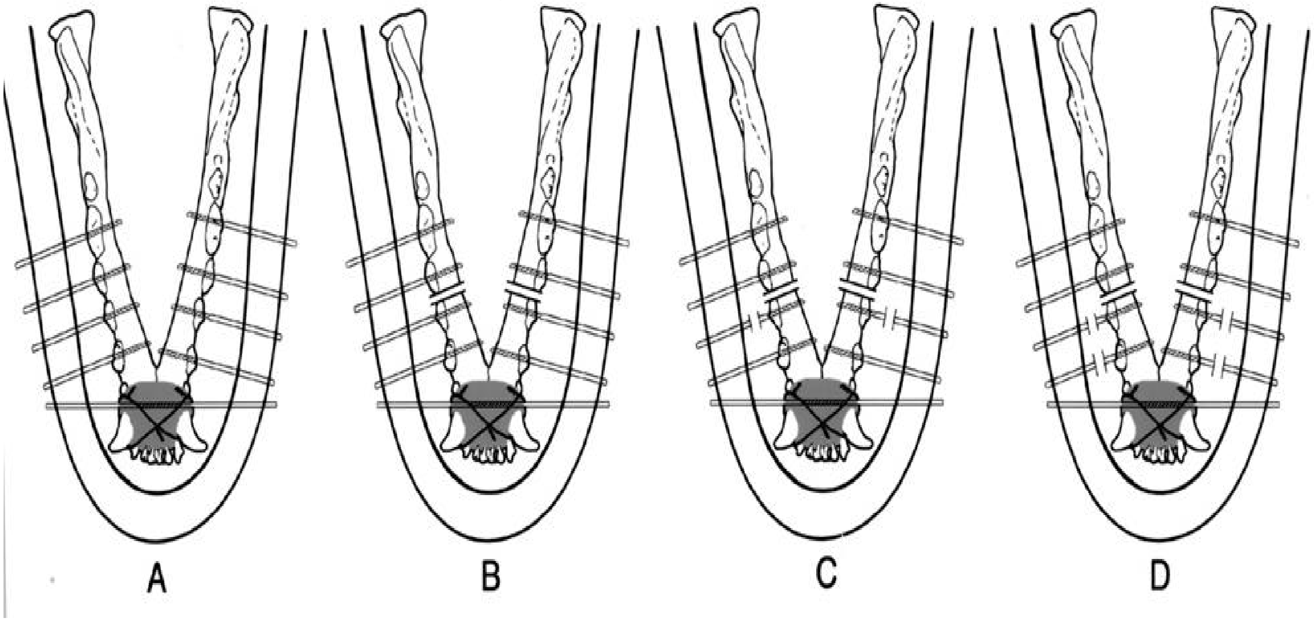

Figure 5: Schematic diagram depicting the 4 configurations tested: A) intact mandible, bilateral type I EF (8 pins) + interdental pin [Group 1];
B) ostectomized mandible, bilateral type I EF, (8 pins) + interdental pin remaining[Group 2]; C) ostectomized mandible, bilateral type I EF with most caudal pin of rostral fragment cut, (6 pins) + interdental pin remaining [Group 3]; D)ostectomized mandible, bilateral type I EF with both pins of rostral fragment cut, (4 pins) + interdental pin remaining[Group 4].

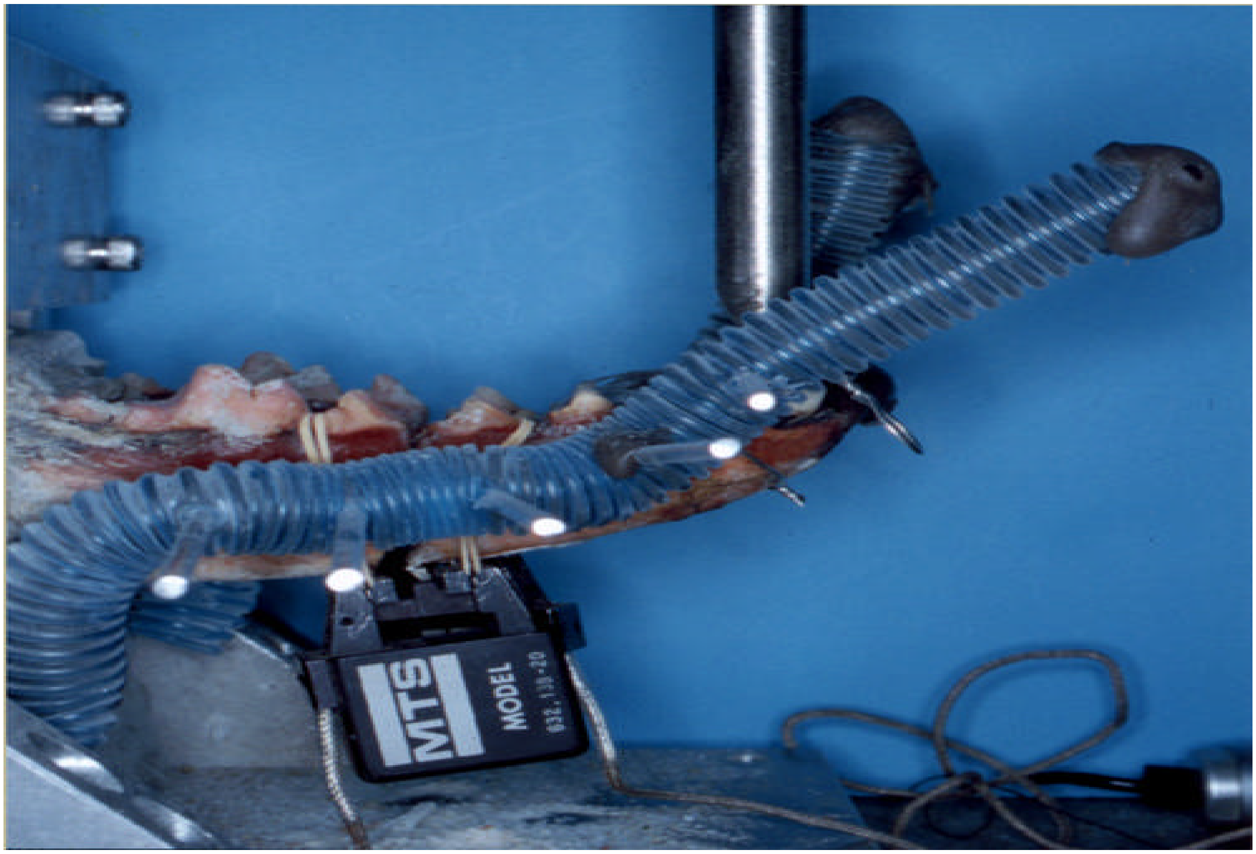

Figure 6 Photographic lateral view of the mandible/external fixator composite during testing. Note the extensometers located at the fracture gap.

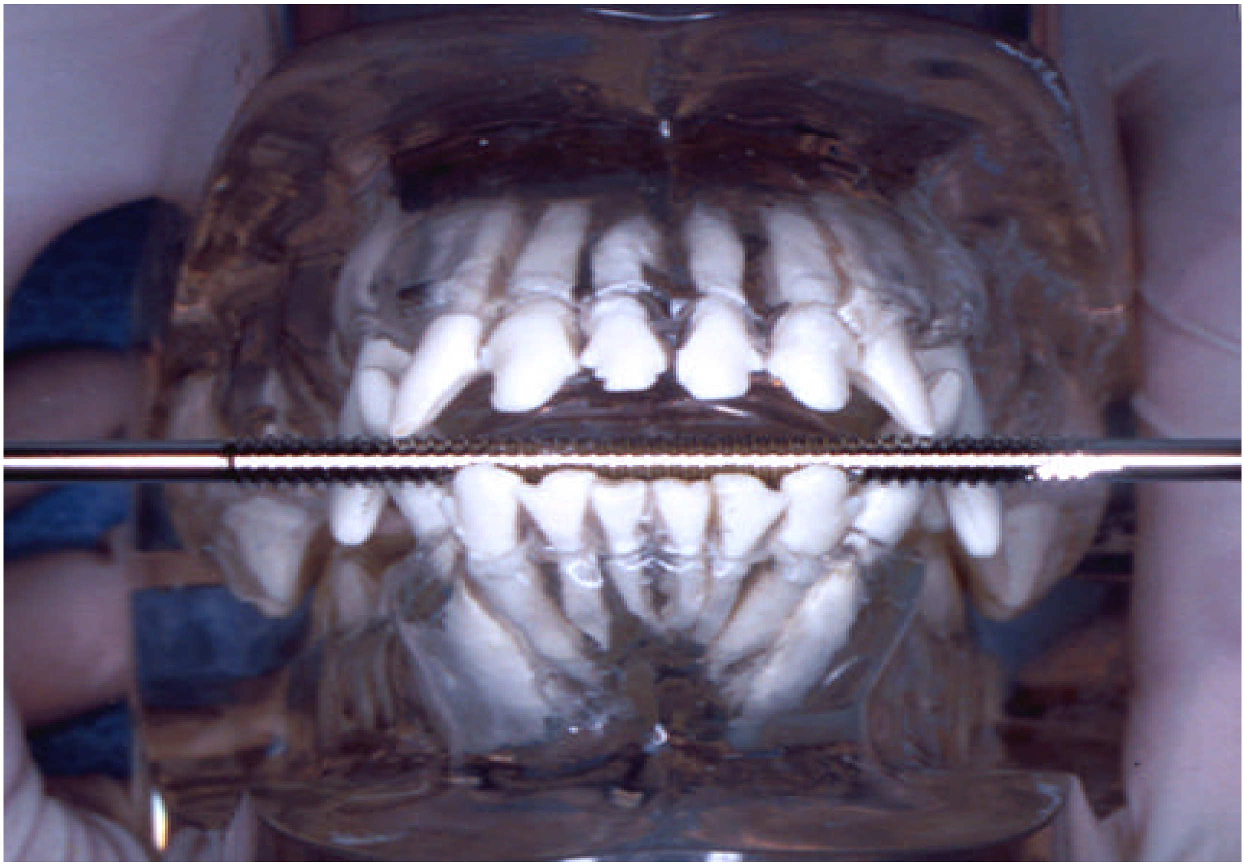

Figure 7: Acrylic oral specimen with an interdental pin. Pin is place at the mesial aspect of the canine teeth. This is different from the study; however, it still demonstrates the potential for mild interference from the apparatus.

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[a] Technovit Liquid and Powder, Jorgensen Laboratories Inc. Loveland, CO

[b] Orthodontic Resin. Milford, DE

[c] APEF system. Rochester, MN

[d] Quikrete Cement Atlanta GA

[e] Imex, Longiew Tx

[f] Stryker, Kalamazoo MI

[g] Blue Ridge Anesthetic Company, Lynchburg VA

[h] Instron 4204, Canton MA

[i] Extensiometer MTS System Corp. Eden Prairie, MN

[j] Statistical Software, Minitab Inc, State College, PA

Vita

Wesley Todd Cook was born on February 21, 1969 in Pisa, Italy, son of Wesley and Linda Cook. He attended Jordan High School in Durham, North Carolina. He then attended Guilford College in Greensboro, NC from 1987 to 1992 where he earned Bachelor of Arts degrees in Biology and Chemistry. While in college, Wesley worked with several veterinarians throughout NC and did research developing electrically conductive plastics. He attended North Carolina State University College of Veterinary Medicine, where he graduated as a Doctor of Veterinary Medicine in 1996.

Wesley completed in 1997 a rotating internship in small animal medicine and surgery at the University of Georgia. In 1997 Wesley started a residency in small animal surgery and the Master's in Veterinary Medical Sciences program at the Virginia-Maryland Regional College of Veterinary Medicine.

In July, Wesley will begin as a Clinical Instructor in Small Animal Surgery at the Virginia-Maryland Regional College of Veterinary Medicine.

Thanks

Sincerely

Wesley Todd Cook, DVM,MS