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Biomechanical evaluation of locking versus nonlocking 2.0-mm malleable L-miniplate fixation of simulated caudal mandibular fractures in cats

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OBJECTIVE
To evaluate the biomechanical properties of the mandibles of cats with experimentally created osteotomies simulating oblique ramus fractures, which were stabilized with malleable L-miniplates with either locking screws [locking construct (LC)] or nonlocking screws [nonlocking construct (NLC)], compared with those for intact mandibles.

SAMPLES
20 mandibles from 10 adult cat cadavers.

PROCEDURES
A block study design was adopted to allocate the mandibles of each cadaver to 2 of the 3 test groups (LC, NLC, or intact mandible). Mandibles within each cadaver were allocated systematically to a test group. For mandibles assigned to an LC and an NLC, a complete oblique osteotomy was performed from the mid rostral aspect of the ramus in a caudoventral direction. All mandibles were loaded in a single-load-to-failure test through cantilever bending. Load and actuator displacement were recorded simultaneously. Mode of failure and radiographic evidence of damage to tooth roots and the mandibular canal were evaluated. Biomechanical properties were compared among the groups.

RESULTS
No iatrogenic tooth root damage was evident, but all mandibles with an LC and an NLC had evidence of screw invasion into the mandibular canal. Plated mandibles had significantly less stiffness and bending moment than intact mandibles. Stiffness was not significantly different between the LC and the NLC; the NLC had a greater bending moment at failure than the LC. The pre-yield stiffness of plated mandibles decreased when the number of screw holes overlapping the mandibular canal increased.

CLINICAL RELEVANCE
The use of a malleable L-miniplate in a caudal mandibular fracture model is feasible. Both the LC and the NLC were inferior mechanically to intact mandibles. Type of construct used did not affect the construct stiffness significantly in tested mandibles.

Mandibular fractures account for 11.4% to 23.1% of all fractures in cats[1–4] and are commonly associated with car accidents,[3,5] fights, and falls from a great height.[6,7] A recent study revealed 86.7% of cats with craniomaxillofacial fractures had evidence of mandibular fractures, of which 18.0% were bilateral.[8] Caudal mandibular fractures, defined as fractures involving the mandible caudal to the mandibular first molar tooth, ramus, coronoid process, and/or condylar process, although seen less frequently alone,[3] are more commonly bilateral in presentation when compared to fractures of rostral mandibular body[8] and are often noted simultaneously with symphyseal separation. In addition to the accompanied hemorrhage and pain, caudal mandibular fractures are usually associated with marked malocclusion secondary to the compression of the fracture segment, which when untreated may result in severe functional deficiencies and disfigurement, as well as osteoarthritis of the temporomandibular joint.[3]

Repair of caudal mandibular fractures is challenging as a result of difficult surgical access as well as limited surface area and bone thickness available for internal fixation[9]; and, therefore, fixation options are limited. Repair techniques described in the literature include maxillomandibular fixation, a bignathic encircling and retaining device, and open reduction and internal fixation (ORIF)[10–14] with the use of miniplates and screws. Morbidities are reported in patients with maxillomandibular fixation[15,16] and a bignathic encircling and retaining device.[17] Slow functional recovery, inadequate fracture healing, and nonunion fracture may also occur. ORIF with miniplates and screws involves open reduction of the fractured bone segments followed by rigid internal fixation, and contributes stability to facilitate fracture healing, rapid restoration of occlusion, and reestablishment of jaw function and support of soft tissues.[10,11] Its use has been well described for human maxillofacial fracture repair.[18–20]

The titanium miniplate system is especially useful for fractures located in the caudal mandible of dogs and cats, with the advantage of small size and light weight, allowing easier application and less soft tissue dissection, thus minimizing damage to tooth roots and structures in the mandibular canal.[21] The titanium plate also has a similar elastic modulus and density compared with bone, and it exhibits good biocompatibility with bone and soft tissues, enabling osteointegration.[21]

The stability of fracture fixation via ORIF and risk of complications are affected by plate positioning, configuration and strength, screw geometry, bone quality, biology, and load environment.[22] In a locking construct (LC), the locking screws are locked into the threaded screw holes of the locking plate when the screws are tightened; hence, screws are unlikely to loosen from the plate, and the construct acts as a form of internal "external fixator."[18] Also, screw insertion does not alter the reduction because the fractured segments are not pulled to the plate. The nonlocking screws in a nonlocking construct (NLC) do not lock into the threaded screw holes of the plate; fractured fragments may be pulled toward the plate, resulting in disturbance of the reduction if plate adaptation is not precise.[23] It has been shown that an LC is able to provide a more stable fixation when compared to nonlocking construct.[23] According to the tension-band principle, miniplates are best placed along the lines of tensile stress (ie, Champy lines) or on the tension surface of the bone (ie, alveolar margin in mandibular fracture) to neutralize the bending forces[21,24,25] and induce load-sharing among the reduced bone fragments in compression. However, plate application is technically difficult in caudal mandibular fractures in cats because of the challenging topographic anatomy of the caudal mandible of cats and bone stress distribution. A malleable titanium miniplate has half the original volume of a Champy miniplate.[26] It is readily shaped and has the advantage of easy adaption, a lesser requirement for contouring, and thus simpler application because of its thinness and malleability.[27]

The L-shaped plate geometry resembles the abaxial contour of the caudal mandible of cats, and may be easier to adapt and contour in fractured ramus. A malleable titanium locking L-miniplate (L-plate) shares the properties described earlier and therefore may be a suitable implant material for cats with caudal mandibular fracture.

However, veterinary descriptions of the use of miniplates, regardless of type and shape, and comparisons among types of plate constructs are limited. In fact, only one study[13] demonstrated the biomechanical properties of intact cat mandibles and those with a caudal simple transverse fracture fixed with straight LCs and NLCs. To date, no biomechanical evaluation has been performed on a caudal mandibular fracture model in cats that involves the ramus and fixation with an L-plate of two different plate constructs.

To bridge the gap in knowledge, the aims of our study were to assess the feasibility of placement of an L-plate in the caudal mandibles of cats; to evaluate the biomechanical properties of cat mandibles with experimentally induced osteotomies simulating oblique fractures involving the ramus at the level of the condylar process, which were plated with locking miniplates with either locking screws or nonlocking screws, resembling LCs and NLCs, respectively; and to compare properties with those of intact feline mandibles.

Materials and Methods

Samples

Twenty clinically healthy mandibles were obtained from 10 adult feline cadavers that were euthanized for reasons unrelated to this study. Mandibles were excised, debrided, and separated at the mandibular symphysis to yield 2 mandibles per cadaver.

Study design

A block study design was adopted to minimize the effect of individual cat variation on the study objectives. The 3 treatments were (1) locking L-plate and locking screws (LC), (2) locking L-plate and nonlocking screws (NLC), and (3) intact mandible (intact control). Each cadaver head was assigned a number and then allocated randomly to 1 of the 3 test groups by drawing numbers. The left and right mandible of each cadaver head were allocated systematically and equally to 1 of the assigned treatments. This enabled the biomechanical comparison of the 2 fixation methods (LC with NLC) in 4 cats, the LC with intact control in 3 cats, and the NLC with intact control in 3 cats.

Fixation methods

The 2.0-mm, 5-hole L-plate (447.318 and 447.319, DePuy Orthopaedics Inc) was assigned to the LC and NLC groups. The location of miniplate application for each mandible was determined visually after subjective assessment of spatial location of tooth roots, the mandibular canal, and the ventral border of the mandible **(Figure 1)**. The long portion of the miniplate was positioned parallel to the ventral border of the mandible, and the short portion of the miniplate was positioned parallel to the axis formed between the condylar process and the

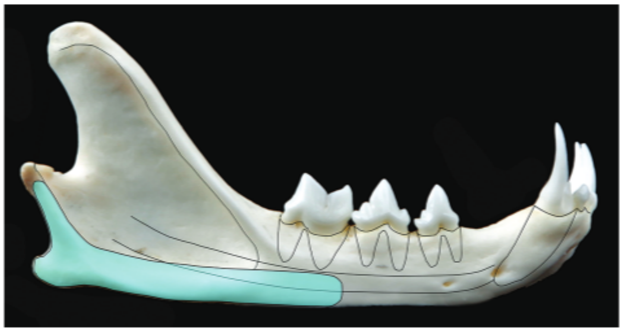

Figure 1—Illustration of the lateral aspect of an intact feline mandible that depicts the ideal (blue) regions for application of a 2.0-mm malleable titanium L-miniplate for caudal mandibular fracture. The ideal region overlies bone capable of supporting internal fixation.

angular process **(Figure 2)**. Prior to application, the miniplate was contoured appropriately for optimal fitting to the mandible.

Screw holes were drilled, and the self-tapping screws were inserted using a 2.0/2.4 cruciform, self retaining screwdriver. For mandibles assigned to the LC group, the miniplate was secured with three 2-mm locking screws (length, 8 mm; VST202.008, DePuy Orthopaedics Inc) on the rostral portion of the plate and two 2-mm locking screws on the caudal portion of the plate. For mandibles assigned to the NLC group, 2-mm nonlocking screws (length, 8 mm; VST201.008, DePuy Orthopaedics Inc) were used in the same manner. All the fixations were performed jointly by a board-certified veterinary dentist (BA) and a dentistry and oral surgery resident veterinarian (CCSK).

A standardized, complete oblique osteotomy was then performed on the plated mandibles using a 0.4-mm disk (545 Diamond Wheel, Dremel) to avoid any osteotomy-induced changes to mandibular dimensions. It was performed along the line joined by two reference points: (1) 10 mm caudal to the most distal aspect of the crown of the first mandibular molar tooth and (2) 10 mm rostral to the most caudal aspect of the angular process. Photographs were obtained for all mandibles prior to mechanical testing.

Radiography

Lateral and ventrodorsal radiographs of all the mandibles were obtained using digital radiography (NEXT; Sound DR) with a generator (HF100/30p; MinXray Inc) before (Figure 2) and after mechanical testing, and after removal of implants, with a calibration ruler in the field. Premechanical testing radiographs were evaluated for 4 parameters: (1) the mandible length with reference to the most rostral aspect of the mandible to the most caudal aspect of the condylar process, (2) the dorsoventral length (a) and mediolateral width (b) with reference to the point immediately caudal to the mandibular first molar tooth to estimate bone cross-sectional area (CSA) using the formula for area of an ellipse: $CSA = \pi \times (a/2) \times (b/2)$, (3) the mandibular first molar mesial root length with reference to its alveolar margin to the root apex, and (4) the root-to-ventral border length with reference to the distance between the apex of the mandibular first molar mesial root and the ventral mandibular border. Imaging software[28] was used to calibrate and make radiographic measurements. Postmechanical testing radiographs were evaluated for mode of failure. Postimplant removal radiographs were assessed for the presence of abnormalities associated with a tooth root or mandibular canal in relation to the screw holes.[29] Evaluators (BA, CCSK) were blinded for assessment of the radiographs to reduce bias.

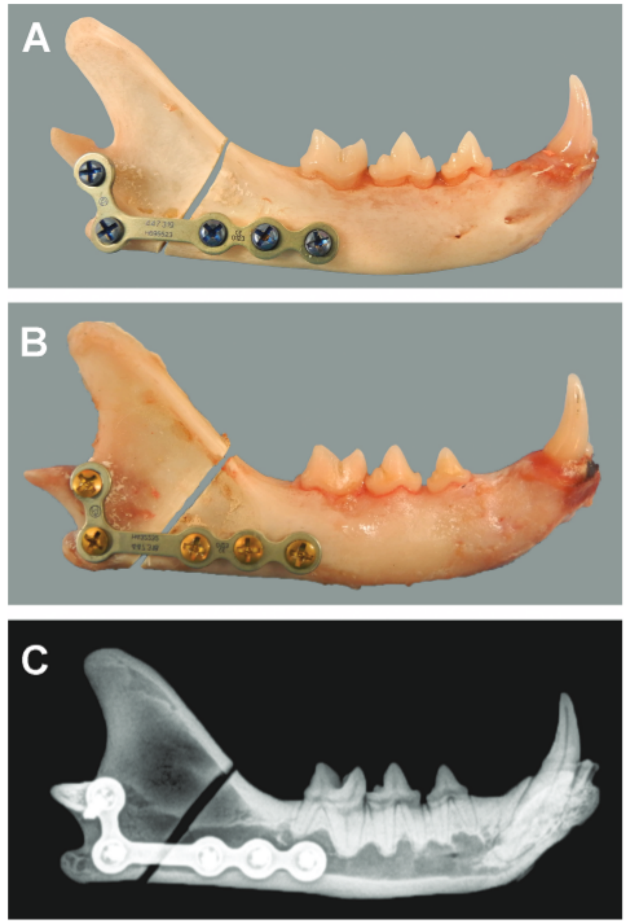

Figure 2—Photographs of the mandibles of 2 different cats with an experimentally created complete oblique osteotomy involving the ramus that was stabilized by an (A) L-miniplate with locking screws and (B) nonlocking screws. Notice the variation of shape and contour of the ramus, condylar process, and angular process between the two specimens, and the relatively optimal fitting of the construct in relation to the fracture location. The short portion of the miniplate in (A) was slightly more angled than (B), as the miniplates were contoured with reference to the topographic anatomy. C—Lateral radiographic view of a mandible of an adult feline cadaver prior to mechanical testing, showing a complete oblique osteotomy of the caudal mandible involving the ramus stabilized with nonlocking screws. Notice the absence of radiographic evidence of screw overlap with the tooth root in the plated mandible, and the relatively large portion of mandibular body space occupied by the mandibular canal.

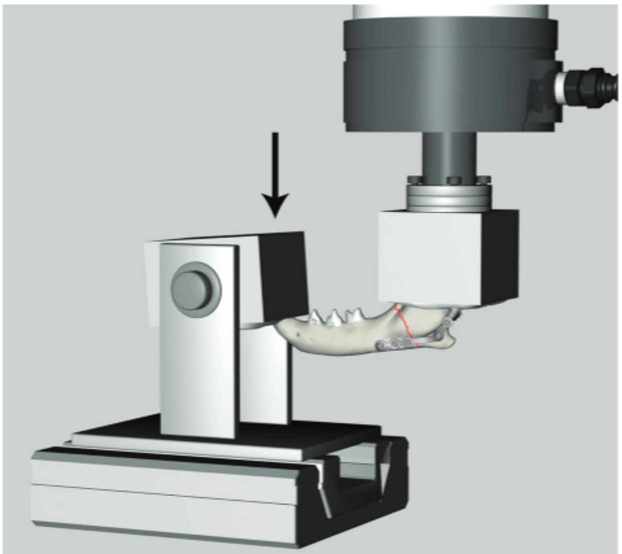

Figure 3—Illustration of the servohydraulic testing system adapted for mechanical testing of the mandibles in the 3 test groups via cantilever bending. The caudodorsal portion of the mandibular ramus and rostral teeth (ie, incisor and canine teeth) were affixed with polymethyl methacrylate and were attached rigidly to the system. Load was applied to the rostral portion of the mandible, in a direction perpendicular to the body of mandible, resembling cantilever bending at the level of the condylar process and coronoid process.

Mechanical testing

Mechanical testing of all mandibles was performed with a servohydraulic testing system (MTS Systems Corp) via cantilever bending **(Figure 3)**. Two transfixation pins (00062, IMEX Veterinary Inc) were placed through the dorsal aspect of the ramus and incorporated with the dorsal aspect of the ramus in a polymethyl methacrylate (PMMA) block (Coe Tray Plastic, GC America Inc) for attachment to the mechanical testing system. The rostral teeth were embedded in a second PMMA block. Each PMMA block was given at least 20 minutes to cure. Physiologic loading was simulated by cantilever bending about the fixed condylar process by applying a ventrally directed load centered on the canine teeth to the rostral teeth block. The rostral teeth block was mounted to linear and rotational bearings to allow unrestricted angular deformation. The bending moment arm for each mandible was measured from the most rostral point of the ramus PMMA block to the most caudal point of the teeth PMMA block. All the mandibles were loaded in a single-load-to-failure test under displacement control (1 mm/s). Load and actuator axial displacement were recorded at 120 Hz. Video (S-PRI, AOS Technologies) was recorded simultaneously at 30 Hz. Tests were discontinued automatically after the load decreased to 50% of the maximum load.

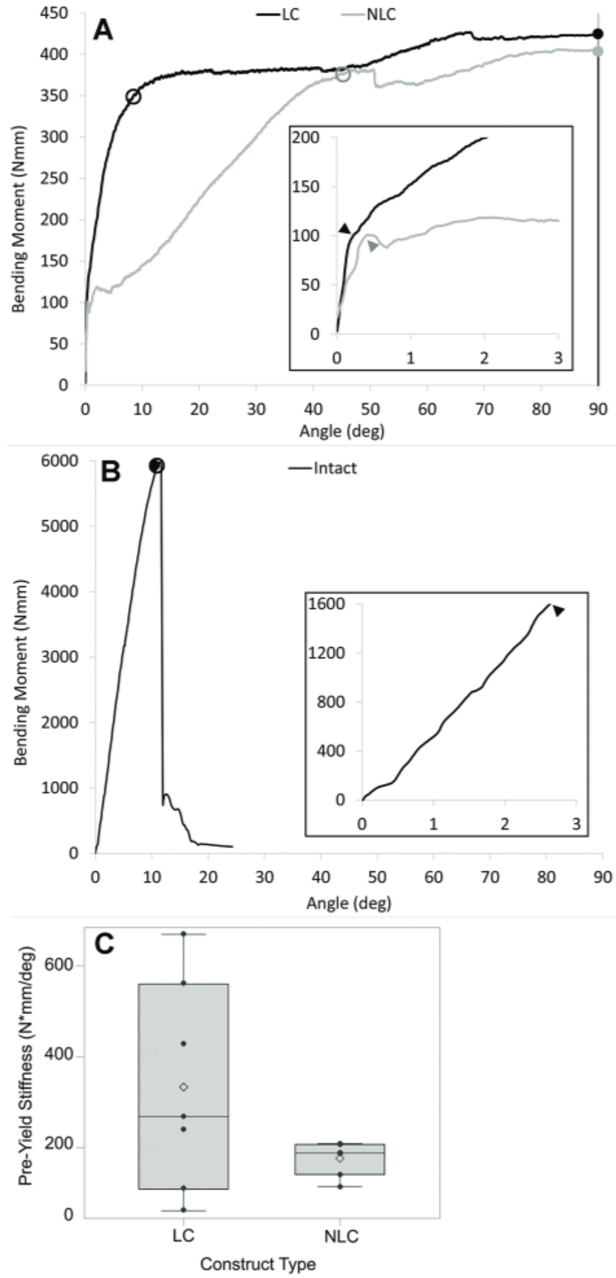

Figure 4—Example of bending moment versus angle curves from (A) a pair of mandibles from one individual with locking construct (LC) and nonlocking construct (NLC), and (B) an intact mandible. The first linear region before yield is indicated in the boxed inset at lower right side of the plots. Yield (arrowheads) and failure (circles) are indicated. C—Boxplots illustrating the data distribution for pre-yield stiffness of mandibles with LC and NLC. The minimum and maximum data points (line extents), 25% and 75% quartiles (box extents), median (horizontal line within box), mean (diamond), and data points (dots) are indicated.

Data analysis

Bending moment and angular displacement data were calculated from load, actuator displacement, and bone geometry, and plotted for each test **(Figure 4)**. Bending moment was calculated as applied force (measured in Newtons) X bending moment arm (measured in millimeters). Angular displacement (Θ) was calculated as arctan (actuator displacement [measured in millimeters]/bending moment arm [measured in millimeters]).

Because maximum load and decrease in load to a 50% maximum occurred after the mandible had bent to 90°, which was greater than physiologically possible and greater than the intact failure angles, the failure point was defined by a stiffness change criterion. The yield point was determined as the first point where angular displacement deviated by at least 0.01° greater than the linear fit of the first linear region of the data. The failure point was determined as the point where the 98% secant line calculated from a linear fit of the second linear portion of the curve intersected with the curve. Construct stiffness was determined before the yield point, and between the yield and failure points by calculating the slope of the middle two-thirds of the recorded data between the respective points. Bending moments and angular displacements were the respective values calculated at each of the determined yield and failure points. Energies were calculated as the areas under the bending moment–angular deformation curve between the respective yield and failure points, and the immediately previous point or zero (for the yield point).

Mode of failure

Each mandible was inspected visually and radiographically immediately after testing. Evaluators (BA, CCSK) were blinded for reviewing of the videos of all tested mandibles to determine the mode of failure. Parameters assessed included site and extent of bone fracture, site and degree of plate bending, and screw failure. Photographs were obtained for all the mandibles after testing.

Statistical analysis

The effects of group (LC, NLC, or intact mandible) on mandibular mechanical properties and mandible characteristics were assessed with ANOVA that accounted for the repeated measures within a cadaver. The relationships of the number of screw holes overlapping the mandibular canal with the mechanical properties were also analyzed by ANOVA. Normality of the model residuals was accepted when the Shapiro-Wilk W test had a P value of > .05. The model residuals for all mechanical test variables were non-normally distributed, and for the mandible size metrics were normally distributed. For variables with non-normally distributed residuals, ANOVA was run on the ranked-transformed data. The relationships of mandible tooth root length and root–ventral border length with CSA and mandible length were analyzed using Pearson's correlation. Values of $P < .05$ were considered statistically significant for all analyses.

Results

Samples

A total of 20 cadaveric mandibles of a similar size, from 10 skeletally mature cats with permanent dentition, were studied. Six intact mandibles served as controls. Fourteen mandibles had simulated complete oblique caudal mandibular fracture; 7 had LC and 7 had NLC stabilization. The mean ± SD length, bending moment arm, and CSA for the 20 mandibles were 67.7 ± 2.1 mm, 39.2 ± 1.9 mm, 60.2 ± 9.8 mm^2, respectively, and there were no statistically significant differences for these mandible characteristics among groups **(Supplementary Table S1)**.

Mechanical properties

Intact mandibles were markedly stiffer and stronger than both plate constructs (Supplementary Table S1). When comparing mandibles with the LC and the NLC, the mean pre-yield stiffness was greater in mandibles with the LC (Figure 4; Supplementary Table S1) but did not differ significantly ($P = .125$). The post-yield stiffness of the 2 groups also showed no significant difference. The median failure bending moment of the NLC was 20% greater than those of the LC ($P = .007$). The median load at 6.4° (ie, the angular deformation at which the tested intact mandibles failed) was not different between LC and NLC mandibles (Supplementary Table S1). The median bending moment and energy of both groups were not statistically different. The pre-yield stiffness of mandibles of all 3 test groups was markedly greater than post-yield stiffness.

Yield in plated mandibles coincided with subtle movement of the construct with opening of the dorsal aspect of the osteotomy gap and closing of the ventral aspect. Yield in intact mandibles coincided with PMMA–mandible interface motion. Failure of plated mandibles coincided with the initiation of plate deformation (7 mandibles; 5 NLCs and 2 LCs), and rostrocaudal displacement of the dorsocaudal screw and plate motion (7 mandibles; 5 LCs and 2 NLCs). Failure of intact mandibles coincided with initiation of bone fracture.

Mode of failure

Five of the 6 intact mandibles failed because of complete bone fracture that propagated from the rostral transfixation pin along the ramus toward the direction of the condylar process. The remaining intact mandible failed because of crown fracture of the canine tooth. Transverse fracture of the ramus was also identified in 2 of the 6 intact mandibles, either at the level of the condylar process or through the dorsal third of the ramus. The two modes of failure identified in plated mandibles were deformation of the miniplate and displacement of the dorsocaudal screw together with the plate **(Figure 5)**. The majority of the mandibles with an LC (5/7) failed because of displacement of the dorsocaudal screw together with the plate. The screw was seen angled in a rostral-to-caudal direction with simultaneous movement of the plate. The remaining 2 mandibles with an LC failed because of deformation of the plate, observed as bending and change in shape of the plate immediately rostral to the ventrocaudal screw at the level of the long arm of the plate. The majority of the mandibles with an NLC (5/7) failed because of deformation of the plate as described for the LC. Two of the 7 mandibles with an NLC failed because of the displacement of the dorsocaudal screw and plate, similar to that described for the LC. There was no significant difference between the constructs in terms of mode of failure ($P = .286$).

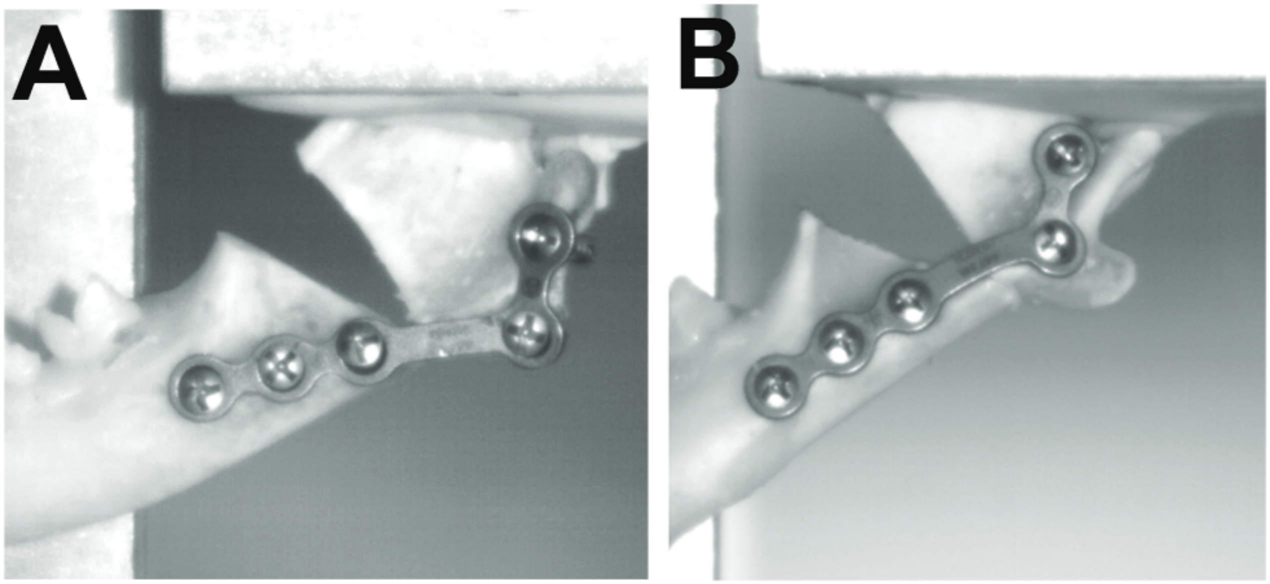

Figure 5—Representative images of mandibles with constructs at the failure showing (A) displacement of the dorsocaudal screw resulting in a relative increase of screw threads seen from this lateral view. B—Deformation of the miniplate at the level of the long arm of the plate, immediately rostral to the ventrocaudal screw.

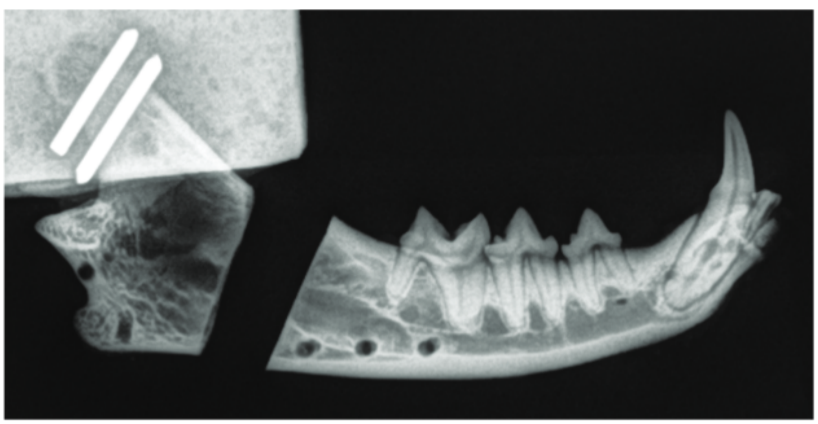

Figure 6—Lateral radiographic view of a mandible of cat postmechanical testing and postconstruct removal. Note the absence of radiographic evidence of the overlap of the screw hole with the tooth root, but superimposition of the rostral screw holes with the mandibular canal.

No bone fracture, fracture of plate, screw breakage, or screw pullout were noted in any of the mandibles with constructs at failure.

Postfailure observation of mandibles with constructs at an angular deformation of > 90° included bone fracture, extreme plate deformation, and screw pullout. No fracture of the plate or screw breakage was noted in any of the mandibles with constructs. These postfailure results are not described further or interpreted because of the nonphysiologic relevance with reference to the extreme angular deformation of the plated mandibles.

Tooth root and mandibular canal damage attributable to plating methods

Postimplant removal radiographs of mandibles revealed all tooth roots were intact, indicating no damage was associated with any tooth root in the 14 plated mandibles **(Figure 6)**. However, incidence of screw approximation or superimposition on the mandibular canal at the rostral segment was noted in all plated mandibles. The mean ± SD for the number of screw holes overlapping with the mandibular canal was 2.0 ± 0.8 per mandible with an LC and 2.6 ± 0.5 per mandible with an NLC; there was no significant difference between the 2 test groups. The most rostral screw hole was associated more frequently with overlapping with the mandibular canal, followed by the second most rostral screw hole and third most rostral screw hole. There was no observation of overlapping of the 2 caudal screw holes (ie, dorsocaudal and ventrocaudal screw holes) with the mandibular canal in any of the plated mandibles **(Supplementary Table S2)**.

The pre-yield stiffness of all plated mandibles decreased when the number of screw holes overlapping with the mandibular canal increased **(Supplementary Table S3)**. Stiffness was less for plated mandibles that had the mandibular canal invaded by 3 screws compared to those invaded by 1 screw or 2 screws. The greater failure energy for 3-screw-invasion mandibles than 1-screw-invasion mandibles is likely related to the greater failure angular displacement for the 3-screw-invasion mandibles. The greater failure bending moment for 3 screws compared to 2-screw-invasion mandibles is paradoxical. The bending moment and energy of plated mandibles at 6.4° angular deformation were not statistically different among screw invasion numbers.

Root length and root–ventral border length

Mandible length did not correlate significantly with root length (r = 0.105, P = .659) or root–ventral border length (r = 0.313, P = .179). CSA correlated significantly with root–ventral border length (r = 0.822, P < .001), but not root length (r = –0.042, P = .861).

Discussion

Our study is the first to evaluate the biomechanical properties of internal fixation using an L-plate for a simulated oblique caudal mandibular fracture in cats. The results indicate that placement of an L-plate in the caudal mandible of cats is feasible, and provide objective data for comparisons of the biomechanical properties among fractured mandibles repaired by an LC or an NLC and those of intact mandibles.

Plated mandibles, regardless of type of construct used, were significantly less stiff and strong in cantilever bending when compared with intact mandibles. The results were consistent with previous studies in cats[13] and dogs.[30] This is likely a result of altered integrity of the mandibles secondary to the presence of simulated fractures with a gap (ie, gap healing), which subject the malleable miniplates to unsupported bending in the initial stages of deformation. However, clinically, fractured mandibles of cats are typically repaired after anatomic reduction of fracture fragments, with an LC depending on the clinical situation (ie, contact vs gap healing).[31,32] Load-sharing by the bone would enhance the ability to withstand acute postprocedure functional load, likely providing adequate stability for healing and facilitating return to function. Cats with plated mandibles will also likely exhibit a reduced bite force after a fracture of the masticatory system or acutely postfixation, as demonstrated in the human medical literature.[33,34] In that context, maximum bite force at the canine teeth of cats typically ranges from 56.0 to 73.3 N.[35,36] When translating this reference to bending moment by using the median value of mandibular length in intact mandibles, the estimated bending moment at rostral teeth of cats ranges from 3,791 to 4,990 N-mm. Considering the results from our study (the bending moment at failure was 439 N-mm for an LC and 528 N-mm for an NLC), considerable reduced functional load would be required for successful stabilization and healing. However, when mandibular fractures are unilateral, a considerable support from soft tissues and the contralateral mandible could contribute significantly to fracture stability. Furthermore, the experimental conditions applied the worst-case scenario, with load only applied at the longest bending moment arm on the canine teeth relative to the temporomandibular joint, and with a gap rather than direct or contact bone reduction. In vivo, the caudal teeth share load during mastication, and carnassial teeth have a greater bite force than canine teeth.[35] Subsequently, the resultant in vivo bending moment on the fracture fixation is expected to be less than the bending moments in our in vitro study.

The type of construct used did not appear to affect the construct stiffness significantly in our study. This finding is different from a previous study,[13] which revealed an LC was mechanically stiffer and stronger than an NLC in cat models with simulated simple transverse caudal mandibular fractures at the level of the first mandibular molar tooth. The previous study differed from ours in the location of the simulated fracture, site of construct placement, shape of miniplate used, the stiffness of the plate (ie, malleable), and the number of screws used. A special note to consider is that the boxplots (Figure 4) in our study revealed mandibles with an LC had a greater pre-yield stiffness when compared to those with an NLC. The wide distribution of the data in mandibles with an LC may have contributed to the statistical insignificance when compared between the two data sets. An LC requires locking of the screwhead to specially designed plate holes. It was proclaimed that the integration of screw and plate results in symmetric loading of mandibular cortices, and therefore a more rigid and stable plating system can be achieved relative to an NLC.[23,37] Our findings suggest that in the current model, the type of construct used may not be the most dependent factor affecting the stiffness of plated caudal mandibles of cats with fractures involving the ramus, and other variables such as clinical or patient-related factors may have an effect. One of the possible variables, the adaptation of miniplate and screw to the mandible, needs to be taken into consideration in our study because of a more diverse and complex contour at the ramus[38] and condylar process. This resultant variability, together with inherent variables in bone quality and quantity in that region, may account for the difference of biomechanical properties between the mandibles with an NLC and an LC, especially regarding the wide distribution of pre-yield stiffness data in mandibles with an LC, as illustrated in the boxplots (Figure 4), and the finding that the NLC was able to withstand a greater bending moment at failure than the LC.

The 2 modes of failure for the constructs in our study were displacement of the dorsocaudal screw together with the plate, indicating some failure at the bone–screw interface and/or deformation of the plate. This finding was different from a previous study,[13] which showed bone fracture as the major mode of failure. In addition to the difference in location of simulated fracture, site of construct placement, shape of plate used, stiffness of the plate, and number of screws used, the peak bending moments resulting in failure of the constructs in the previous study were markedly greater than those in our study. This difference in bending moments may account for the observation that no bone fracture was seen at failure in plated mandibles in our study, but was noted postfailure when bending moments continued to increase.

Displacement of the screw together with the plate was more often seen associated with failure of mandibles with an LC, likely related to the locking mechanism that screws, and the plate acted as a single unit, allowing locking screws to dissipate forces to the unit,[23,37] while simultaneously inducing greater stress at the bone–screw interface. Although the screws used for the constructs in our study engaged both the lateral and medial cortices of the mandible, the thin bone along the condylar process (ie, where the two most caudal screws were placed) compared to the screw size inevitably affected the bone's ability to withstand either the primary load or the stress built up on those screws secondary to the application of load during cantilever bending, leading to screw and plate displacement and thus failure. This effect is particularly evident on the dorsocaudal screw, as illustrated in our findings. Plate deformation was seen more commonly as the mode of failure in mandibles with an NLC. This is likely associated with the fact that, in NLCs, the nonlocking screwhead does not lock into the plate, indicating the screw–plate interface may be weaker than the bone–screw interface at failure in mandibles with an NLC, allowing the plate to rotate—especially at the axis of the ventrocaudal screw—bend, and deform at the level of the long arm of the plate immediately rostral to the ventrocaudal screw.

Our study revealed that damage to the tooth root could be prevented with the use of an L-plate for fixation of caudal mandibular fractures in cats. This is an encouraging result because complications associated with screw-induced dental trauma (eg, infection or inflammation, fixation failure, tooth loss[21,39]) could be avoided. However, all the plated mandibles had radiographic signs of damage to mandibular canal, rostral to the simulated fracture; these data are consistent with a previous study.[13] The small size of the feline mandible and the relatively large volume of the mandibular canal, with resulting limited bone available for fixation, contribute to this finding. Screw damage to the intact mandibular canal may cause trauma to the inferior alveolar neurovascular bundle (IAN) and may lead to transient or permanent paresthesia or dysesthesia.[40,41] However, our clinical experience indicates that cats with caudal mandibular fractures or mandibular body fractures would likely experience IAN injury prior to fixation, and the true effect of IAN caused by screw damage may not be able to be determined. Nevertheless, revascularization and regeneration of IAN within the mandibular canal have been reported in dogs[42,43] and rabbits.[44]

To our knowledge, our study is the first to report the effect of the number of screw holes overlapping with the mandibular canal on biomechanical variables at a designated angular deformation during cantilever bending of feline plated mandibles. The pre-yield stiffness of plated mandibles with 3 screws invaded into the mandibular canal was significantly less than those invaded by 1 screw or 2 screws. Screws used for ORIF are designed to have threads that optimize initial contact and surface area, allowing dissipation and distribution of forces to occur at the screw–bone interface, and have greater pull-out resistance to load.[45] These properties are based primarily on the fact that screw threads engage bone material. Because the mandibular canal is a hollow space that carries the inferior alveolar neurovascular bundle,[46] it is possible that the biomechanical properties of the constructs could be altered inferiorly when a portion of the screw threads engages either the soft tissues or nothing in the mandibular canal instead of bone.

In conclusion, placement of a malleable L-plate on a feline caudal mandible to address fracture involving the ramus is feasible. Both the LC and the NLC were mechanically inferior to intact mandibles. There was no significant difference in stiffness between the LC and the NLC; the NLC had a greater bending moment at failure than the LC. No iatrogenic tooth root damage was evident, but the incidence of damage to the mandibular canal was the same in mandibles with an LC and an NLC. The pre-yield stiffness of plated mandibles that had the mandibular canal invaded by 3 screws was significantly less than those invaded by 1 screw or 2 screws. We recommended careful case selection and surgical planning with the aid of advanced imaging for application of internal fixation in cats with challenging caudal mandibular fracture to minimize iatrogenic damage. Type of construct used may not be the most dependent factor affecting the biomechanical performance of constructs with fractures involving the ramus; other variable clinical or patient factors should be considered.

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The authors declare that there were no conflicts of interest.

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Supplementary Materials

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