Canine Elbow Dysplasia

Medial Compartment Disease and Osteoarthritis

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KEYWORDS

- Elbow • Degenerative joint disease (DJD) • Osteoarthritis (OA)
- Medial compartment disease • Sliding humeral osteotomy (SHO)
- Proximal abducting ulnar osteotomy (PAUL) • Canine unicompartmental elbow (CUE)
- Partial elbow replacement (KYON BANC)

KEY POINTS

- Degenerative joint disease (DJD)/osteoarthritis (OA) of the elbow often is associated with elbow dysplasia or traumatic injury.
- DJD/OA of the elbow most commonly affects primarily the humeroulnar articulation or medial compartment. This has been termed, *medial compartment disease* or *medial compartment syndrome*.
- The degree of cartilage loss can be defined and categorized using a modified Outerbridge scoring system.
- When medical management is not effective in palliating signs of DJD/OA, surgical strategies include off-loading of the medial compartment by axis-shifting osteotomies, including proximal abducting ulnar osteotomy and sliding humeral osteotomy. Other strategies involve replacement of portions or all of the articular surface of the medial compartment with canine unicompartmental elbow or partial elbow replacement. With global elbow joint OA (medial and lateral compartment), a total elbow replacement may be required.

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INTRODUCTION

Erosion of the articular cartilage of the medial compartment of the elbow (the humeroulnar articulation) secondary to incongruency associated with elbow dysplasia (fragmented coronoid process/osteochondritis dissecans) or traumatic injury has been termed, *medial compartment disease* (*MCD*).[1] The end result is degenerative joint disease (DJD) and osteoarthritis (OA) that primarily affects the medial compartment (humeroulnar articulation) while largely sparing the lateral compartment (humeroradial articulation) of the elbow joint.

The severity of cartilage loss has been described and quantified using a modified Outerbridge classification. This system assigns a grade of 0-IV based on severity of cartilage damage/loss.[2]

Modified Outerbridge scores (**Fig. 1**):

0—normal cartilage

I—chondromalacia

II—fibrillation and damage to the superficial matrix only

III—full-thickness fissure, thus loss of the cellular components

IV—full-thickness erosion of cartilage to the level of subchondral bone

Modified Outerbridge scores of grades I to II may be reversible. Due to the loss of cellular components, grades III to IV scores generally are thought to be irreversible and progressive (**Fig. 2**).

Nonsurgical strategies to palliate discomfort associated with OA include

- Weight control
- Activity restrictions (encourage low-impact activity and discourage high-impact activity)
- Joint supplements containing glucosamine, chondroitin, Polysulfate glycosaminoglycans (PSGAGs), and omega-3 essential fatty acid (EFA)
- Nonsteroidal anti-inflammatory drugs (NSAIDs)
- Nonopioid analgesics (eg, gabapentin and amantadine)
- Intra-articular injections (hyaluronate and corticosteroids)
- Regenerative medicine (intra-articular stem cells and platelet-rich plasma)
- External rehabilitation modalities, such as class 3 laser

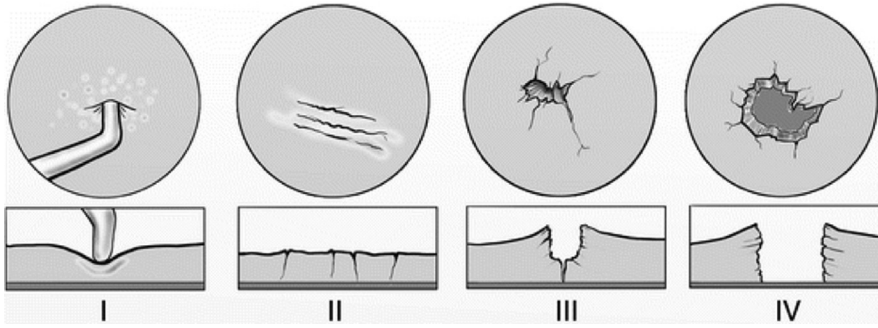

Fig. 1. Modified Outerbridge scores of articular cartilage damage. 0—normal cartilage, I—chondromalacia; II—fibrillation and damage to the superficial matrix only; III—full-thickness fissure, thus loss of the cellular components; and IV, —full-thickness erosion of cartilage to the level of subchondral bone. (*From* Lasanianos NG, Kanakaris NK. Chondral Lesions. In: Lasanianos NG, Kanakaris NK., Giannoudis PV, eds. Trauma and Orthopaedic Classifications: A Comprehensive Overview. London, UK: Springer-Verlag; 2015:501-504; with permission. (Org Fig 113.1).)

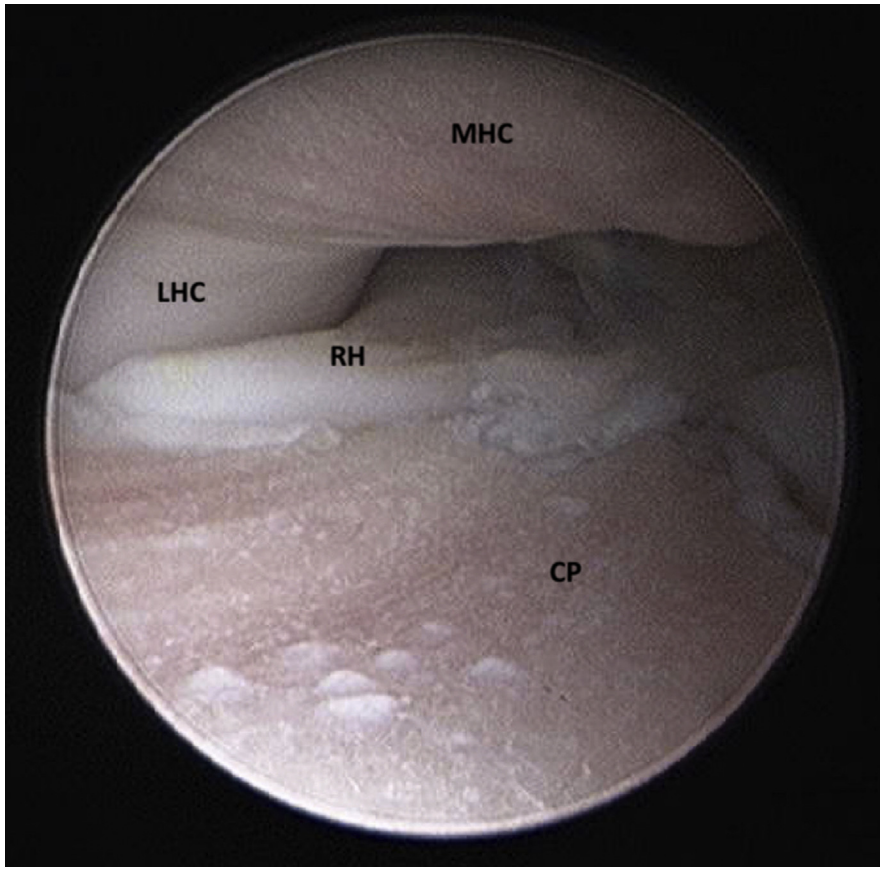

Fig. 2. MCD—arthroscopic image of left elbow with full-thickness cartilage loss of humeroulnar joint surfaces consistent with grade 4 modified Outerbridge score. The lateral compartment is visually healthy. CP, coronoid process; LHC, lateral humeral condyle; MHC, medial humeral condyle; RH, radial head.

- External beam radiation and radiation delivery through intra-articular injection (Synovetin OA [Exubrion, Buford, Georgia, USA])

Surgical strategies to reduce pain through offloading of the medial compartment by load shifting osteotomies include Proximal Abducting Ulnar Osteotomy (PAUL) by KYON and Sliding Humeral Osteotomy (SHO) by New generations devices (DGD). Other strategies involve replacement of portions or all of the articular surface of the medial compartment. This article discusses the canine unicompartmental elbow (CUE) by Arthrex and the biomechanically anatomic, nonconstrained, and compartmental (BANC) partial elbow replacement (PER) system by KYON. With global elbow joint OA (medial and lateral compartment), a total elbow replacement (TER) may be required, with the TATE system by BioMedtrix being the focus.

SLIDING HUMERAL OSTEOTOMY

Rationale

The SHO was reported in 2009 in a pair of articles by Fitzpatrick and colleagues[3,4] as a technique used to decrease weight-bearing load within the medial compartment of the

elbow joint. There were precursors to this more refined procedure in the early 2000s, evidenced by the humeral wedge and humeral slide osteotomies.[5,6] Further research was done looking at medium-term and long-term outcomes, gaining this procedure a spot in the armament against MCD.[7]

The goal of the SHO is to shift the weight-bearing axis of the forelimb (digits to shoulder) as it crosses the elbow joint (in particular, the humeroulnar contact) laterally. This decreases the weight-bearing load within the medial compartment of the elbow joint, because this is where the majority of pathology resides (**Fig. 3**). The exact cause of MCD largely is unknown; however, it is evidenced as advancing cartilage wear and

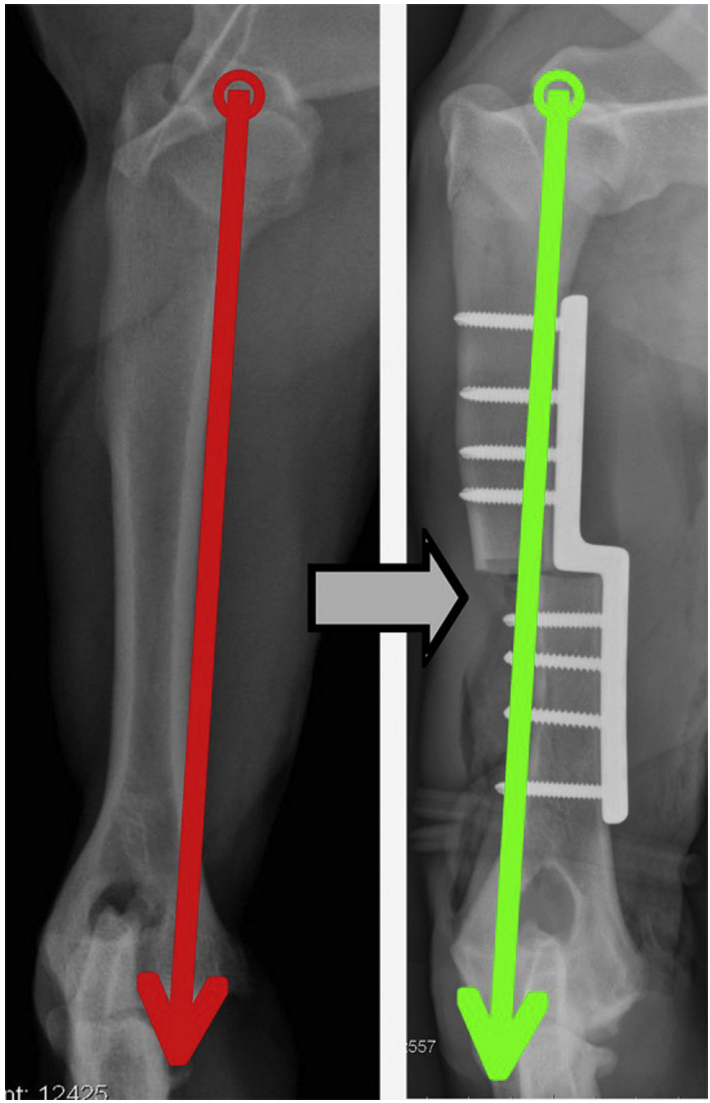

Fig. 3. Craniocaudal radiographs depicting the shift in weight-bearing access from medial (*red arrow* in the left image) to lateral (*green arrow* in the right image) following SHO.

exposure/sclerosis of subchondral bone on both the ulnar and opposing humeral surfaces.

Case Selection

Case selection for this procedure is of utmost importance because the objective of this procedure is to improve the weight-bearing axis of the limb and over time improve the gait of the patient and decrease the secondary effects of MCD. To that goal, patients with advanced degenerative changes are not ideal candidates. Conversely, skeletally immature patients also are not ideal due to open physeal regions that could develop abnormally with the change in force. An ideal candidate is a patient diagnosed arthroscopically with MCD that is skeletally mature (assessed via radiography) and with mild to moderate degenerative changes. A study evaluating dogs with osteochondrosis of the medial humeral condyle that were treated with an SHO procedure showed continued degenerative changes, although this was a small group.[8]

Description of Procedure and Instrumentation

The patient typically is in lateral recumbency, with the affected limb near the table and prepped in a hanging position. A standard medial approach is needed to access the medial aspect of the diaphysis of the humerus. Dissection to the diaphysis of the humerus is important with the distal epicondyle being palpable for a landmark. Retraction of the brachiocephalicus and biceps brachii cranially and the triceps brachii and superficial pectoral muscles caudally using Hohmann retractors is recommended.[9] Care is taken to not disrupt the neurovascular bundle near the distal diaphysis of the humerus. This should be identified and retracted. Once the mid to distal diaphysis is exposed, an appropriate SHO plate is selected. The plate and locking screws are manufactured by New Generation Devices (Glen Rock, New Jersey, USA) as are the drill guides for the locking system.

There are 2 variants of the plates (all same design), 7.5 mm and 10 mm, according to the size of the step desired. Although in general large breed dogs accept the 10-mm plate and medium-sized dogs the 7.5-mm plate, sizing also can be done by planning software, attempting to achieve 50% contact of the cut. A minimum bone overlap of one-third is needed.[9] There is a specific sequence of screw placement (described previously)—in general, the proximal 4 holes use locking screws while cortical screws are initially placed in the center 2 holes of the distal segment of the SHO plate, prior to the mid-diaphyseal transverse bone cut[3] (**Fig. 4**). Once the osteotomy is complete, the 2 cortical screws in the distal fragment are tightened sequentially, drawing the bone to the plate—providing the offset sliding motion of the humerus (**Fig. 5**). The remaining locking screws are placed, and the cortical screws then are converted to locking screws (**Fig. 6**). Closure is performed in normal fashion. Some modifications have been made since this technique first was reported in an attempt to reduce potential short-term complications. In larger dogs, the author (Dr. Benjamino) has added either a cranial or caudal plate and screws (SOP plating system [Orthomed, Huddersfield, West Yorkshire, England]).

Outcome

There have been 2 peer-reviewed articles that have looked at both medium-term and long-term results in dogs that have received an SHO[7,9] (**Fig. 7**). In the study by Wendelburg and Beale[7] (32 cases), 30 dogs exceeded their preoperative ground reactive forces and improvement was noted compared with the contralateral limb. Also, in this study, it was noted that 31 dogs did not have radiographic progression of osteophytosis. These data might be skewed, with a mean follow-up radiographic time of

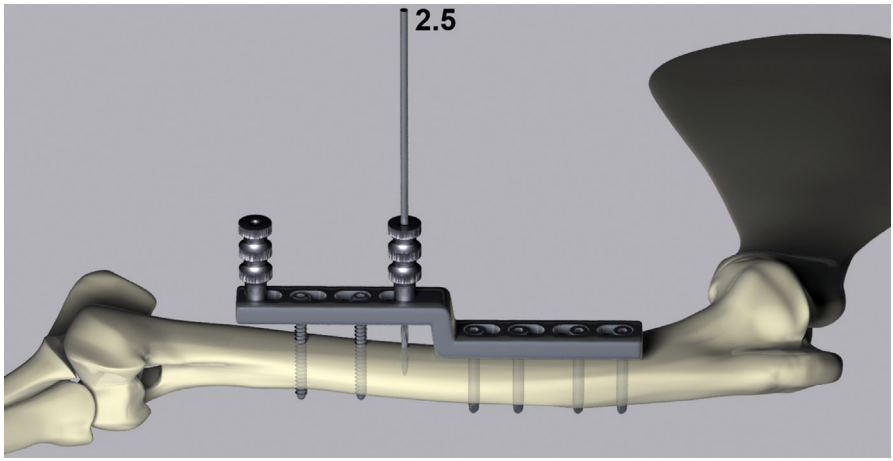

Fig. 4. The proximal portion of the plate is fixed to the humerus with locking screws. Bicortical Cortical screws are placed in holes #6 and #7 before performing the osteotomy.

49 weeks and only 8 dogs having radiographic follow-up greater than 1 year. Most owners (90%) felt there was improvement compared with preoperative lameness. In this case series, there were 10/32 cases with postoperative complications, 6 requiring further surgery.

In the other article, assessing medium-term outcomes (Fitzpatrick and colleagues[9]) (46 dogs/60 elbows), it was reported that lameness improved in all limbs by 12 weeks and resolved in 49 limbs. There were no major complications and 4.17% minor

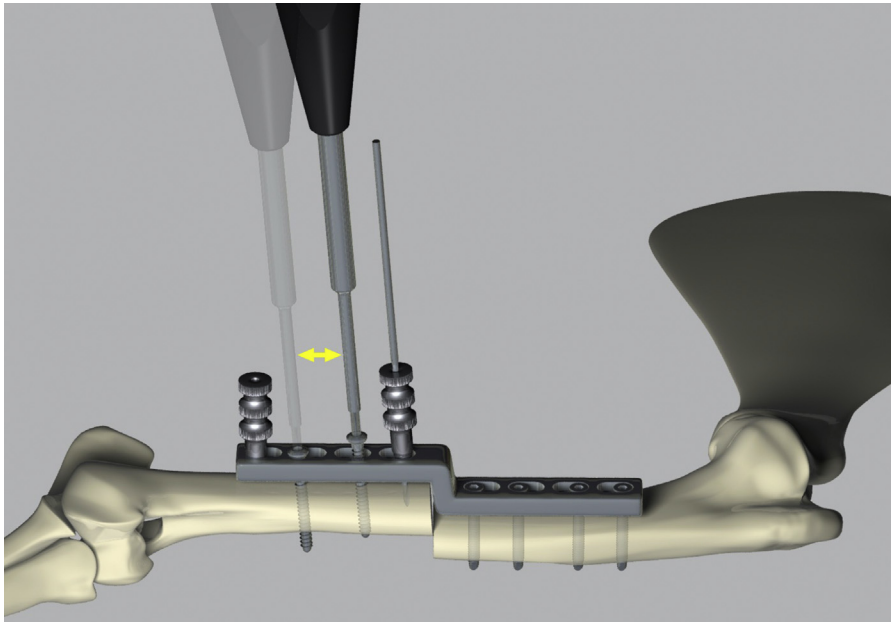

Fig. 5. A transverse osteotomy is made and the cortical screws in the distal segment are sequentially tightened, pulling the distal humerus up to the plate.

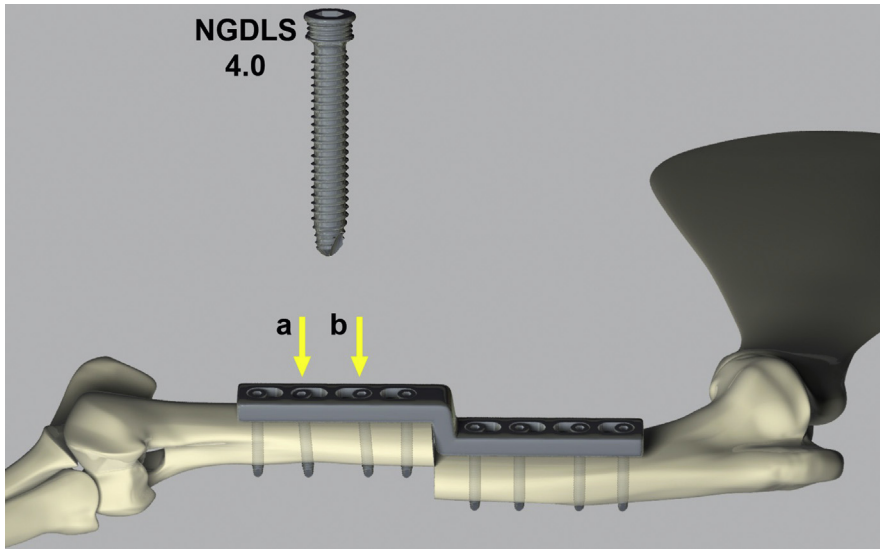

Fig. 6. Locking screws are placed in the remaining holes of the distal segment. The cortical screws (*a,b*) are replaced with locking screws for additional stability. (*Courtesy of* New Generation Devices, Glen Rock, New Jersey, USA).

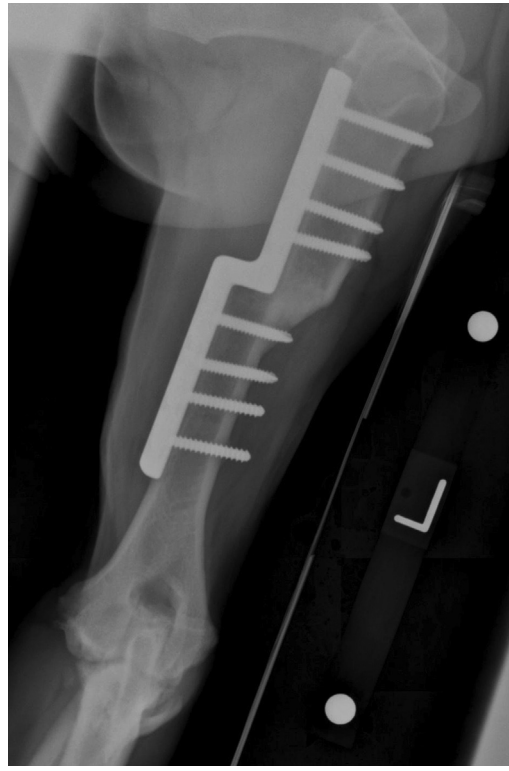

Fig. 7. Craniocaudal radiograph 3 months postoperative SHO showing complete healing.

complications cited.[9] In this article, there had been a change in application of the plate, which contributed to the decreased morbidity, according to the investigators. One potentially unintended secondary outcome associated with the SHO is alteration of limb alignment in the frontal plane of the thoracic limb, as demonstrated in a cadaveric study by Breiteneicher and colleagues.[10]

Overall, the SHO has been shown to be a reasonable option in the patient that has confirmed MCD (based on arthroscopy) (Fig. 8). There are some studies that have shown marked improvement in patient lameness, generally occurring after 8 weeks postoperatively. The authors do find this procedure to be useful in the select patient.

PROXIMAL ABDUCTING ULNAR OSTEOTOMY

Rationale

The PAUL technique was developed on the basis of several observations and biomechanical analysis of the canine elbow joint[11]:

- A consequence of MCD, a subset of elbow dysplasia, is medial collapse of the contact mechanics of the elbow joint.
- Medial collapse overloads the medial compartment, exacerbating existing lameness and joint pain.
- A slight abduction, by 4° to 6°, of the ulna results in an unloading of the medial compartment, alleviating pain.

In 2007, Ingo Pfeil and Slobodan Tepic theorized that proximal osteotomy of the ulna fixed by a special plate would shift, abduct, and rotate the ulna, which would lead to lateralization of the paw, thus, unloading of the medial compartment (Pfeil I, personal communication. KYON Symposium, November 12, 2010, Zurich). The proposed biomechanics of PAUL are similar to high tibial osteotomy for treatment of varus deformity of the knee and medial compartment syndrome in humans (Fig. 9) as an alternative to unicompartmental knee joint replacement, which may be carried out later on in cases of progressive OA. This procedure in people consists of a medial

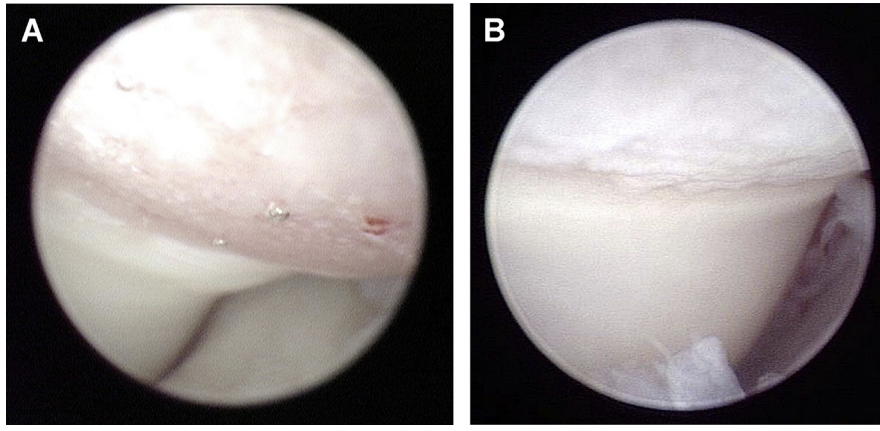

Fig. 8. Arthroscopic images of the medial humeral condyle: (*A*) preoperative and (*B*) 1-year pro-operative SHO depicting cartilage regrowth. (*From* Fitzpatrick N, Yeadon R, Smith T, et al. Techniques of application and initial clinical experience with sliding humeral osteotomy for treatment of medial compartment disease of the canine elbow. Vet Surg. 2009 Feb;38(2):261-78; with permission.)

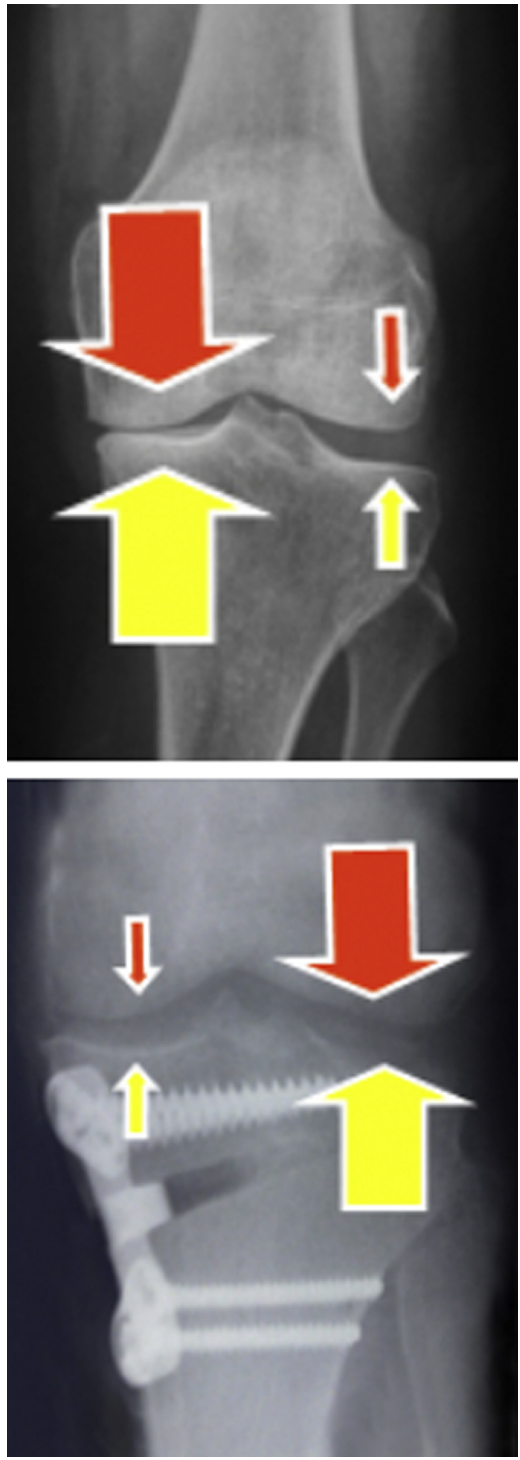

Fig. 9. High tibial osteotomy for treatment of varus deformity of the knee and medial compartment syndrome in humans.

open wedge osteotomy of the tibial plateau and elevation of the tibial plateau medially to allow the distal limb to move laterally. This loads the lateral compartment of the knee and unloads the medial compartment. The PAUL plate produced by KYON is a straight plate with a step of 2 mm to 3 mm and is applied to the lateral surface of the proximal ulna (Fig. 10). This is theorized to raise the ulna on the medial humeral condyle and result in a lateral shift of the distal limb, with increased load on the lateral compartment and decreased load on the medial compartment (Fig. 11). According to KYON, the amount of achieved abduction is approximately 4° with the 2-mm step plate and 6° with the 3-mm plate, plus 4° to 5° attributable to the natural curvature of the ulna, which is straightened by the plate. The final lateral shift is approximately 8° with the 2-mm step plate and 11° with the 3-mm step plate. In 2019, a new PAUL plate was released by KYON, called PAUL II, which utilizes a different locking screw design.

Case Selection

Dogs at skeletal maturity up to 9 years, not responsive to conservative management and having arthroscopically confirmed MCD (without significant pathology in the lateral compartment), are candidates for PAUL osteotomy. Arthroscopic confirmation is done immediately before PAUL surgery or at a previous operation at the time of conventional joint débridement. PAUL is offered to dog owners as a palliative treatment of

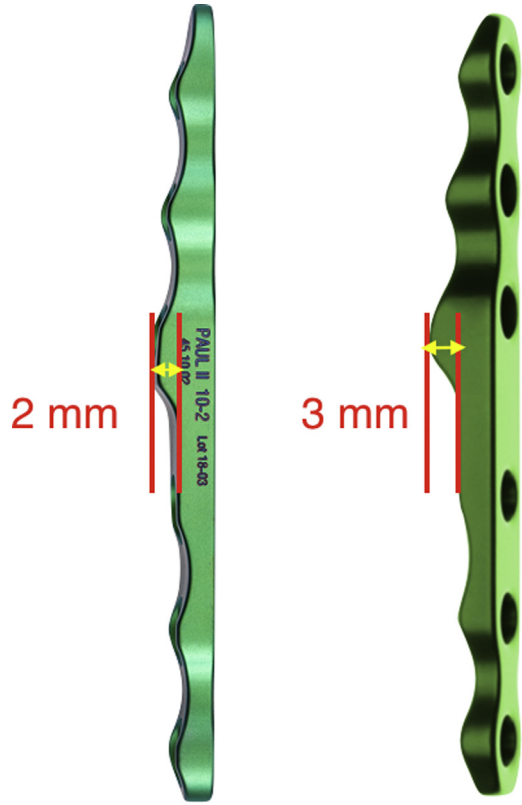

Fig. 10. PAUL II stepped plate available with 2 mm offset (*left*) and 3 mm offset (*right*) and utilizes a conical locking screw design.

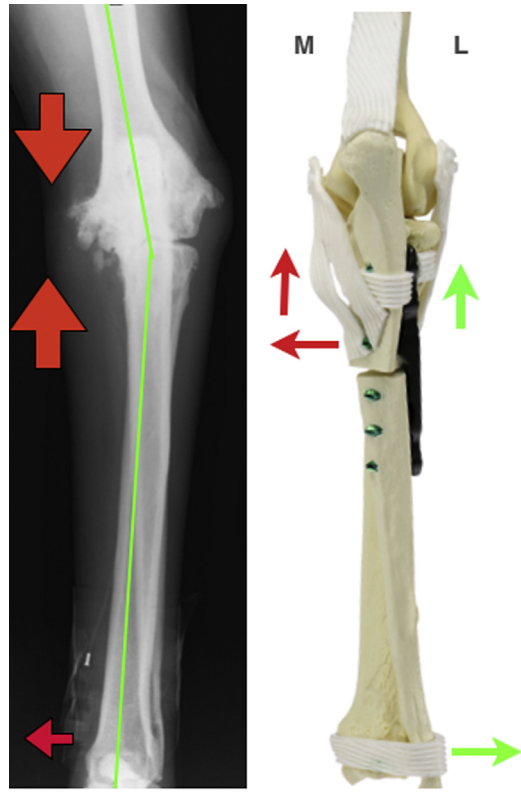

Fig. 11. The stepped plate of PAUL raises the ulna on the medial humeral condyle and results in a lateral shift of the distal limb with increased load on the lateral compartment and decreased load on the medial compartment.

MCD. The authors do not recommend PAUL when arthroscopy shows MCD without significant involvement of the remaining medial compartment. PAUL also is contraindicated when the lateral compartment shows cartilage erosion or in dogs greater than 9 years of age because of irreversible joint changes.

Preoperative Planning

The craniocaudal radiographic view with the olecranon well centered over the humeral condyle is used to evaluate the mechanical medial elbow angle (mMEA). A line from the center of the humeral condyle and the center of the antebrachiocarpal joint is traced and the medial angle between that line and the elbow joint reference line (tangent to the humeral condyles) is measured (Fig. 12). The mMEA has a normal range of 81.5° ± 2.5° (Pfeil I, personal communication, KYON Symposium 2010, Zürich, Switzerland). In cases of an mMEA less than or equal to 80°, a 3-mm step PAUL plate is used, and, in cases of an mMEA greater than 80°, a 2-mm step PAUL plate is used. In older dogs with severe OA, a 2-mm step plate could be indicated even with mMEA less than 80° because loss of elasticity of the interosseus ligament may be a limiting factor.

Implant size selection is determined by superimposing a template over the conventional craniocaudal (CrCd) and mediolateral (ML) radiographs or using plug-in software

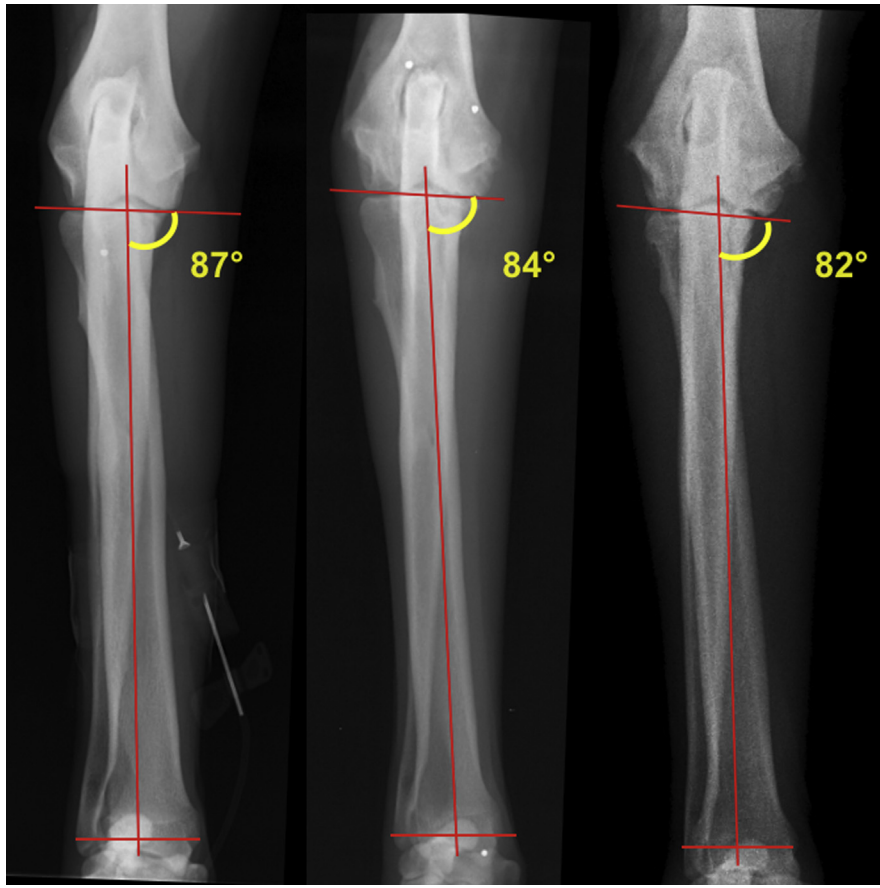

Fig. 12. The craniocaudal radiographic view with the olecranon well centered over the humeral condyle is used to evaluate the mMEA. A line from the center of the humeral condyle and the center of the antebrachiocarpal joint is traced and the medial angle between that line and the elbow joint reference line (tangent to the humeral condyles) is measured.

on digital images. It is recommended to use the largest plate suitable to fit the curvature of the ulna in the ML view, avoidance of the interosseous ligament, and sufficient ulna diameter at the location of the most distal screw. The following are general guidelines for patient weights and implant sizes:

- Dog weight less than 20 kg: PAUL plate size 8
- Dog weight 20 kg–25 kg: PAUL plate size 9
- Dog weight 25 kg–45 kg: PAUL plate size 10
- Dog weight greater than 45 kg: PAUL plate size 11

After the implant size is selected, the osteotomy location can be determined. Two measurements, D1 and D2, are calculated on a calibrated radiograph for reference in surgery. Measurement D1 refers to the distance from the radial head to the preferred osteotomy location, which generally is between 3 cm and 4.5 cm. D2 refers to the distance from the olecranon to the preferred osteotomy location. The proximal tip of the plate should be just below the level of the radial head (Fig. 13).

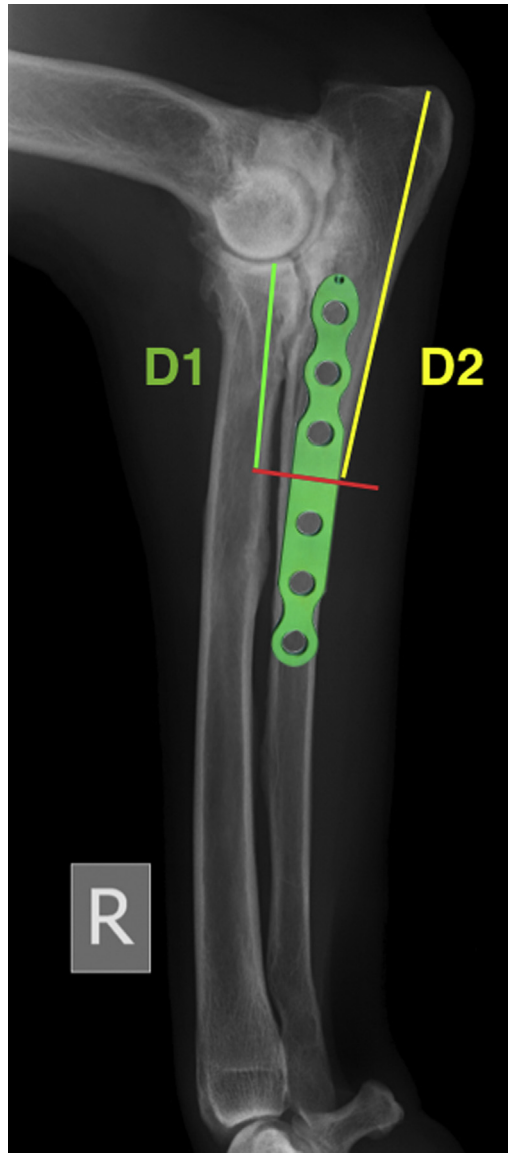

Fig. 13. Implant size selection is determined by superimposing a template over the conventional CrCd and ML radiographs or using plug-in on digital images.

Surgical Technique

Surgical approach

With the patient positioned in dorsal or lateral recumbency, a lateral approach to the proximal ulna is made.

Osteotomy of the ulna

Ulnar osteotomy is carried out perpendicular to the bone with a straight thin and sharp saw blade, from lateral to medial, recognizing that the radius lies adjacent to the ulna.

To reduce the gap at the osteotomy, 5° to 10° of inclination of the osteotomy in the sagittal plane from distal to proximal can be helpful. Excessive inclination of the osteotomy should be avoided; otherwise, the third screw may be too close to the osteotomy.

Plate position/closure

The bone plate is applied such that the top of the plate is at the level of the humeroradial joint. Closure is routine.

Postoperative Radiographs

Position of the osteotomy and implants is confirmed with orthogonal radiographs.

ML and craniocaudal radiographs are taken and the positions of the plate and of the ulna osteotomy are evaluated (Fig. 14):

- Plate alignment
- Screw direction, perpendicular to plate and parallel to each other
- Screw #6 screw centered in the distal ulna
- Location of the osteotomy, as planned
- Caudal tilt to the proximal segment
- Step from the proximal to distal segment

Postoperative Care

Soft padded bandage for 2 days to 3 days can be applied to reduce seroma formation.

Follow-up radiographs are obtained every few weeks to months until evidence of osseous union is noted.

Complications

Intraoperative complications

Mainly due to mistakes in the surgical execution

- Plate is not centered distally, which could interfere with the radius during pronation and supination causing pain.
- Plate is not parallel to the distal ulnar segment, which could cause the proximal part of the plate to be too caudal, with less bone purchase, or too cranial, interfering with the radius and possibly causing radial subluxation.
- Osteotomy is not centered in between holes 3 and 4, resulting in excessive correction when the plate is more proximal or less correction when it is more distal (Fig. 15).
- Plate is not fixed parallel to the sagittal plane, reducing the efficacy of the procedure.
- Screws are too short, not purchasing enough in the trans cortex, reducing the stability of the fixation.
- There is accidental damage to the radius when the osteotomy of the ulna is performed from caudal to cranial.

Postoperative complications

Among 116 cases with follow-up evaluation of 2 months, the authors observed 5 major complications requiring revision (4%), all requiring plate removal because of loosening, infection, or stress shielding (plates too big in small dogs). In the same group of cases, there were 3 minor complications not requiring surgical revision, 2 partial screw breakages not affecting the osteotomy healing, and 1 asymptomatic stable nonunion.[12]

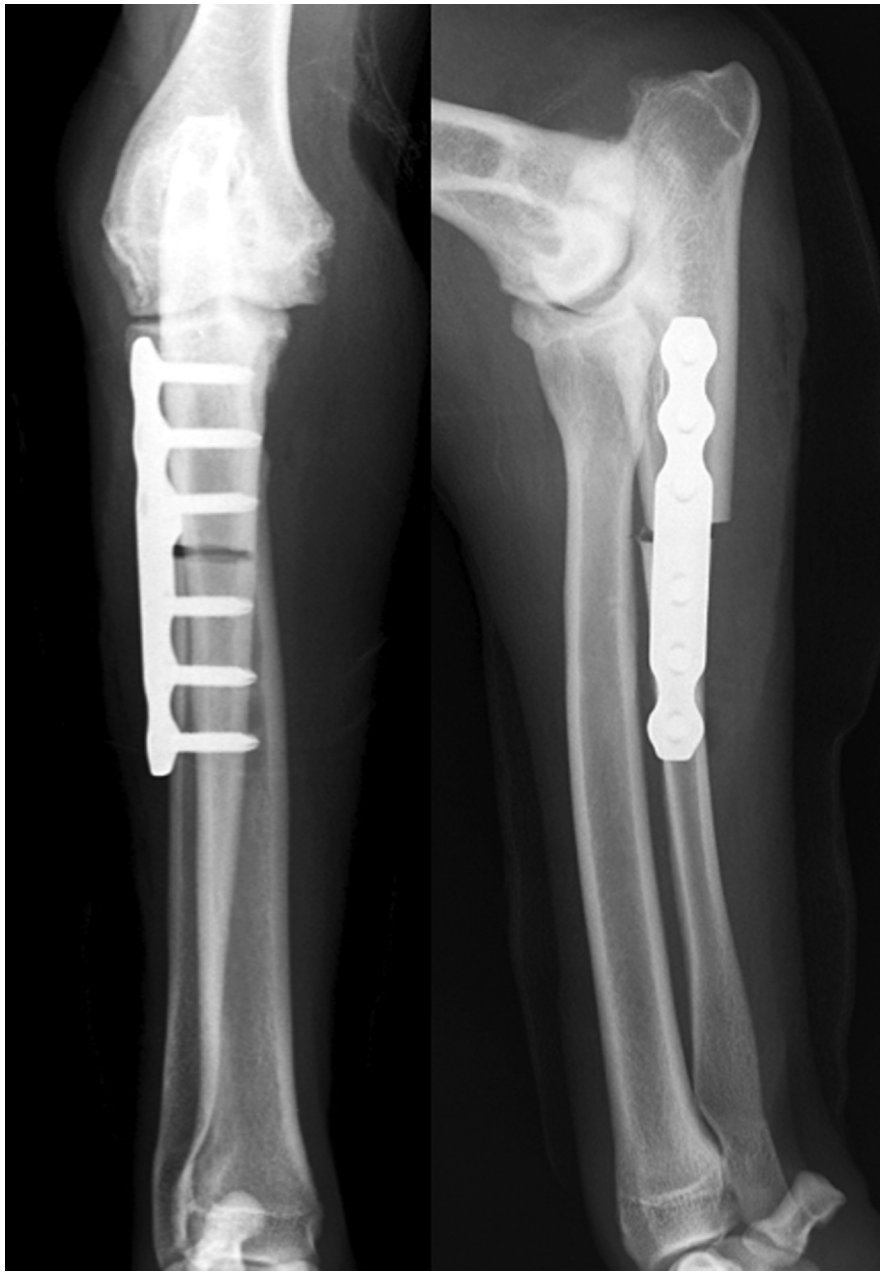

Fig. 14. Postoperative orthogonal radiographs depicting proper osteotomy and implant placement.

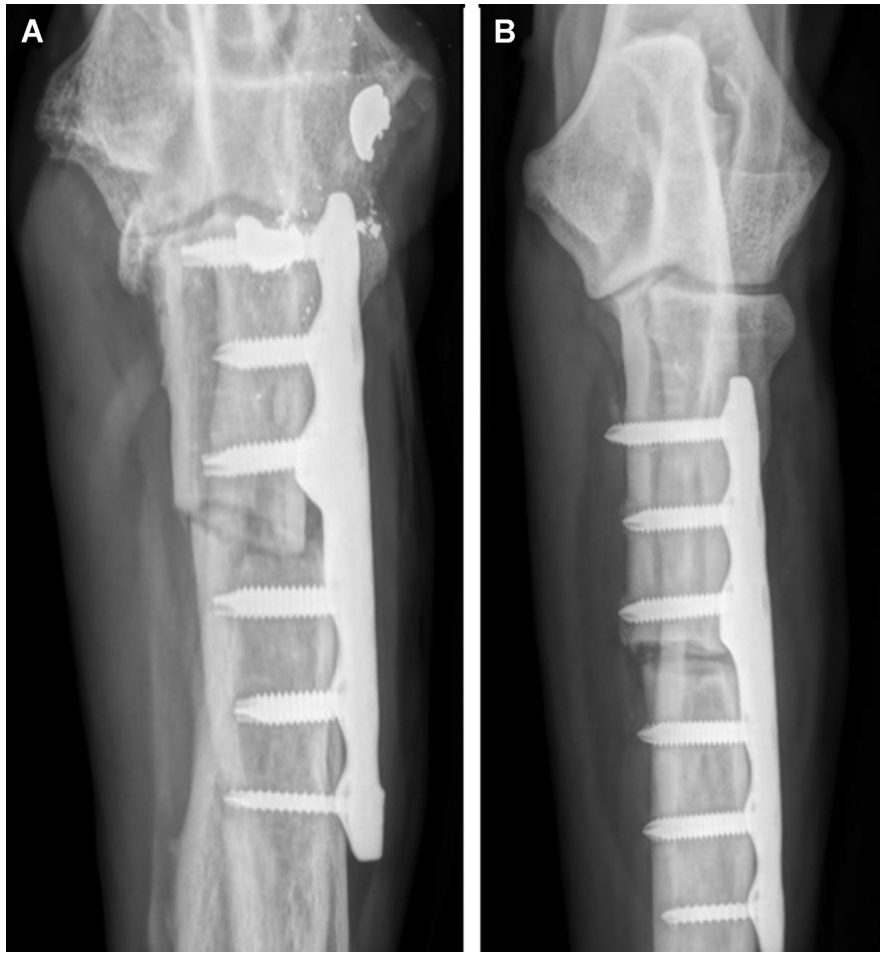

Fig. 15. Craniocaudal radiograph views depicting improper osteotomy and implant position: (*A*) too proximal and (*B*) too distal.

Functional Outcome

The expected functional outcome after PAUL is in relation to the severity of the preoperative severity of OA and the age of the dog. Owners should be aware that elbow OA will not be reversed, but that in most cases it will not progress significantly. A reduction of joint pain is expected due to elimination of the friction in the medial elbow compartment, which provides a reduction in lameness, less need of NSAIDs, and more mobility. Nevertheless, relapses of lameness due to environmental factors, like strong exercise of meteorologic variations, could occur, requiring few days of rest and NSAID therapy.

PAUL-treated elbows were rechecked postoperatively with clinical measures and radiographs (Fig. 16). Of the 130 treated elbows, 116 had a recheck between 2 months and 6 months, 49 were rechecked between 6 months and 12 months, and 33 were rechecked 1 to 7 years postoperatively.[12] Lameness was assessed subjectively on a 4-point grading scale: 0—no lameness; 1—mild lameness at walk and trot; 2—moderate lameness; 3—severe lameness; and 4—non–weight-bearing lameness. No

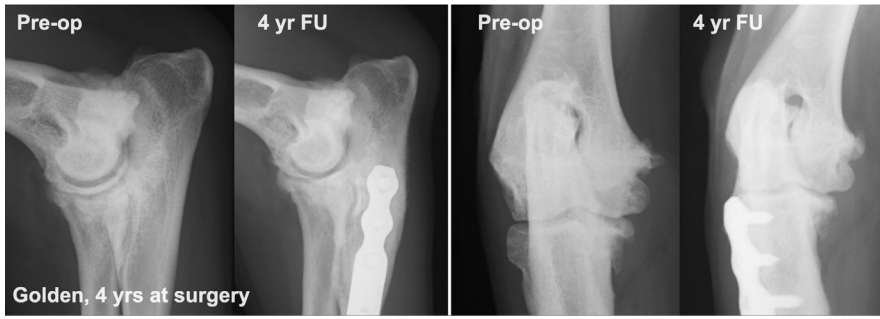

Fig. 16. Minimal progression of radiographic evidence of DJD in this case at 4-year follow-up.

patients were sound (grade 0) and no patients were non–weight bearing (grade 4) preoperatively; 92% had lameness of grade 2 to grade 3 preoperatively. At 6 months postoperative, only 9% were subjectively assessed with grade 2 lameness. There was no grade 3 or grade 4 lameness; 51% were sound and 40% had mild grade 1 lameness. Of the 33 cases followed more than 1 year, 68% were sound (no lameness), 21% had grade 1 lameness, 9% had grade 2 lameness, and 2% had grade 3 lameness.

To get the clients' perspectives, 28 of the dogs also were assessed preoperatively and postoperatively with the Liverpool Osteoarthritis in Dogs client questionnaire. Client impressions paralleled clinician assessment, with improvement in activities of daily living and quality of life 1 or more years after surgery.

A Gait4Dogs pressure-sensitive walkway was used to assess vertical ground reaction forces and contact area of the weight-bearing paw as the patients walked across the mat in 29 dogs preoperatively and beyond 1 year postoperatively. Pressure-sensitive data confirmed the subjective clinician and owner assessments.

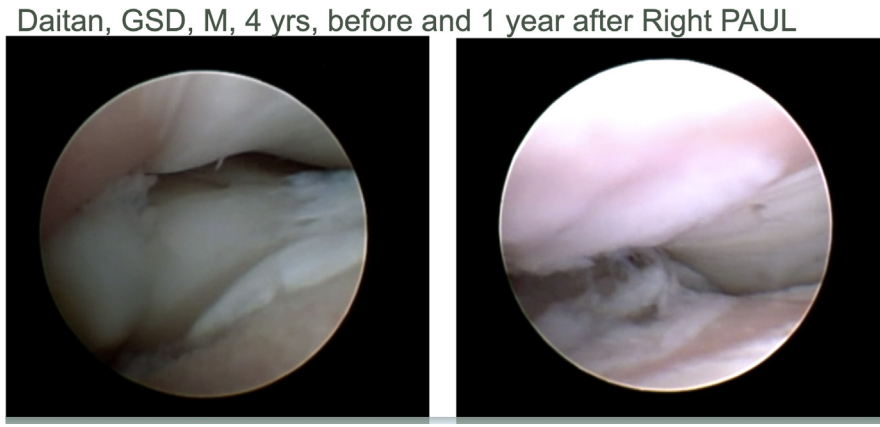

Fig. 17. Second-look arthroscopy in a German shepherd dog at 12 months postoperative. The formation of fibrocartilage in the medial compartment 12 months after PAUL was noted, where erosion (modified Outerbridge score grade 4) was present before surgery.

Second-Look Arthroscopy

Pfeil I (personal communication, Kion Symposium 2010, Zürich, Switzerland), in a second arthroscopy evaluation in a Bernese mountain dog, 7 months after PAUL, observed the formation of fibrocartilage in the medial compartment. Similarly, in second-look arthroscopy in a German shepherd dog, the authors observed the formation of fibrocartilage in the medial compartment 12 months after PAUL, where full erosion was present before surgery (**Fig. 17**).

Ongoing Clinical Studies

Standing weight-bearing radiographs are performed before and after PAUL to measure the elbow mechanical axis of deviation, upon suggestion by Brian Saunders (Texas A&M, College Station, Texas, USA). Preliminary results showed that PAUL reduces elbow mechanical axis of deviation and lateralizes and externally rotates the manus.

SUMMARY

Long-term results indicate that approximately 89% had full restoration of weight bearing or were only occasionally lame. The risk of major complications after PAUL requiring surgical revision was small (4%) and easily resolved, mainly requiring plate removal. Long-term follow-up evaluations up to 9 years have not revealed excessive wear of the lateral compartment due to the intended mechanical axis shift and load redistribution from the medial compartment. The new PAUL plate, with 4.0-mm conical locking screws, showed an overall increased strength to better withstand the strong forces transmitted to the osteotomy by the triceps muscle, promoting quicker bone healing of the ulnar osteotomy.

CANINE UNICOMPARTMENTAL ELBOW ARTHROPLASTY

Rationale

In the late 2000s, the CUE arthroplasty was conceived and developed by James L. Cook, DVM, MS, DACVS, and Kurt Schultz, DVM, MS, DACVS, in association with Arthrex engineer, Josh Karnes.[13] The original concept was to aid in the treatment of clinically symptomatic elbow joint pain and lameness caused by MCD in the canine elbow. MCD is defined as full-thickness articular cartilage loss of the medial humeral condyle and corresponding medial coronoid region of the ulna.[14,15] Subchondral bone devoid of protective articular cartilage allows constant stimulation of subchondral bone nociceptors, leading to debilitating elbow pain. Applying the concept of a unicompartmental rather than a total joint resurfacing procedure more closely maintains physiologic load transmission and distribution throughout the joint, while also preserving anatomic joint stabilizers, thereby mitigating the likelihood of lateral articular cartilage overload, malalignment, instability, and/or luxation. The CUE implant eliminates or limits bone-on-bone disease while maintaining the natural joint stabilizers of the native elbow, thus improving functional weight bearing and elbow joint range of motion and reducing pain and lameness.

The principles behind the development of the CUE implants and procedure included being bone sparing and cementless as well as being a safe procedure with low morbidity. Concerns about limb alignment should not be a significant factor, because the implant has continuous contact throughout gait range of motion. There is diminished stimulation of subchondral bone nociceptors and enhancement of the potential to promote fibrocartilage ingrowth by replacing bone-on-bone contact with implant contact through a functional range of motion of 90° to 150°. The CUE was intended

to be a straightforward and repeatable procedure, with simplicity of instrumentation, limited implant inventory needs, and acceptable price point.

Implant Design

The CUE implants consist of both humeral and ulnar components (Fig. 18). The humeral component has a curvilinear double-snowman shape composed of a cobalt-chrome alloy surface with high strength and durable wear characteristics. This is mounted to a BioSync-titanium base, which has both high corrosion resistance and outstanding biocompatibility.[16] The implants are available in both medium and large sizes, which cover patient weight ranges from approximately 25 kg to 75 kg. The ulnar component originally was designed as an on-growth ultra high molecular weight polyethylene (UHMWPE) plug, which, due to its small size and point contact, minimizes the chance of secondary polyethylene wear products. A second-generation G2 implant was introduced in 2017, which allowed for the incorporation of a BioSync-titanium ingrowth base attached to an UHMWPE weight-bearing surface.

Instrumentation

The CUE implant system instrumentation is relatively simple in design and concept. The system comprises 2 sizes, medium and large, of both humeral and ulnar Beathe pin guides and reamer guides along with implant impaction instrumentation.

Preoperative Guides for Patient Selection

As with any joint replacement or resurfacing procedure, patient selection is critical to success. The patient should be in relatively good health with minimal comorbidities, illness, or evidence of skin infection. Candidates typically are between 3 years and 10 years of age, in a weight range of between 25 kg to 75 kg, and have elbow arthrosis with corresponding MCD and significant secondary chronic pain and lameness not responsive to medical management (Fig. 19). The degree of medial joint collapse and periarticular osteophytosis can range from mild to severe; however, an ideal candidate is in the mild to moderate category with a relatively normal lateral joint compartment (radial head and lateral humeral condyle) usually confirmed arthroscopically. There currently is not an implant templating or sizing guide.

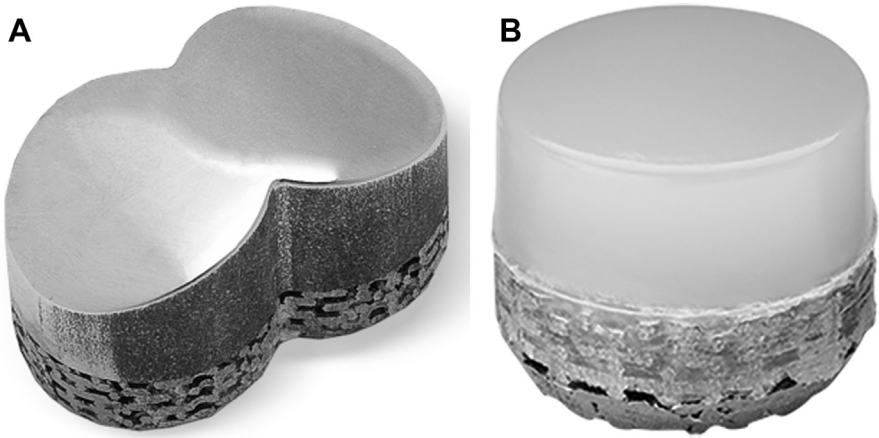

Fig. 18. Implants of the CUE system: (*A*) CUE humeral component and (*B*) CUE ulnar component. (*Courtesy of* Arthrex, Inc., Naples, FL.)

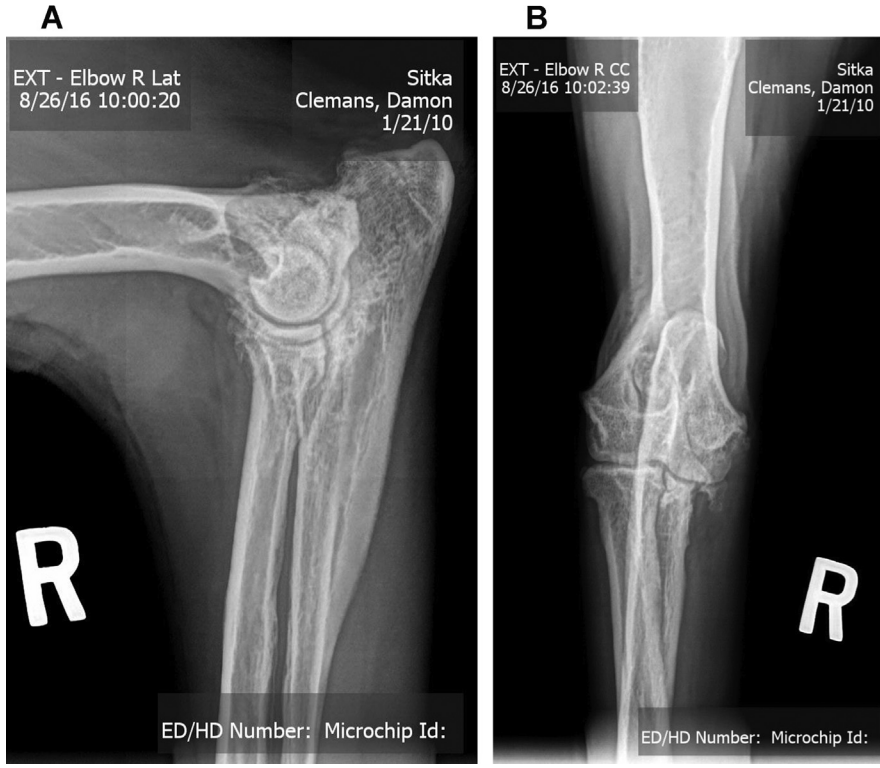

Fig. 19. (*A, B*) Preoperative orthogonal radiographs depicting MCD.

Canine Unicompartmental Elbow Technical Procedure

Approach

Cook and Shultz[18] initially described the approach to the medial elbow as a tenotomy of the medial flexor tendons to allow for adequate exposure of the articulating weight bearing surfaces of the medial humeral condyle and ulna. This quickly evolved to an epicondylar osteotomy with retraction of the flexor tendon origin to gain adequate exposure to the medial humeral condyle and medial coronoid regions. A caudomedial approach (CMA) to the elbow based on a modification of Aman and Wendelberg's[17] initial work toward medial unicompartmental elbow replacement may eliminate the need for epicondylar osteotomy (Fig. 20).

Implant location and placement

The ulnar implant location initially is determined after access to the joint through one of the procedures, discussed previously. Depending on the size of the patient and the medial coronoid process, a medium or large ulnar Beathe pin guide is used to place a single pin tangential from the base of the medial coronoid through the caudal spine of the ulna. The elbow joint is reduced while pin tip marks are made in full extension and 135° and 90° of flexion. This ensures proper alignment for humeral implant reaming and ultimate implant orientation and placement. The ulnar socket then is reamed with the appropriate medium or larger reamer.

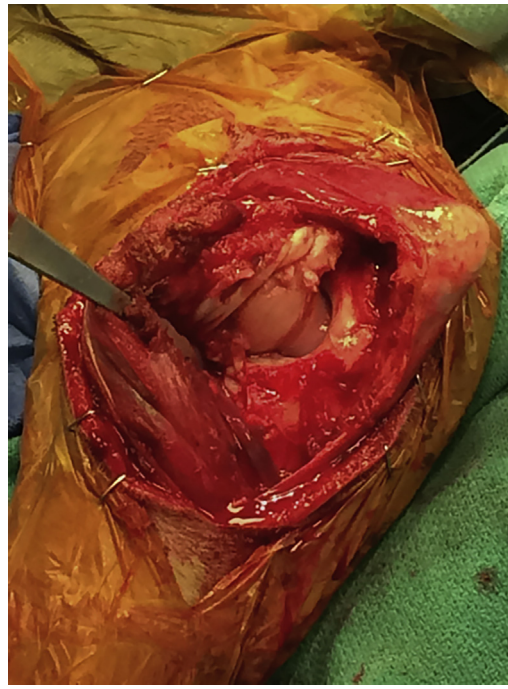

Fig. 20. Modified CMA to the elbow joint.

A humeral guide then is placed along the sagittal line created by the previously made pin marks, described previously. The caudal aspect of the guide should just cover the caudal-most pin mark. Two Beathe pins are placed to allow for proper reamer guide placement and reaming.

After careful cleaning of both the ulnar and humeral bone sockets, implant templating instruments are used to assure proper bone socket depth prior to implantation. Implantation of the ulnar socket is recommended first, followed by placement of the humeral implant. The joint then is reduced and elbow range of motion confirmed.

Closure

If an epicondyle osteotomy was required, reattachment and stabilization using Kirschner wire and single 3.5 mm bone screw is performed. Soft tissue reattachment of the flexor carpi ulnaris muscle origin to the ulna (CMA), followed by routine soft tissue and skin closure.

Radiographs

Orthogonal radiographs are obtained immediately postoperatively and at recheck intervals, as indicated (**Fig. 21**).

Postoperative Management

It is recommended that patients be placed in a soft padded or soft cast bandage for 2 weeks to limit risk of seroma formation. Activity should be limited to (progressive) leash walk activity for 8 weeks to allow for adequate implant bone integration, osteotomy, and soft tissue healing. Gradual increase in leash activity should occur over the

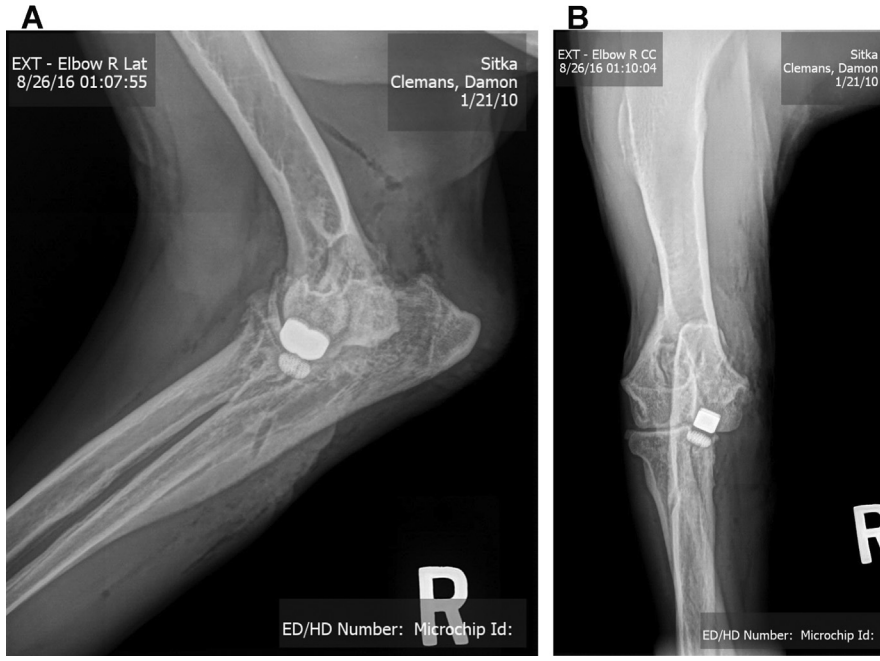

Fig. 21. (*A*, *B*) CUE postoperative orthogonal radiographs of the same patient depicted in Fig. 19.

following 8 weeks to 16 weeks. Patients typically can resume full activity by 12 weeks to 16 weeks postoperatively.

Outcomes

Published outcomes for the CUE arthroplasty currently are limited to the initial article by Cook and colleagues,[18] which described the mid-term to long-term (4-6 months) outcomes with respect to function and complications. This article shows full and acceptable functional outcome of 91% and what is considered an acceptable major/catastrophic complication rate, of 11.7%.

Biomechanically Anatomic, Nonconstrained, and Compartmental Unicompartmental Elbow Replacement

Compartmental joint disease has long been recognized in the human knee joint. The unicompartmental joint replacement for the human knee has been successfully performed since the 1970s. The nonconstrained compartmental prosthetic arthroplasty in the human knee has been reported to have 10 year or greater survivorship rates of more than 96%.[19]

Development of the KYON Biomechanically Anatomic Non-constrained Compartmental partial elbow replacement (BANC PER) began in 2006 with well-defined objectives. The design objectives for the development of the KYON elbow replacement system can be summarized as a BANC arthroplasty. To be biomechanically anatomic, the prosthetic arthroplasty must provide a normal sagittal hinge range of motion arc (SROMA) of the antebrachium about a precisely normal center of rotation, along with allowing for normal protonation and supination throughout the gait (Fig. 22).

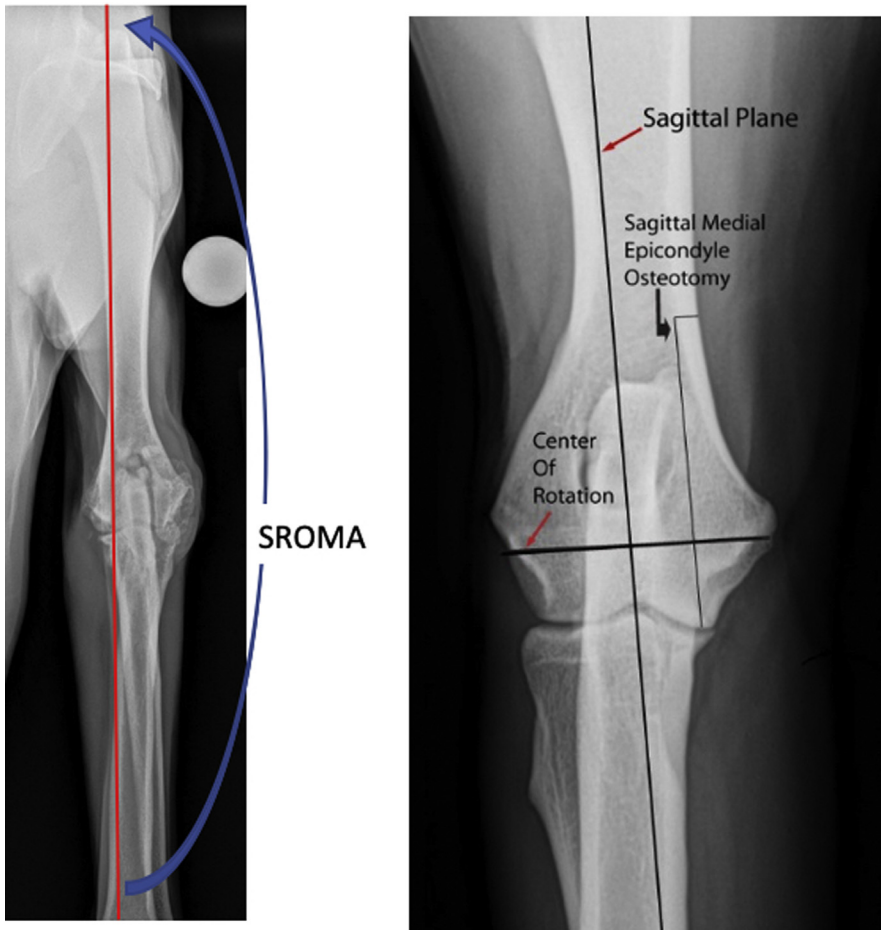

Fig. 22. The SROMA extending through the mechanical axis of the antebrachium

Cadaveric testing continued through 2011, when biomechanical load to failure testing of the first-generation design was compared with paired normal thoracic limbs.[20] Clinical cases of the PER began in 2011.

Design Considerations and Development

Constraint of a prosthetic arthroplasty can be classified as constrained, semiconstrained, or nonconstrained. The elbow joint contains 3 separate articulation compartments, which include the humeroulnar, humeroradial, and radioulnar (RU) articulations with respect to constraint. Constraint is a mechanical link or coupling of the prosthesis between the implanted bones of the joint or between the articulation compartments of the elbow. Constraint causes normal joint movements to transfer significant stresses to the implant-bone interface and has been associated with loosening and metal failure responsible for high failure rates.[21]

The elbow joint also can be described as a 2-compartment joint with respect to the anatomy of the humeral condyles. The lateral capitulum (lateral condyle) articulates with the radial head and the lateral coronoid of the ulna within the lateral compartment.

The medial trochlea (medial condyle) articulates with the ulna within the medial compartment. The KYON BANC PER system is compartmental, allowing it to replace just the affected medial compartment of the elbow, while having no constraint of the radial head as it rotates within the radial notch of the ulna during normal pronation and supination. The original design allows for conversion to a BANC TER if needed, although this may not be required and has not yet been attempted in clinical cases.

Implant Design

Since the first clinical case in 2011, the BANC PER implant has undergone 5 design modifications. The implants consist of a cylindrical medial humeral component with a UHMWPE conical disc press fitted over it and a semicircular medial ulnar component made of titanium, which articulates with the humeral implant. This allows for replacement of the medial condyle of the humerus and the medial coronoid of the ulna as well as the medial aspect of the trochlear notch and anconeal process. The polyethylene ring acts as a meniscus between the metal implants, allowing it to distribute motion and friction between both the circular metal barrel of the humeral implant and the articulation of the metal ulnar component. The humeral implant is held in place with a large diameter transcondylar screw with an internally threaded screw head (Fig. 23). The medial epicondyle osteotomy is compressed into the medial ingrowth plate of the humeral component using an epicondylar screw placed through a medial epicondylar advanced locking plate (ALPS) on the medial surface of the humerus. The ulnar implant is compressed into the milled bone bed with radially positioned cortical screws. Stability of the implants is achieved with osseointegration over time. The first-generation device had a ridged titanium bony on-growth surface; however, with the third-generation device, this was substituted for electron beam melting (EBM) of the titanium components. In the third-generation device, the EBM surface was welded onto the existing implant, which maintained stability while encouraging boney ingrowth. To facilitate larger-scale manufacturing, however, this design was altered from a welded EBM bone ingrowth surface to the entire implant, manufactured as a trabecular EBM, weakening the resulting fourth-generation construct. The most recent implant (fifth generation) has remedied this and allowed for improved osteointegration without compromising implant integrity and strength. Additional changes from the first generation to the current model of implant included increasing

Fig. 23. Implants of the KYON BANC unicompartmental elbow replacement system. (*Courtesy of* KYON Veterinary Surgical Products, Boston, MA.)

the diameter of the transcondylar and epicondylar screws. Following fracture of the screw at the epicondylar-implant interface in the first clinical case using the original implant, the diameter of both components was increased, from 3.8 mm to 7 mm for the transcondylar screw and from 3.0 mm to 4.5 mm for the epicondylar component. This allowed for decreased risk of fatigue fracture and partial pullout or bending of the epicondylar or transcondylar fixation screws.

Indications and Preoperative Planning

Indications for the BANC PER include dogs with severe lameness and OA secondary MCD of the elbow that is refractory to medical or other surgical management. As such, CT scan and elbow arthroscopy are recommended prior to BANC PER to evaluate the status of the lateral compartment. Although patients with intact articular cartilage in the lateral compartment make the most ideal candidates for BANC PEA, anecdotally, even patients with severe wear in the lateral compartment seem to benefit from the replacement of the medial compartment. In addition to advanced imaging, precisely positioned preoperative orthogonal view radiographs are essential for accurate preoperative planning and implant sizing. Medial-lateral views of the elbow are used to template the diameter of the milling reamer and the humeral/ulnar implant using available mylar templates or computer software. Current sizing includes large dog implants (30 mm, 32 mm, and 34 mm) that typically can accommodate an average Labrador retriever to some of the giant breeds. Medium-sized dog implants (24 mm, 26 mm, and 28 mm) currently are being considered for future development.

Surgical Technique

The patient is positioned in oblique dorsal recumbency with a sterile Mayo stand or thin instrument table placed at a right angle to support the forelimb and the BANC SROMA board.[22] Sagittally placed pins are inserted into the proximal humerus and mid-humerus and then are anchored to the SROMA board using posts and clamps. The sagittal distal radius then is inserted just lateral to the extensor carpi radialis groove, and the limb is put through range of motion. SROMA points are marked at full flexion, mid-flexion, and full extension by using posts and clamps at the level of the distal radius pin as it travels through the SROMA. The distal radius is attached to the positioning board with a post and clamp. A connecting bar then is placed between the 2 clamps and serves as the means of achieving appropriate positioning of the guides (**Fig. 24**).

A CMA to the elbow with medial epicondyle ostectomy is performed. The limb then can be mounted to the BANC SROMA board. The use of purpose-specific saw guides and drill guides allows for accurate milling to accept the humeral and ulnar BANC prostheses (**Fig. 25**).

Following insertion of the prosthesis, the media epicondyle ostectomy is reduced and stabilized with ALPS (KYON) plate and screws (**Fig. 26**). The remainder of closure is routine.

Postoperative Evaluation and Management

Patients are hospitalized for 2 days to ensure adequate comfort and mobility. A soft padded bandage is placed postoperatively and maintained for 2 weeks with a bandage change recommended at 1 week. Activity restriction is essential for adequate bony healing and to prevent implant-related complications. Strict activity restriction is recommended for 2 months, allowing for controlled walking only, followed by gradual increased in controlled activity for 1 month (month 3

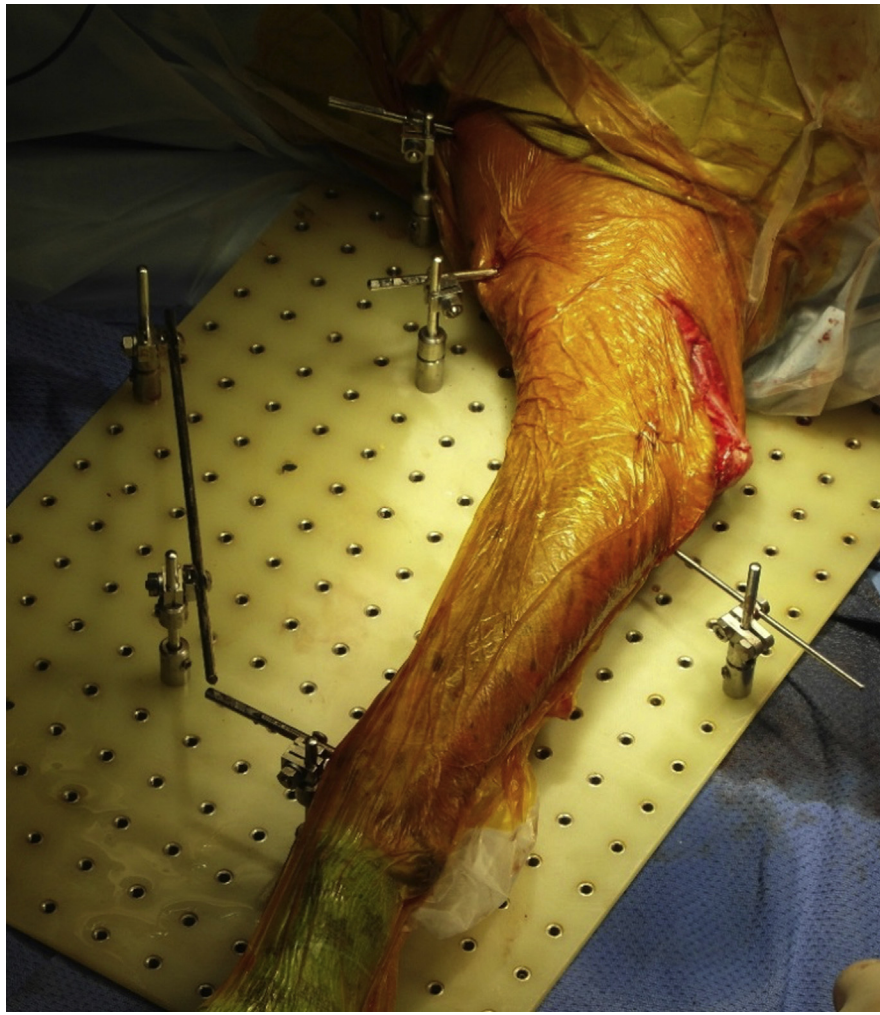

Fig. 24. The humerus and radius are attached to the SROMA board with all post clamps at the level of the SROMA. The connecting rod serves as a sagittal line guide for the paddles of the sagittal saw guide and the transverse drill guide.

postoperatively). This usually involves lengthening the duration of leash walks every 3 days to 5 days for 2 weeks, followed by controlled trotting and jogging for an additional 2 weeks. By 3 months to 4 months they are permitted to have off-leash activity. Immediate postoperative orthogonal radiography is essential to evaluate appropriate implant alignment and positioning as well as reduction and fixation of the epicondylar and ulnar osteotomies (Fig. 27). Further radiographic follow-up is recommended at 2 weeks, 1 month, 2 months, 3 months, 4 months, 6 months, and 1 year postoperatively, followed by annual radiographic reassessment. This allows for monitoring of bony ingrowth and signs of implant failure during confinement, rehabilitation, and free activity. Yearly radiographs allow screening for implant associated complications, such as fatigue fracture or aseptic loosening.

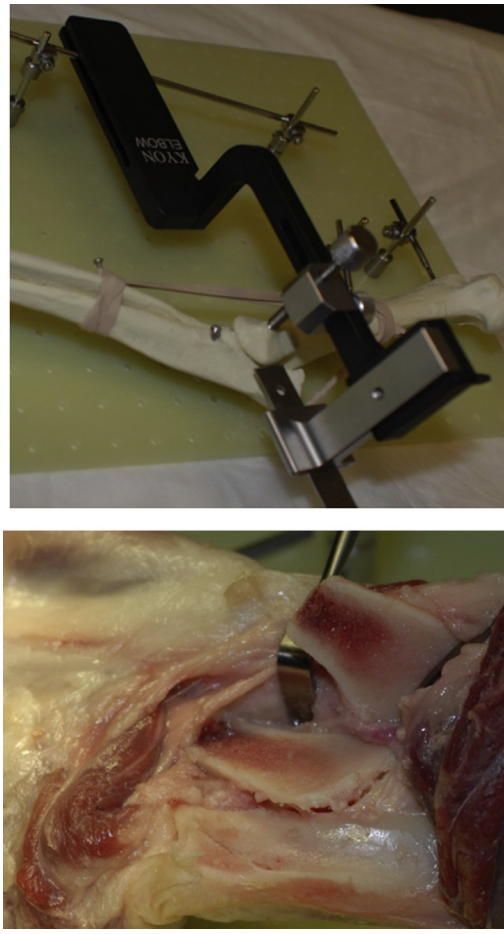

Fig. 25. The sagittal saw guide is used to produce the osteotomy of the medial epicondyle. The medial epicondyle is retracted cranially to the level of the trochlea of the medial humeral condyle.

Clinical Outcome and Complications

Since the first clinical case in 2011, a total of 15 BANC PER procedures have been performed in the United States, with several more performed in Europe. Various modifications were made to address any concerns with implants, instrumentation, and surgical technique. The progressive improvement of older generations of implants, instrumentation, and surgical technique has led to the gradual evolution of the prosthesis to its current version.

Patient outcomes generally have shown a significant improvement in gait and elbow pain. Most patients throughout the history of the KYON partial joint replacement returned to normal athletic activity, free of lameness or pain (base on owner evaluation and follow-up examinations), and have discontinued the use of NSAIDs following the procedure. There was a short period during evolution of the implant, which resulted in 4 cracked or broken implants observed from 1 month to 12 months postoperatively. This occurred after converting the titanium of the ulnar and humeral component to

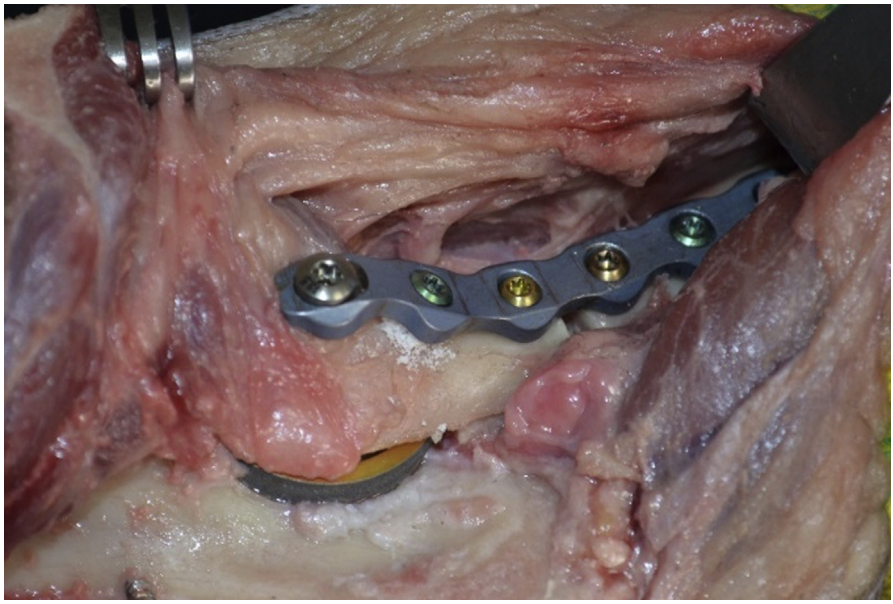

Fig. 26. The epicondyle screw is compressed into the transcondylar screw head and the medial epicondyle osteotomy stabilized with ALPS plate and screws.

an EBM manufacturing process in order to configure a trabecular mesh with the objective of improved osseointegration. These dogs accounted for all of the major complications in the 9-year series of cases in the United States. Although 2 dogs with cracked implants never showed clinical signs of lameness or pain secondary to the cracked metal, 1 dog required a successful revision to replace the implants and return to normal function, whereas another case (in a 73 kg rottweiler) resulted in a failed revision of the crushed implants. The implant manufacturing process converted back to solid titanium with a thin layer of hydroxyapatite (HA) or EBM mesh to promote bony ingrowth. Long-term data beyond 4 years postoperatively currently are unavailable because earlier patients have died for reasons unrelated to the elbow replacement. Objective force plate data are lacking and need to be collected. The clinical evaluation of short-term and long-term outcomes of the BANC PER, however, is ongoing (Follette and Wendelburg, unpublished, 2021).

Limitations

Limitations of the BANC partial elbow arthroplasty system are inherent to any elbow replacement system in that few acceptable options for revision are available. Although implant revision can be performed successfully, severe cases of failure or infection likely result in arthrodesis or possibly amputation. For this reason, owner education on alternative therapies and risks as well as full disclosure of the limited long-term data on this procedure is essential.

TATE TOTAL ELBOW REPLACEMENT IN DOGS

Rationale

During the past 30 years, functional limitations of conservative management and nonreplacement surgeries for the treatment of end-stage canine elbow OA have fueled

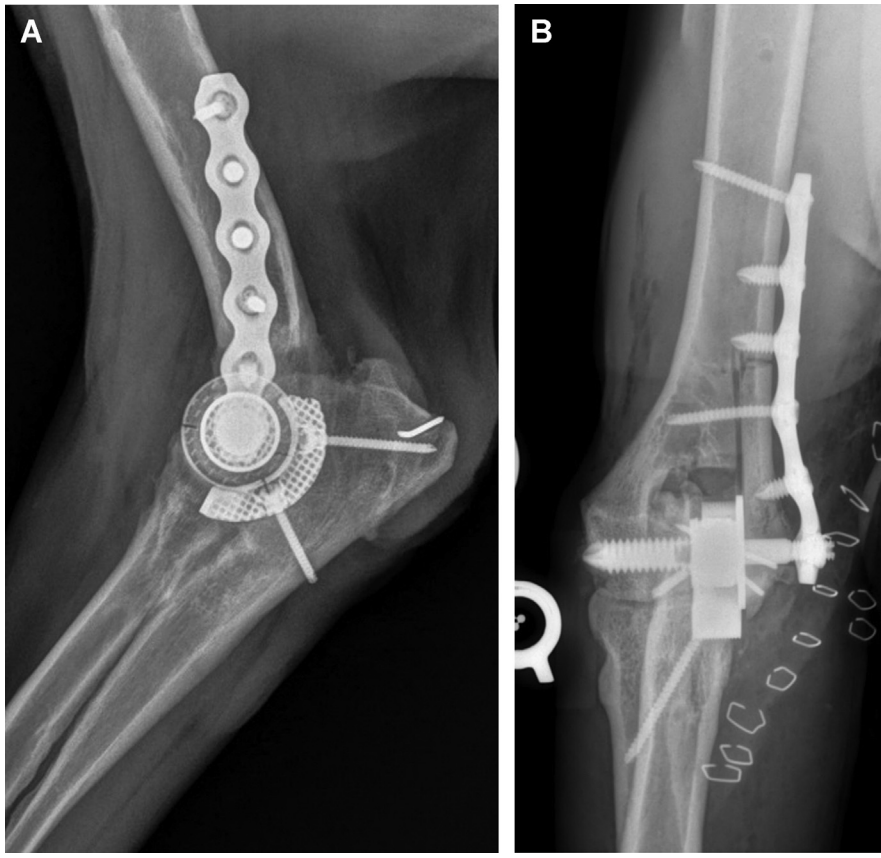

Fig. 27. Immediate postoperative orthogonal view radiographs [*A*] ML view; [*B*] CrCd view of patient with BANC PER. (*Courtesy of* KYON Veterinary Surgical Products, Boston, MA.)

growing interest in TER and PER. Clinical use of a TER first was reported by Whittick and colleagues,[23] who in 1964, used a custom-made spherical hinged prosthesis to treat a gunshot-induced comminuted elbow fracture in a cat. To the authors' knowledge, the first clinical canine TER was implanted in 1989 by Chancrin, who used a prototype cemented hinged prosthesis to treat a Labrador retriever affected with end-stage OA (Chancrin J, personal communication, 2008). Subsequently in 1996, Lewis[24] reported on the first clinical results of a hinged TER implanted in 10 dogs. In these first-generation systems, Chancrin and Lewis used cemented, fully constrained hinged designs (linked systems). Because of the rigid mechanical link between the humeral and RU components, most of the forces across the joint were transmitted through the implant to the cement and its interfaces.[25] The high complication rates encountered with these initial designs quickly led to a paradigm shift to unlinked TER designs. Vasseur (Sidebotham CG, personal communication, 2008), Lewis (second and third generations),[24] Cook,[26] and Conzemius[27,28] developed the first unlinked designs in the late 1990s. All encountered unacceptable postoperative morbidity that led either to termination or further refinement of the respective designs. Following iterations of his earlier designs, Conzemius and colleagues[29,30] reported encouraging results after TER in 6 normal dogs, then 2 years later, in 20 dogs afflicted

with naturally occurring OA. Minor modifications, including the addition of porous coated surfaces to the lateral and medial aspects of the humeral component as well as curvilinear humeral articular profile, led to Conzemius' fifth TER generation, which became commercially available in 2005 (Iowa State system, BioMedtrix, Whippany, New Jersey).

More recently, a radically novel TER system (TATE Elbow system, BioMedtrix) was developed by Acker and Van Der Meulen[31,32] (**Fig. 28**). Similar to Iowa State System prosthesis, the TATE uses an unlinked, semiconstrained design. Several fundamental differences exist, however, between these 2 systems. Unlike previous conventional stemmed and cemented systems, the cementless TATE implant was designed to use a novel resurfacing concept as well as less invasive surgical approaches. In 2008, Acker and Van Der Meulen[33] reported satisfactory results 6 months after implantation of this resurfacing system in 6 dogs affected with end-stage OA.

In 2003, a UK company (OsteoGen, Bath, United Kingdom) began developing the Sirius, a TER design that is based in part on resurfacing technology for both humeral

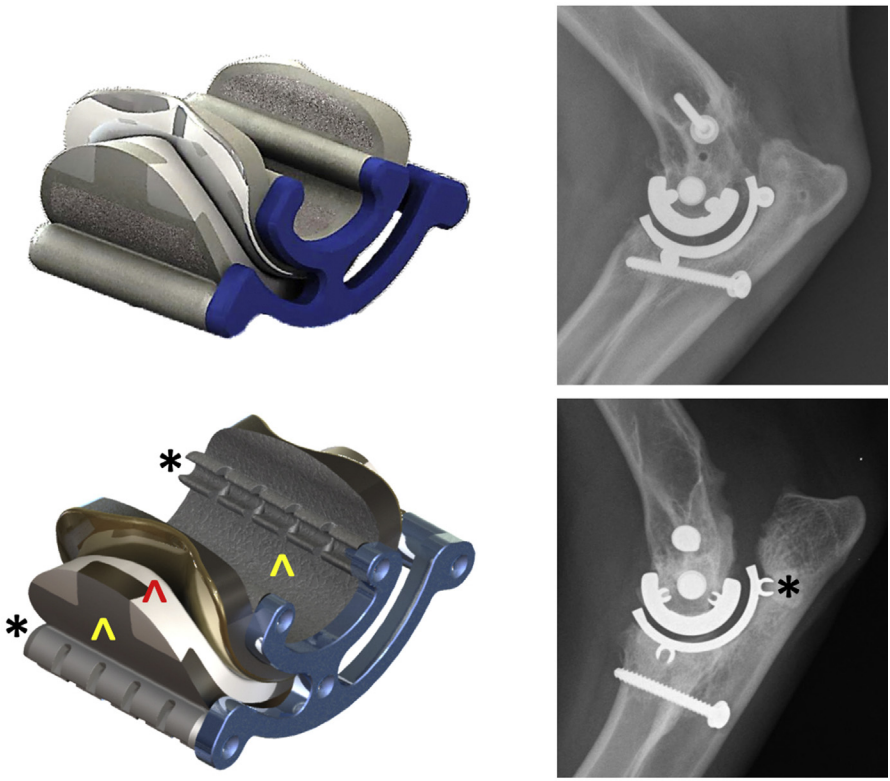

Fig. 28. Computer-generated rendering of the first-generation (*top row*) and second-generation (*bottom row*) TATE prostheses and corresponding postoperative 24 weeks' radiographs. To optimize osteointegration potential, the following iterations were implemented in the second-generation design: (1) hollow primary fixation posts to the surface area of the implant/bone interface (*asterisk*), (2) HA-coated prosthetic surfaces (*yellow ^*), and (3) flattening of the RU UHMWE lining ridge (*red ^*). The latter was intended to reduce prosthetic congruity in order to reduce implant/bone interface shear stresses. The 24 weeks postoperative radiographs show robust osteointegration of the humeral and RU components. (*Courtesy of* BioMedtrix, Whippany, NJ.)

and RU components. Similar to the Iowa State system, and unlike the TATE, however, the humeral component featured a cemented stem. Yet another crucial difference between the TATE and the Sirius prostheses is that the latter relies on RU cortical screws to achieve primary fixation of the RU component. Over the ensuing 15 years, OsteoGen continued to develop this novel design in collaboration with Innes and Pettitt, then at the University of Liverpool.[34] Mixed clinical results have led to several iterations of the original designs.

Design Rationale

The TATE Elbow system uses an unlinked semiconstrained 2-component design. In the absence of a rigid mechanical link between the humeral and RU components, the stability of unlinked prostheses is provided by the matching geometry of the prosthetic articulating surfaces and the surrounding soft tissue envelope.[25] Specifically, some of the transarticular forces (eg, the forces in varus-valgus) almost exclusively are counteracted by passive soft tissue constraints (ie, collateral ligaments), whereas other forces (eg, internal/external rotation and ML translation) also are controlled by the geometry of the prosthetic articular surfaces. Although contributing to joint stability, prosthetic constraint has been shown to influence stresses at the bone-implant interface. Interfacial stress distribution is further complicated by the fact that the TATE system features a single RU component that eliminates motion between the radius and the ulna.

Although the ideal prosthesis should allow near-normal joint kinematics of humeroantebrachial and RU joints, such a design would require more complex 3-component systems featuring separate components to replace the radial head and the ulnar notch. Nonetheless, 3-component prostheses have been used in the past (Vasseur, 1993 [Sidebotham CG, personal communication, 2008]; and Lewis, 1996)[24] and subsequently were abandoned due to poor clinical results. Thanks to recent technological advancement in design (resurfacing rather than stemmed or screwed components), materials (titanium rather than cobalt-chrome alloys), and interface surface texture (EBM rather than bead sintering), there is a renewed interest in developing 3-component prostheses. The current TATE design likely was chosen as a compromise between optimal joint kinematics and decreased prosthetic complexity and related risk of implant failure.

Although physiologic RU motion is limited in arthritic elbows, residual motion could be detrimental to the osteointegration of the RU component and thus its long-term stability. To reduce the risk of interfacial failure at the level of the RU component, the surgical procedure includes an RU synostosis.

The original TATE Elbow system uses a cementless resurfacing design consisting of a cobalt-chrome humeral component and a 175° arc UHMWPE RU component featuring a cobalt-chrome metal backing. Both humeral component and RU metal backing feature 2 ML posts for primary fixation and a porous surface for long-term stability via bone ingrowth. The TATE Elbow system was designed to use a relatively less-invasive approach than previous systems, via osteotomy of the medial humeral epicondyle. During implantation, both components are linked by a set plate and are inserted simultaneously as a cartridge implant.

In an effort to optimize bone ingrowth a second-generation TATE Elbow system was released early 2010. This refined design has been progressively replacing the first TATE generation. Design modifications included hollow primary fixation posts and HA coating. In addition, reduced prosthetic constraint in rotation and ML translation was achieved through modification of the RU articular profile.[35,36] Although no cases of implant loosening had been documented with the first-generation TATE when the

second-generation design iterations were implemented, the rationale for changes was to promote implant osteointegration. Further modifications were introduced in 2016 and included (1) titanium 3-dimensional (3-D) humeral component and RU metal back, (2) titanium nitride coating of the articular surface of the humeral component, and (3) HA coating of the metal/bone interfaces of both humeral and RU components.

Indications–Contraindications

The primary indication for TER is severe, intractable DJD that is not responsive or poorly responsive to medical management. Although elbow OA is associated most commonly with elbow dysplasia, it also can result from articular fracture, elbow luxation, or angular limb deformities with subsequent elbow incongruity. Because of the limited long-term follow-up available for the currently available systems, it has been recommended that TER be restricted to older dogs with a clearly decreased quality of life on a day-to-day basis, which cannot be managed satisfactorily with medical treatment. Based on their favorable experience with the TATE prosthesis, however, the authors have extended their recommendation for TER to include younger dogs afflicted with intractable end-stage OA. Similarly, due to the risk of potentially severe complications, with limited revision strategies, early TERs were preferentially, yet not exclusively, performed in dogs with unilateral elbow OA. As with the initial age restriction, encouraging results with the TATE prosthesis have led the authors to recommend TER in dogs with severe bilateral elbow OA. As for any total joint replacement, systemic or local infections (eg, local pyoderma, bacterial cystitis, otitis externa, and periodontal disease) increase the risk of postoperative infection and should be identified and addressed before surgery. Chronic elbow luxation is a relative contraindication to TER. The compromised periarticular soft tissue envelope may increase the risk of postoperative luxation with the currently available, unlinked, systems. Finally, severe malunion may preclude the use of the resurfacing TATE Elbow system. Neurologic dysfunction and skeletally immature dogs represent other potential contraindications.

Preoperative Evaluation

Comprehensive physical, orthopedic (including goniometry), and neurologic examinations are mandatory to fully assess functional alterations in the affected elbow joint, to rule out other potential causes of thoracic limb lameness, and to document concurrent abnormalities.

Radiography then is used to confirm the diagnosis and assess the severity of the periarticular osteophytosis. Standard, accurate craniocaudal and ML views with concomitant use of a magnification phantom are mandatory, because these films are used with acetate or digital templates to select an appropriately sized prosthesis. When extensive periarticular osteophytosis is present, a computed tomography (CT) scan with 3-D reconstruction of the elbow is useful for surgical planning. Poor identification of anatomic landmarks during the implantation surgery can result in an improperly aligned implant and can have disastrous effects on the outcome.

Surgical Technique

The elbow joint is approached through a medial epicondyle osteotomy. The elbow axis of rotation (AOR) is identified with the use of dedicated instruments. A datum pin, inserted along the AOR, serves as a reference throughout the procedure. The elbow is flexed at approximately 90° and then is locked in place using an alignment plate screwed into the humerus, radius, and ulna. Next, a drilling guide is loaded onto the AOR pin and is used to drill 4 transverse holes (2 in the humerus, 1 in the radius, and 2 in the ulna) that accommodates the ML posts in the matching prosthetic

components. Using a custom end mill, the proximal (humeral) and distal (RU) articular surfaces are removed simultaneously along a 200° arc concentric to the AOR. A cartridge implant then is press-fitted into the open joint space. A set plate used to link the components during impaction is removed, and the elbow range of motion is assessed. If cranial or caudal impingements are present, osteophytes are débrided with the use of rongeurs or a high-speed burr. The medial epicondyle is reduced and fixed with transcondylar and epicondylar lag screws or a bone plate. Routine closure in layers concludes the procedure.

Postoperative Evaluation and Management

ML and craniocaudal elbow radiographic views are obtained to assess proper implant alignment and positioning as well as osteotomy reduction and fixation. Subsequent radiographic evaluations are recommended at 6 weeks, 12 weeks, 24 weeks, and 52 weeks, then yearly thereafter, to assess bone ingrowth as well as implant stability and/or failure (eg, aseptic loosening). Postoperative radiographs are shown in **Fig. 29**. A soft padded bandage is applied for a few days after surgery. Professional physical rehabilitation, after an initial 6-week period of restricted activity, is strongly encouraged.

Clinical Outcome–Complications

To date, although clinical and experimental studies are ongoing, no objective data are available on the TATE Elbow system. This dearth of information may be explained by the relatively recent release of this prosthesis and by the limited number of cases performed by any given surgical group. The only report currently available required the compilation of 32 clinical cases (33 elbows) by 7 surgeons from a mix of 5 academic institutions and specialized private practices.[37] In that retrospective study, the long-term clinical outcomes after TATE Elbow replacement was evaluated subjectively by means of radiographs as well as via surgeon and owner questionnaires; objective evaluation, such as force plate analysis or kinematic gait assessment, was not performed. Although surgeons reported 76% of full (24%) or acceptable (52%) function, 24% of the cases had unacceptable clinical outcomes. This evaluation was corroborated somewhat by the 19 owners (67%) who provided feedback. Of these, 12 (63%) were very satisfied with the procedure, 5 (26%) were somewhat disappointed, and 2 (11%) had no opinion.

Despite a surprisingly high rate of major (15 cases [45%]) or catastrophic (5 cases [15%]) complications, this report concluded that the TATE procedure provided a significant reduction in pain severity in most cases, although mobility scores were unchanged over time. Infections occurred in 10 cases (30%) up to 12 months postoperatively. Finally, the investigators reported suboptimal implant positioning in 97% of the cases, while acknowledging that this finding had no impact on clinical outcome. Nonetheless, such high complication rates are unusual in orthopedic surgery. Although the nature of these complications (infection and implant malposition) suggests surgical and/or technical errors, it may highlight the difficult learning curve associated with this procedure, despite the availability of a precise, dedicated instrumentation designed to normalize surgical steps. Considering that most cases[16] were performed by a single surgeon (Burton N, personal communication, VOS meeting 2016.) it might be assumed that the remaining investigators may have contributed a substantially lower number of cases and, therefore, may have been in the early phase of the learning curve. As suggested previously, the limited number of cases performed by any given surgical group and the lack of objective outcome measures may contribute to the dearth of peer-reviewed publications. Conversely, the question is,

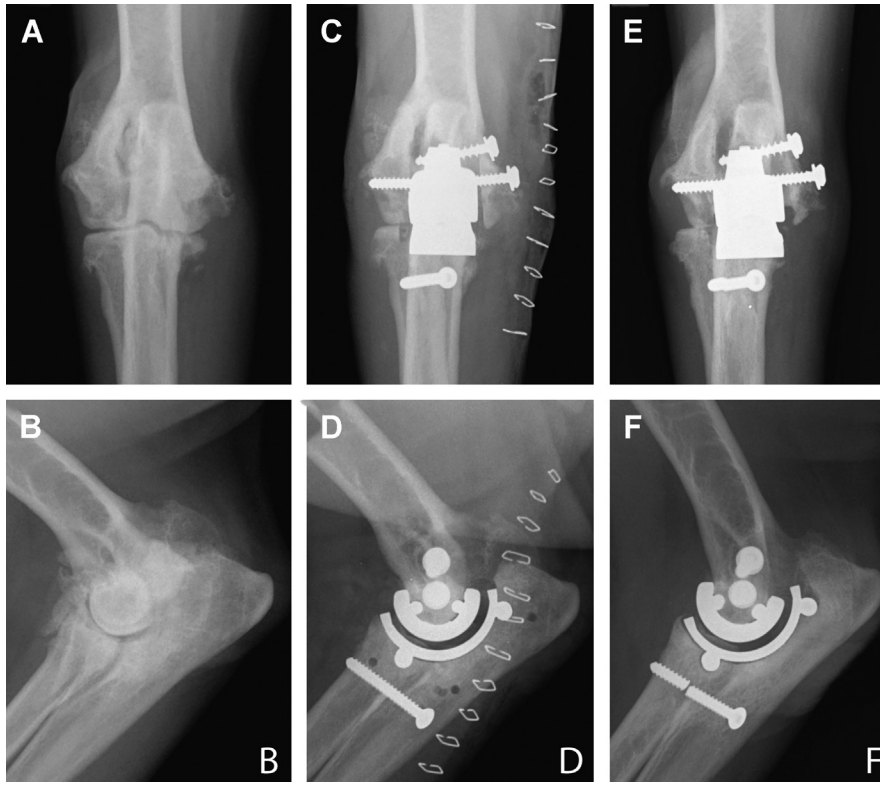

Fig. 29. Preoperative (*A*, *B*) and postoperative (*C*, *D*) radiographs showing proper positioning of a TATE prosthesis as well as the bone implant interface 21 months later (*E*, *F*). The proximal screws are used to stabilize the medial epicondyle. Lagged between the radius and the ulna, the distal screw is used to maintain stability during healing of a surgical RU synostosis. Note the fractured RU screw and the mild local bone resorption around the ulnar post. (*Courtesy of* L. Déjardin, DVM, East Lansing, MI. and BioMedtrix, Whippany, NJ.)

how might the compilation of a few cases from numerous sources affect the interpretation of the findings of the clinical reports?.

What follows is a synthesis of subjective data provided by fellow surgeons who have performed at least 5 procedures. The authors strongly emphasize that this information is anecdotal in nature and, therefore, should be assessed cautiously.

It is estimated that the TATE prosthesis has been implanted in approximately 250 cases worldwide since July 2007. In 2009[38] and then 2010,[39] the authors reported subjective data compiled through feedback from the 6 centers, where more than 5 cases had been performed (total of 73 elbows at the time). Three severe complications, consisting of 2 humeral fractures and 1 implant loosening, were recorded, all within 5 weeks postoperatively (rate of 4%). Of these, 2 cases were associated with secondary infection and 1 case with secondary ulnar fracture. Two cases were euthanized by the referring veterinarian without reevaluation by the primary surgeon, and 1 was amputated because of concomitant deep infection (**Fig. 30**).

Although recent biomechanical studies have demonstrated that implant intrinsic stability is lower in both TATE Elbow generations than in the Iowa State system (first

commercially available TER system), luxations have not been reported in any TATE cases. This finding suggests that weakening of the joint's passive constraints, as a result of lateral collateral ligament desmotomy during implantation of the Iowa State system, offsets the potential benefit (stability) of more congruent designs. Similarly, primary ulnar fractures, another complication seen with the Iowa State system,[30,40,41] have not been observed with either TATE Elbow generations.

A variety of minor complications, including pin migration, screw loosening, fracture and/or clinically inconsequential delayed union of the medial epicondylar fragment, skin dehiscence, and neuropraxia were seen in approximately 8% of the cases. Successful revisions consisted of pin removal, screw retightening, primary repair, and local wound care. Iatrogenic intraoperative complications due to surgical error (transection of the ulnar nerve and trochlear fracture) were described by Acker in 1 dog, which remains ambulatory nearly 3 years postoperatively.

The authors have limited knowledge of 20 additional cases treated elsewhere with the assistance of a trained surgeon. In that subgroup, the authors are aware of 4 severe complications (20%). Humeral fractures were reported in 2 cases, 1 of which was successfully repaired, whereas the other resulted in an amputation because of associated methicillin-resistant *Staphylococcus aureus* infection. The remaining 2 cases developed infection; 1 patient underwent successful arthrodesis and the other was lost to follow-up.

Since their 2010 report, to the authors' knowledge, approximately 45 and 10 additional cases have been treated with a TATE by the Acker (65 cases) and Michigan State University (20 cases) groups, respectively. Although no further postoperative major complications have been reported by Acker, clinical outcome on these cases is lacking. In 1 of the 10 additional cases operated by the authors' team, milling difficulties during surgery led to the presence a greater than 1-mm gap along the ulnar

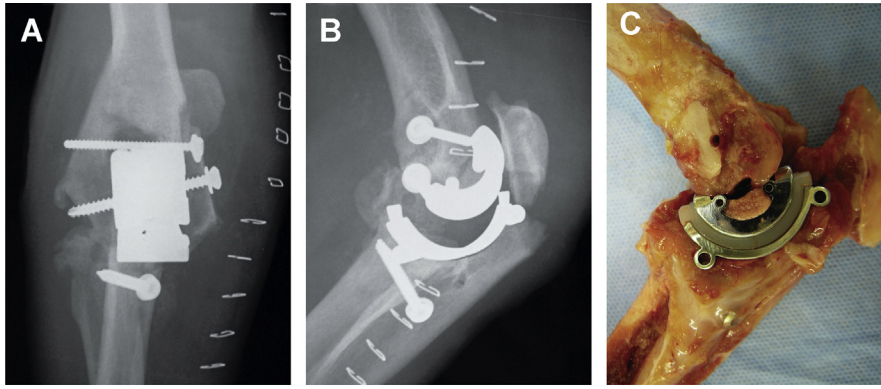

Fig. 30. Radiographs (*A*, *B*) and photograph (*C*) of a gross specimen 2 weeks after implantation of a TATE Elbow system. Failure occurred 7 days postoperatively and was attributed to an intraoperative technical error that resulted in iatrogenic widening of the axis of rotation drill hole at the center of the trochlea. Based on owner testimony, the authors believe that this led to an initial condylar fracture between the 2 humeral component posts, followed by an olecranon fracture during a sudden subsequent fall. Although osteosynthesis might have been attempted immediately after the fracture occurred, deep infection was present by the time we became aware of the incident. Because elbow arthritis was unilateral in this dog, amputation rather than arthrodesis was elected. (*Courtesy of* L. Déjardin, DVM, East Lansing, MI. and BioMedtrix, Whippany, NJ.)

bone interface of a first-generation TATE prosthesis. Limited osteointegration of the RU component was observed at 6 months and was followed by premature loosening, with debonding of the sintered beads along the RU/bone interface, 36 weeks postoperatively. Amputation eventually was performed 2 years postoperatively due to the lack of clinical improvement.

Objective data regarding functional outcome following TATE implantation still are lacking at this point in time. Subjective clinical evaluation from the authors' group (unpublished data on 21 elbows in 20 cases) suggest that limb function improves over time after an initial aggravation at 6 weeks to 12 weeks. Although dogs appear pain-free and show improved range of motion, mainly in extension, subtle to mild lameness may persist. These findings agree with those reported by De Sousa and colleagues.[37] As part of an ongoing prospective clinical study led by Michigan State University, objective force plate analysis is being conducted on 14 of these 20 dogs up to 6 years following implantation of a TATE Elbow system. In all cases, the peak vertical force of the affected front limb was significantly lower than the normal reported range of 105% to 125% of body weight at the trot.[42] By 6 months to 12 months following surgery, the peak vertical ground reaction force (PVGRF) of the operated limb was greater than that of the contralateral side. Continued improvement was seen at 2 years, as the peak vertical force of the operated limbs had returned to a normal reported value of approximately 115% of body weight. Although these data highlight the slow functional recovery following TATE Elbow replacement, it is worth noting that mean PVGRF of the operated side became significantly greater than that of the affected side approximately 1 year after surgery (unpublished, ongoing data collection).

Prospective experimental and clinical evaluations of the TATE Elbow system are ongoing and may provide some needed objective data in the near future. The objectives of this research program are to characterize functional outcomes and expectations further, to identify potential pitfalls, and, if deemed necessary, to refine the implant design and/or surgical technique.

Ongoing Design Evolution

Starting in 2019, BioMedtrix initiated the development of a third-generation TATE prosthesis along with a simplification of both instrumentation and surgical technique. Although this new design is fundamentally similar to that of the second generation, components modifications were introduced to improve immediate and long-term stability. These include (1) deformable fixation posts that can be expanded to enhance primary fixation and (2) EBM surface treatment of the titanium humeral and RU components intended to promote bone ingrowth (**Fig. 31**). Identification of the AOR as well as determination of the milling depth and amplitude originally were achieved using a condylar clamp and a caliper while the elbow was secured to the surgical table via an articulated positioning arm. Although effective, this instrumentation was relatively complex. The new, simplified instrumentation relies on CT based, 3-D printed, patient-specific instrumentation (PSI) to accurately identify the AOR and position the elbow joint (**Fig. 32**). Subsequently, the joint is locked in place using a modified alignment plate prior to milling at a depth predetermined from CT data. Finally, capitalizing on the total ankle replacement experience, the milling technique also has been refined. First, milling is conducted in 2 increments, starting with a narrower milling bit followed by a final size bit. The purpose of this stepwise approach is to enhance milling accuracy while reducing the risk of thermal damage to the bone and therefore promote osteointegration of the prosthesis. Second, the milling arm and alignment plate feature high-power magnets that provide a tight linkage between these instruments during

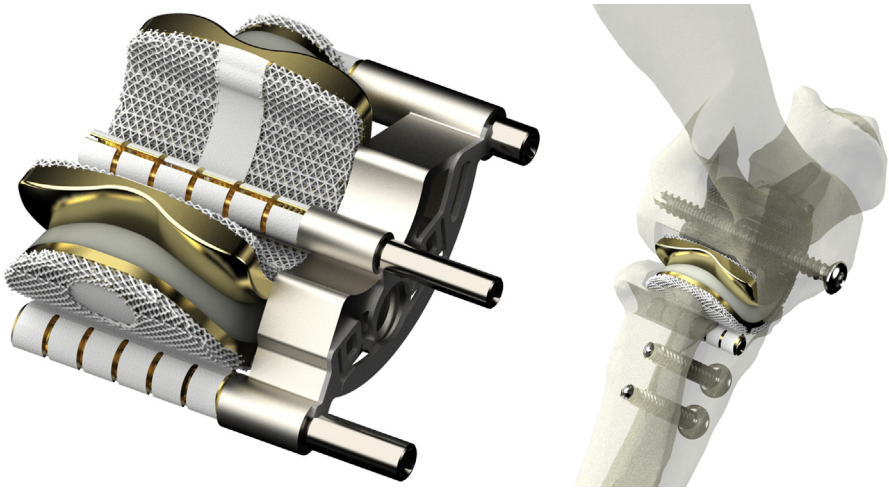

Fig. 31. Computer-generated image of the third-generation TATE prosthesis (*left*) and 3-D rendering of the prosthesis in situ. Although most design changes of the second generation were maintained, additional iterations were made to simplify the surgical technique while further improving primary and secondary fixation. The humeral component features a single-fixation post rather than 2 as in the second-generation TATE. To improve immediate stability, a cam system allowing expansion of the posts has been added. To promote bone ingrowth and, therefore, the long-term stability of the prosthesis, EBM now is used as a surface treatment of the titanium humeral and RU components. In addition, deleterious shear stresses at the RU bone/implant interface are reduced by eliminating prosupination using 2 RU lag screws to create a synostosis. (*Courtesy of* BioMedtrix, Whippany, NJ.)

milling (Sidebotham CG, personal communication, 2008). By virtually eliminating vibrations, precisely milled walls can be obtained reliably, which further improves the potential for rapid and successful osteointegration of the prosthesis. At this time, the third-generation TATE has been tested successfully in bone models and ex vivo specimens, and a limited clinical trial is ongoing at Michigan State University.

Limitations of Total Elbow Replacement

A major limitation of TER is the absence of effective revision options in cases of failure. Unfortunately, because end-stage elbow OA often is a bilateral condition, amputation is not a valid option in most cases, and arthrodesis remains the main alternative. Although some fractures or luxations may be repaired successfully, others may require explantation and arthrodesis because of the limited bone stock available for implant fixation or continuous joint instability. Infection is and likely will continue to be the most challenging complication because antibiotic therapy alone unlikely is effective as long as the prosthesis is implanted. As with intractable fractures and luxations, cases of infection might be treated by explantation and arthrodesis. Alternatively, in cases of unilateral end-stage OA, amputation may represent a safer alternative to arthrodesis. Although the purpose of arthrodesis is to eliminate pain, variable alterations in limb function, or even quality of life, should be considered carefully if painful contralateral ankylosis is present or in cases that may require bilateral elbow arthrodesis. With unilateral arthrodesis, however, limb function has been described as acceptable in most cases, despite continuous limb circumduction. Because of these limitations, owner education is critical and must be thorough and

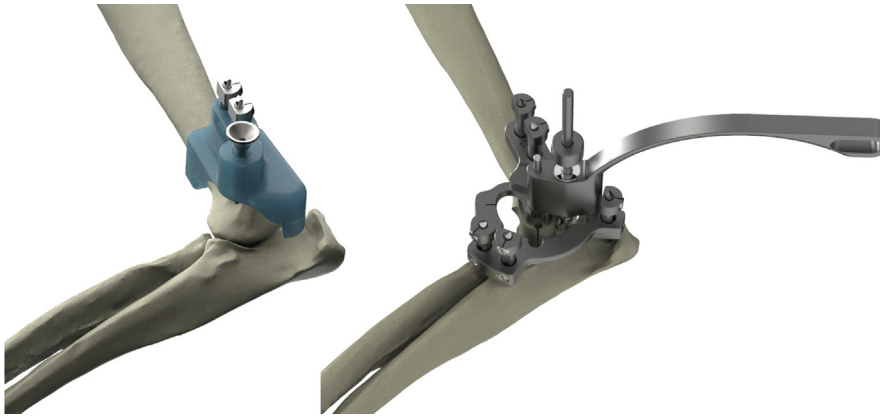

Fig. 32. A CT-based PSI is printed to improve identification of the joint axis of rotation. The PSI block (*left*) locks on the distal aspect of the humerus and features a guide hole accurately aligned with the axis of rotation. Milling accuracy has been enhanced by using high power magnets imbedded in the milling arm and alignment plate (*right*). The tight linkage between these instruments virtually eliminates vibrations during milling. As a result, precisely milled walls can be reliably obtained, which further improves the potential for rapid and successful osteointegration of the prosthesis.

objective. Fair disclosure of alternative treatments and realistic expectations, particularly with regard to complications and revisions, should be presented to anyone contemplating TER.

Despite an enormous amount of work from forward-thinking surgeons, such as Whittick, Chancrin, Lewis, Vasseur, Conzemius, Acker, and others, as well as engineers, the ideal prosthetic design remains elusive. Based on early experiences and failures, however, substantial improvements in both design and surgical procedures have been made in recent years. Nonetheless, questions regarding optimal articular surface constraint and long-term periprosthetic osteolysis or osteointegration remain unanswered. Similarly, long-term objective clinical trials and retrieval analyses are desperately needed. Furthermore, limited revision options will continue to constitute one of the most serious hurdles to be overcome in the foreseeable future. Although further advancements are required before TER gains widespread acceptance as a reliable treatment option for end-stage elbow OA in dogs, novel ideas and promising, although imperfect, clinical results likely will continue to generate interest and much needed research in this open and challenging field.

SUMMARY

The elbow joint is a complex joint. Erosion of the articular cartilage of the medial compartment, resulting in DJD and OA secondary to incongruity associated with elbow dysplasia or trauma, is the most common cause of lameness of the forelimb of mature dogs in the authors' orthopedic practices.

In cases of early detection and mild cartilage loss (modified Outerbridge scores of I–II), PAUL and SHO have shown to decrease or even reverse arthroscopic evidence of cartilage loss. In more advanced, severe irreversible cartilage loss and DJD (modified Outerbridge scores of III–IV), resurfacing with CUE, partial elbow joint replacement

(eg, BANC), or total joint replacement (eg, TATE) may be a more appropriate consideration.

External beam radiation has had some positive effect in palliating signs of elbow OA/DJD in the short term.[43] Recently, conversion electron therapy that targets macrophages and synoviocytes delivered by intra-articular injection (Synovetin OA) has been approved for use in dogs with elbow OA with a proposed benefit of up to 1 year.[44] Although these treatment modalities may benefit patients that are not considered good surgical candidates, long-term results are not published for either.

CLINIC CARE POINTS

- Erosion of the articular cartilage of the medial compartment of the elbow secondary to incongruity associated with elbow dysplasia or traumatic injury has been termed, *MCD* or *medial compartment syndrome*.
- Mild to moderate cartilage loss may be managed successfully with PAUL or SHO by shifting the weight-bearing axis more laterally.
- In severe cases of cartilage loss of the medial compartment, management with resurfacing by CUE or PER with the unicompartmental BANC prosthesis is more appropriate.
- TER may be warranted in cases of severe and end-stage OA or global cartilage loss.
- External beam radiation and intra-articular conversion electron therapy may be short-term options for improving comfort in patients not deemed suitable for surgical management.

DISCLOSURE

K.L. Wendelburg holds a US patent for the Unicompartmental Partial Elbow Replacement System and Surgical Technique as well as honoraria from KYON for teaching the surgical technique.

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