In vitro experimental study of the effect of radial shortening and ulnar ostectomy on contact patterns in the elbow joint of dogs

Chris A. Preston, BVSc; Kurt S. Schulz, DVM, MS; Ken T. Taylor, MS; Philip H. Kass, DVM, PhD; Catherine E. Hagan, BS; Sue M. Stover, DVM, PhD

Objective—To determine effects of incremental radial shortening and subsequent ulnar ostectomies on joint surface contact patterns in a canine elbow joint model.

Sample Population—Paired forelimbs from 9 adult dogs.

Procedure—Joint casting was performed by placement of colored polymethylmethacrylate in the elbow joint cavity and loading in a materials testing system at physiologic angle and load. Joint casting was performed in unaltered specimens, after radial shortening, and after subsequent distal ulnar ostectomy, proximal ulnar ostectomy, and proximal ulnar ostectomy with intramedullary pinning. Computer-aided analysis of photographs of proximal radial and ulnar articular surfaces without joint casts was performed before and after each casting procedure.

Results—All increments of radial shortening changed the size and location of radial and ulnar contact areas. The radial contact area became smaller, the anconal contact area disappeared, the medial coronoid contact area migrated cranioleterally, and the lateral projection of the coronoid process became a contact area. A proximal ulnar ostectomy stabilized with an intramedullary pin restored normal contact area size and location and restored continuity of the radial and coronoid contact areas across the radioulnar articulation in 6 of 10 specimens. A midshaft ulnar ostectomy, distal to the level of the radioulnar ligament, had no effect on contact patterns. A proximal ulnar ostectomy without stabilization resulted in varus deformity during loading.

Conclusions and Clinical Relevance—Proximal radial shortening, which creates articular step incongruity, changes the location and size of the radioulnar contact areas. Dynamically stabilized ulnar ostectomies proximal to the radioulnar ligament restore contact patterns in vitro. (Am J Vet Res 2001;62:1548–1556)

Fragmentation of the medial coronoid process (FCP) of the ulna is a common developmental orthopedic disease that causes joint pain and lameness in many large- and giant-breed dogs.1-5 The cause of FCP is unknown. Proposed causes include asynchronous growth between the humeral trochlea and the trochlear notch of the ulna, resulting in humero-ulnar incongruency, and asynchronous longitudinal growth between the radius and ulna, resulting in an intra-articular step in the elbow joint.6-9 Surgical removal of retained intra-articular osteochondral fragments has not resulted in improvements in long-term clinical outcome, compared with analgesic medication.6-8

Loads are transmitted through diarthrodial joints across contact areas. Contact areas are regions of a bearing surface that are in direct contact with an opposing bearing surface during functional loading. Contact areas of a joint alter with different loading conditions and joint positions.7 Pathologic joint conditions such as ligamentous instability, intra-articular fractures, and incongruency may lead to cartilage damage attributable to reductions in contact area size and changes in contact area location.9,10 If the same loads generated from the forces of gravity and muscle contraction are transmitted across smaller contact areas, the solid proteoglycan-collagen matrix receives increased pressure.10-12 Supraphysiologic cartilage pressures cause matrix degeneration and chondrocyte death, initiating secondary osteoarthritis.10,12 Results of experimental studies10-12 consistently indicate that malreduction of the bearing surface of the fracture leads to preferential loading of the elevated side of the step defect, a reduction in size of contact areas, and development of osteoarthritis. Concentration of joint contact and load in articular areas with minimal underlying subchondral bone may result in osteochondral fragmentation.12 This develops if a contact area moves from the center of a bearing surface to the edge of a bearing surface, and the exposed edge is unable to withstand the shearing forces generated, resulting in a slab fracture of the edge of the articular surface.12

Joint congruency refers to the similarity in geometric shape of 2 interacting bearing surfaces.13 Physiologic incongruency is thought to exist in normal joints to optimize stress distribution under maximal loading conditions when elastic deformation results in joint incongruence.13,14-16 Monocentric humeroradial and bicentric concave humeroulnar incongruency has been demonstrated in normal canine elbow joints in vitro. Pathologic incongruency is caused by articular fractures with malreduction, local chondral defects, and alterations in the process of endochondral ossification of physeal and epiphyseal growth plates.10,12,16

Step incongruency, with an abrupt change in normal surface contour, may cause damage to the exposed or elevated surface.11,12 There is no surface-level step incongruency across the radioulnar articulation in normal canine elbow joints in vitro.12 The biomechanical consequences of radioulnar step incongruency are
unknown. It is possible that the initial event in the pathogenesis of elbow joint dysplasia is asynchronous growth of the paired antebrachial long bones resulting in step incongruency across the radioulnar articulation.1 2 This may affect joint contact patterns and alter load transmission.1 2 If the ulnar bearing area is elevated relative to the adjacent radial head, increased loading of the coronoid contact area may occur. The location and type of lesions seen in clinical cases of FCP suggest mechanical overload may be involved in the pathogenesis of elbow joint dysplasia.1 2

The purposes of this study were to determine the effects of radial shortening on radial and ulnar contact area size and location in vitro and determine the ability of 3 different ulnar ostotomies to restore normal contact patterns in the radial shortening model.

Materials and Methods

Study design—Canine forelimbs were prepared for loading in a materials testing system. Joint casting was performed by placement of colored polymethylmethacrylate in the elbow joint cavity followed by loading at physiologic angle and load. Joint casting was performed in unaltered specimens, after radial shortening, and after subsequent distal ulnar ostectomy, proximal ulnar ostectomy, and proximal ulnar ostectomy with intramedullary pin. Standardized photographs were obtained of proximal radial and ulnar articular surfaces without joint casts and after each casting procedure. Joint surface contact was defined as the region of articular surfaces without joint casts and after each casting procedure. Joint surface contact was measured as the area of the articular surface that was not covered by casting agent. Computer-aided analysis of photographs was used to determine the total amount and relative (to total articular area) amount of joint surface contact in normal and altered specimens to evaluate the effect of radial shortening and subsequent ulnar ostotomies on elbow joint surface contact.

Specimens—Forelimbs were harvested from skeletally mature mixed-breed dogs weighing between 21 and 38 kg. Specimens were disarticulated at the glenohumeral joint and stored in a freezer at –20 C until the time of testing. Limbs were thawed at 20 C the day prior to testing. Radiographs of the elbow joints were obtained, and specimens were excluded if evidence of abnormality was identified. Seventeen limbs from 9 dogs were identified for evaluation and were randomly assigned to phases I (7 limbs) or II (10 limbs) of the study.

Model—Soft tissues proximal to the elbow joint were removed except for the origins of the antebrachial muscles and the tendon of insertion of the triceps brachii muscle. Medial and lateral collateral ligaments were preserved. The extensor carpi radialis, common digital extensor, and supinator muscle bellies were excised to expose the cranial aspect of the radial diaphysis. A 4-mm transverse transcondylar humeral bone tunnel was drilled from the lateral to medial humeral epicondyle. Medial and lateral epicondyar osteotomies centered over the drilled bone tunnel were created, using a bone saw. The epicondyles could be reflected distally, preserving the integrity of the remaining antebrachial myotendinous units and the collateral ligaments. The epicondyles could be relocated anatomically and held in situ by insertion of a 3.8-mm transcondylar bolt and wingnut. The joint capsule and anconeus muscle were excised. The annular ligament and all carpals and digital flexor myotendinous units were preserved.

The triceps brachii myotendinous unit was simulated by attaching a wire cable from the load cell of a materials testing system (MTS) to the tendon of insertion of the muscle (Fig 1). Wire aircraft cable (84-kg test) was passed through a metal rivet located in the proximal humeral metaphysis to align the pull of the triceps mechanism in a direction considered representative of the 4 muscle bellies and to prevent the cable cutting through the bone. The cable was attached distally to a freeze clamp on the triceps tendon. The clamp was tightened onto the tendon and frozen with pressurized liquid nitrogen for 3 to 5 minutes prior to specimen loading. An internal turnbuckle allowed adjustment of the length of the triceps mechanism. The elbow joint angle was set at 135° measured from the greater tubercle of the humerus to the lateral humeral epicondyle to the ulnar styloid process.

An external fixation apparatus was applied to each specimen to ensure repeatability of photographic positioning. Two half pins were placed from the medial aspect of the antebrachium into the distal radius, parallel to the axis of the transcondylar bolt. One pin was placed at the level of the metaphysis, and the other was placed 5 cm proximally in the radial diaphysis. External fixation clamps and a connecting bar were secured to the pins 3 cm medial to the skin surface. The model used in this study was designed to simulate the in vivo loading conditions during the midstance phase of the canine gait cycle.21 The axial load chosen was used to represent the vertical ground-reaction force of clinically normal dogs trotting at 1.5 m/s.22 24 The elbow joint flexion angle was the mean angle during the stance phase of trotting in healthy Greyhounds studied noninvasively with computer-assisted

Figure 1—Lateral view of a loaded canine elbow joint model. A brass freeze clamp is gripping the triceps tendon. A steel cable connects the freeze clamp to a bracket on the materials testing system machine. The steel cable runs through a hole in the proximal portion of the humerus, simulating the triceps muscle.
kinematics. The extensor carpi radialis, common digital extensor, and supinator muscle bellies were excised to permit exposure to the elbow joint and placement of a bone plate on the radius. It was felt that removal of carpal and digital extensors would minimally affect the results in a model simulating the stance phase of gait. The remaining soft tissues distal to the elbow joint were preserved to permit anatomic transfer of the ground reaction forces through the digital and metacarpal pads.

**Phase I**—The purpose of phase I was to determine the effect of radial shortening on joint surface contact in the clinically normal elbow joint. Shortening was achieved by performing an ostectomy in the radius and then shortening the ostectomy by use of the compressive function of a 2.7-mm *dynamic compression plate* (DCP). When a screw is placed, the load drill guide of a 2.7-mm DCP, tightening of the screw will result in movement of the attached bone segment 0.8 mm toward the center of the bone plate. This dynamic action was used to collapse a radial ostectomy, thereby shortening the overall length of the radius.

Seven forelimbs were examined in the first phase of the study. A contoured 9-hole 2.7-mm DCP was applied to the cranial aspect of the proximal radial diaphysis, using 2.7-mm self-tapping bicortical bone screws. The plate was positioned centrally on the convex cranial cortex and aligned parallel to the long axis of the radial diaphysis. Care was taken to maximize contact of the plate and underlying bone and to avoid excessive screw length with threads extending beyond the transcortex. A 2.7-mm DCP neutral and load drill guide was used to drill screw holes. Initially the neutral guide was used to place 2 screws into the radial head in the most proximal 2 holes in the plate (holes 1 and 2). An additional 2 screws were placed in holes 4 and 7.

Joint casting was performed after plate application but before radial ostectomy. For each individual joint cast, 5 ml of viscous-phase polymethylmethacrylate was applied to the combined radioulnar articular surface with the humerus disarticulated from the elbow joint. The joint was then rearticulated, and the epicondyles were repositioned anatomically and immobilized relative to the humeral condyle by insertion of the trans-condylar bolt and hand-tightening of the wing nut. The proximal aspect of the triceps cable was attached to the load cell, and the specimen was positioned in the MTS with the humeral head in the center of the load cell and the paw placed vertically under the humeral head. Care was taken to avoid inadvertent compression of the joint surface prior to placing the specimens in the MTS. Specimens were axially compressed at a rate of 200 N/second to the desired load. This load was maintained static until the polymethylmethacrylate had cured. Elbow joint angle was checked during testing to ensure that it was fixed. Physiologic saline (0.9% NaCl) solution was periodically sprayed onto exposed soft tissue during testing to avoid dessication. After terminating the load, the specimen was removed, and the elbow joint was disarticulated by removing the wing nut and transcondylar bolt.

The bone plate was removed, and a 5-mm-wide transverse radial ostectomy was made, centered at the level of plate hole 3. The plate was reapplied with the original 4 screws in holes 1, 2, 4, and 7 (Fig 2). Casts were made after radial ostectomy to determine whether the plate was able to effectively buttress the bone defect under the loading conditions. The remainder of the screws was placed distal to the ostectomy site, using the load drill guide with the direction of compression toward the ostectomy site, to achieve maximal shortening. Use of the Association for the Study of Internal Fixation (ASIF) load guide was intended to decrease the size of the ostectomy (radial shortening) by 0.8 mm/screw added. This is based on principles of bone movement when using the compression function of the 2.7-mm ASIF plate. Joint casts were made after each incremental radial shortening (0.8, 1.6, 2.4, 3.2 mm).

**Phase II**—The purpose of phase II was to determine whether any of 3 examined ulnar ostectomies could restore normal joint surface contact in limbs that had radioulnar incongruence created by radial shortening. Ten forelimbs were studied. Bone plates were applied as described, and joint casts were created. The radii were shortened by 1.6 mm, and casts were repeated on all limbs.

Normograde placement and removal of a 1/8-in intramedullary pin was performed on each specimen, starting the pin at the olecranon. This was done to establish a pin track for easier replacement of the pin later in the study. A 5-mm-wide segmental ostectomy of the midshaft of the ulna was then performed halfway between the olecranon and the styloid process. Each specimen was returned to the MTS machine for joint casting, as described. A 5-mm-wide ostectomy located one third of the distance from the olecranon to the styloid process was performed on each specimen, followed again by joint casting. Intramedullary pins were replaced with the trocar as distal as possible without cortical penetration and with the proximal aspect flush with the ulna to minimize tendon impingement (Fig 3). Final joint casts were then created from each specimen. After testing, all antebrachii were dissected to determine location of the ostectomies relative to the radioulnar interosseous ligament.

![Figure 2—Cranialateral view of a loaded canine elbow joint model. A brass freeze clamp is gripping the triceps tendon. A wingnut has been manually tightened on a transcondylar bolt to immobilize the epicondyles. A bone plate is bridging the proximal radial ostectomy.](image-url)
Data collection—Four standardized photographic views of each cast were taken with an in-frame metric scale. Repeatable orientation of the specimen was achieved by securing the external fixator connecting bar in 1 of 4 clamps attached to a supporting apparatus. Radial articular contact areas were calculated from a view taken perpendicular to the radial head (radial view), taking care to avoid superimposition of the anconeus. Contact areas of distal ulnar articular surface were measured on 2 views. The first view was perpendicular to the medial coronoid process (coronoid view). The second was taken from the cranial aspect of the joint angled 45° distally (oblique view). Contact areas of the proximal ulnar articular surface were measured from the cranial aspect with the camera positioned along the sagittal plane of elbow joint flexion (anconeal view). Each of the views was repeated for each of the specimens without casting material in place.

Color 35-mm transparencies were digitized by use of a high resolution scanner into a computer. Contact areas from these images were measured (mm²), using image analysis software. Surfaces not covered by casting agent were considered to be contact areas. Total articular areas were measured (mm²) for each of the 4 photographic views. Total articular areas were defined subjectively as the area of the proximal radial or ulnar articular surface likely to potentially contact the opposing humeral surface.

For each view, the measured contact areas were divided by the respective total articular areas to yield a proportion called the relative contact area (RCA).

Statistical analyses—In phase I of the study, 2-way repeated measures ANOVA was used to evaluate the potential main and joint effects of osteotomy (preostectomy vs postostectomy) and test condition (radial shortening, 0, 0.8, 1.6, 2.4, and 3.2 mm). In phase II of the study, 1-way repeated measures ANOVA was used to evaluate the potential effect of osteotomy (preostectomy, radial shortening, midshaft ulnar shortening, and proximal ulnar shortening with and without the intramedullary fixation device). The P values were corrected for departure from compound symmetry by use of the Huynh-Feldt method. When significance (P < 0.05) was determined, specific contrasts were tested by use of a paired t-test.

Results
Phase I—There were no significant differences between the RCA from the joint casts before radial osteotomy and after radial osteotomy (prior to com-
pression) for the coronoid, anconeal, and oblique photographic views ($P = 0.36, 0.63, \text{ and } 0.19$, respectively). The RCA for the radial view were significantly ($P = 0.004$) different, with larger preostectomy RCA in all casts. In all 7 specimens, for the pre- and postradial ostectomy casts, there was continuity of the coronoid and radial contact areas across the radioulnar articulation (Fig 4). All increments of radial shortening resulted in visible incongruity at the radioulnar articulation and separation of the coronoid and radial contact areas (Fig 5).

The size of the radial RCA was significantly reduced at all 4 magnitudes of radial shortening (0.8 mm, $P = 0.01$; 1.6 mm, $P = 0.006$; 2.4 mm, $P = 0.005$; 3.6 mm, $P = 0.001$), compared with control specimens (Fig 6). The medial edge of the radial head became a noncontact area for all radial shortenings in all limbs (28/28 casts). The size of the coronoid RCA were not different from control at 0.8 mm and 1.6 mm radial shortening ($P = 0.51$ and 0.40, respectively) but were smaller at 2.4 mm and 3.2 mm radial shortening ($P = 0.01$ and 0.004, respectively; Fig 7). The location of the coronoid contact area did not change except for subjectively greater involvement of the lateral edge of the medial coronoid process. The anconeal RCA were significantly smaller at radial shortenings of 0.8 and 1.6 mm ($P < 0.001$ and 0.006, respectively), and the proximal ulnar articular surface became a noncontact area in 13 of 14 casts after radial shortening of 2.4 and 3.2 mm (Fig 8). The size of the RCA from the oblique

<table>
<thead>
<tr>
<th>Radial</th>
<th>RCA</th>
<th>Magnitude of radial shortening (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>75</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>75</td>
<td>0</td>
</tr>
<tr>
<td>0.8</td>
<td>70</td>
<td>*</td>
</tr>
<tr>
<td>1.6</td>
<td>60</td>
<td>*</td>
</tr>
<tr>
<td>2.4</td>
<td>50</td>
<td>*</td>
</tr>
<tr>
<td>3.2</td>
<td>40</td>
<td>*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Coronoïd</th>
<th>RCA</th>
<th>Magnitude of radial shortening (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>75</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>75</td>
<td>0</td>
</tr>
<tr>
<td>0.8</td>
<td>70</td>
<td>*</td>
</tr>
<tr>
<td>1.6</td>
<td>60</td>
<td>*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Anconeal</th>
<th>RCA</th>
<th>Magnitude of radial shortening (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>75</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>75</td>
<td>0</td>
</tr>
<tr>
<td>0.8</td>
<td>70</td>
<td>*</td>
</tr>
</tbody>
</table>

Figure 5—Photograph of joint cast of control specimen after radial shortening but before ulnar ostectomy. Notice loss of continuity of the contact areas of the radial (R) and ulnar (U) surfaces.

Figure 6—Mean ± SD (n = 7) of cast-derived relative contact area (RCA [%]) under the test conditions of phase I for the radial view. *Significant ($P < 0.05$) difference, compared with intact normal control specimen. N = Intact normal control specimen. C = Control specimen after plate application but prior to radial shortening.

Figure 7—Mean ± SD (n = 7) of cast-derived RCA (%) under the test conditions of phase I for the coronoïd view. See Figure 6 for key.

Figure 8—Mean ± SD (n = 7) of cast-derived RCA (%) under the test conditions of phase I for the anconeal view. See Figure 6 for key.
photographic view were not different at 0.8 mm of radial shortening ($P = 0.17$) and were larger than in normal joints for radial shortening increments of 1.6, 2.4, and 3.2 mm ($P = 0.02, 0.006,$ and $0.01$, respectively; Fig 9).

Phase II—The radial RCA for the 1.6-mm radial shortening and the midshaft ulna ostectomy were smaller than preostectomy RCA ($P = 0.002$ and 0.03, respectively); however, they were not different for proximal ulnar ostectomies with and without an intramedullary pin ($P = 0.2$ and 0.09, respectively; Fig 10). The radial and coronoid contact areas were not continuous across the radioulnar articulation in 10 of 10 casts made from specimens after the mid-diaphyseal ulnar ostectomy. Proximal ulnar ostectomies stabilized with an intramedullary pin resulted in continuity of the radial and coronoid contact areas across the radioulnar articulation in 6 of 10 specimens (Fig 11).

In 4 of 10 specimens, the lateral edge of the medial coronoid process became a noncontact area, because the lateral edge of the medial coronoid process was located distal to the medial edge of the radial head. In 6 of 6 specimens that developed mild varus deformity after proximal ulnar ostectomy with pin removal, the radial and coronoid contact areas were separate, and the lateral edge of the medial coronoid process was a noncontact area, because the lateral edge of the medial coronoid process was located distal to the medial edge of the radial head.
There was no difference in the size of the coronoid RCA under any test condition in phase II \( (P > 0.09); \text{Fig 12} \). The anconeal RCA were smaller at 1.6-mm radial shortening and after midshaft ulnar ostectomies \( (P = 0.003 \text{ and } 0.02, \text{ respectively}) \) but not different after proximal ulnar ostectomies with and without an intramedullary pin \( (P = 0.08 \text{ and } 0.31, \text{ respectively}; \text{Fig 13}) \). The oblique view RCA were larger for 1.6-mm radial shortening and midshaft ulnar ostectomies \( (P = 0.01 \text{ and } 0.02, \text{ respectively}) \) and not different after proximal ulnar ostectomies with and without an intramedullary pin \( (P = 0.4 \text{ and } 0.9, \text{ respectively}; \text{Fig 14}) \). In 10 of 10 specimens, the ostectomies were located proximal and distal to the radioulnar ligament, respectively \( (\text{Fig 15}) \). All specimens had varus deformity at the level of the elbow joint during axial compressive loading after proximal ulnar ostectomy and intramedullary pin removal. In 4 instances, the magnitude of the deformity resulted in dislodgement of the specimen from the load cell and required termination of the loading sequence. Contact area determination was not possible for these specimens.

**Discussion**

The radial shortening model used in this study resulted in a number of significant changes to the normal in vitro elbow joint contact patterns.\textsuperscript{19} Radial shortening resulted in a reduction in the size of the radial contact area, a reduction or loss of the proximal ulnar contact area, enlargement of the distal aspect of the ulnar trochlear notch contact area in the region of the lateral coronoid process, and migration of the coronoid contact area to the lateral projection of the medial coronoid process. In all specimens, the medial edge of the radius became a noncontact area, whereas the length of the lateral edge of the coronoid contact area increased. Reduction in the combined radioulnar contact area, under fixed loads, suggests that surface level incongruency attributable to radial shortening may increase local pressure in the articular cartilage and underlying subchondral bone. Articular step incongru-
ency may concentrate physiologic forces on the elevated lateral edge of the medial coronoid process, resulting in osteochondral fragmentation. The findings of this study support a mechanical cause of the coronoid lesions found in spontaneous cases of elbow joint dysplasia.

A proximal ulnar ostectomy stabilized with an intramedullary pin was most effective in its ability to restore a normal contact pattern after radial shortening of 1.6 mm. This degree of shortening was selected on the basis of a study in which 2-mm step defects in dogs with FCP were reported. The approximation of 2 mm with 1.6 mm was attributed to the dynamics of the bone plate. Proximal ulnar ostectomy was able to reestablish the proximal and distal ulnar contact areas, restore contact area continuity across the radioulnar articulation in 6 of 10 joints, and prevent gross elbow joint varus deformity under axial compressive loading. The cause of failure to restore contact area continuity in 4 of the joints is unknown. This may have been attributable to resistance of the remaining soft tissues—preventing adequate distal migration of the proximal ulnar segment or attributable to subtile torsion or angulation of the proximal segment after the ostectomy. The purpose of the intramedullary device was to resist shear and bending forces at the ostectomy site while permitting axial translation of the proximal ulna relative to the pin. The unstabilized proximal ulnar ostectomy was found to be inferior in terms of its ability to restore normal contact patterns, and severe elbow joint varus deformity was common under axial loading. Limited limb use, attributable to postoperative pain and enforced exercise restriction, may explain the low incidence of angular deformities in previous case series in which unstabilized proximal ostectomies were performed with minimal bone healing problems. The proximal ostectomy used in our study was intended to simulate the mechanics of a proximal oblique ostectomy. The transverse ostectomy was chosen because it eliminates contact between the bone ends that may interfere with distal movement of the proximal segment in an acute testing model. The oblique ostectomy is intended to limit caudal rotation of the proximal segment, thereby eliminating the need for an intramedullary pin; however, it is uncertain if the nature of this ostectomy will also eliminate the varus deformity observed in this study.

The mid-diaphyseal transverse ulnar ostectomy had no detectable effect on the contact patterns in the acute radial shortening model. The location of this ostectomy was always distal to the radioulnar ligament. The radioulnar ligament is short and of considerable tensile strength and may have prevented distal migration of the proximal ulnar fragment, relative to the radius. Fatigue and elongation of viscoelastic connective tissue develops under chronic loading conditions and may permit axial movement of the ulna in vivo. Fatigue testing of mid-diaphyseal and distal corrective ulnar ostectomies in vitro and in vivo is warranted, because these procedures are unlikely to require implant stabilization to achieve uncomplicated bone union, and they are technically easier to perform than proximal ulnar ostectomies. The choice of the order of ostectomies in this study was based on practicality of the study design. It is uncertain if the order had any effect on the outcome.

The only myotendinous unit simulated in this model was the triceps brachii, which is likely the major contractile element spanning the elbow joint during forced elbow joint extension. Simulation of muscle contraction in vitro requires attachment of tension-producing devices to musculotendinous units. A freeze clamp was used to affix a wire cable directly to the triceps tendon, maintaining the anatomic insertion. This coupling device minimizes slippage during simulated in vivo joint loading in cadaveric biomechanical studies by providing an interface for force transfer via interdigitation of the frozen tissue with the serrations of the clamp.

The ability of a bone plate to maintain the fracture gap in a buttress fashion and maintain spatial orientation of the proximal radial articular surface was evaluated by comparing RCA and contact area location before and after radial ostectomy. Although the anconeal, coronoid, and oblique RCA were not significantly different, and all of the distal contact areas were continuous across the radioulnar articulation, the radial RCA after ostectomy were significantly different from the corresponding RCA prior to ostectomy. The postostectomy RCA were all smaller (1.4 to 8.8% less than normal RCA), compared with the preostectomy RCA. The reason for this may be insufficient plate stiffness or an inability to effectively buttress the lateral joint compartment. It is also possible that radial shortening may have been inadvertently induced during tightening of neutral bone screws after the ostectomy procedure.

One of the limitations of our model is that sustained static loading during curing of a casting agent may result in creep deformation of the articular cartilage attributable to its viscoelastic properties. This may change the geometry of the interacting surfaces and lead to false elevations of the true contact area. Another limitation was use of a model that preserved soft-tissue structures between the proximal radial fragment and the ulna. Subsequent experience suggests that the fracture gap may not be shortened by 0.8 mm with each application of a load screw because of ligamentous and other soft tissue constraints of the model. Variation in gap shortening may also have been caused by failure of bone screws to induce shortening. We recommend that gap shortening be achieved by use of a type-II external fixator with linear motors and that the amount of gap shortening be measured directly from the specimen.

Corrective ulnar ostectomies may have a role in the treatment of elbow joint disorders characterized by radioulnar step incongruency in which the radius is disproportionately short. The type and location of osteochondral fragments found in spontaneously occurring cases of elbow joint dysplasia suggest step incongruency may contribute to the pathogenesis of this disease. Ostectomies proximal to the radioulnar ligament allow distal movement of the medial coronoid process relative to the radial head and reestablishment of contact area continuity across the radioulnar articular...
luation. The potential complications associated with use of a smooth intramedullary device used in isolation to stabilize an ostectomy are unknown and require further investigation before clinical use of this technique can be recommended.

References