Over the last 20 years, the limited success of conservative management and arthroscopic surgeries to treat elbow osteoarthritis (OA) has stimulated a growing interest in the development of total elbow replacements (TER). The elbow is arguably the most complex joint in the body and thus inherently difficult to replicate. Implant designs, up until the last few years, were based upon a limited collective knowledge of the biomechanics and kinematics of the elbow. As a result, the “successful” implants were designed to achieve no more than basic function (i.e. flexion and extension) and at best, “salvage” a limb. However, over the last few years significant research has been done to improve our understanding of the kinematics and biomechanics of this joint and advancements have been made in prosthetic designs.

The 90’s saw the first attempts at developing TER systems. BioMedtrix designed a 3-component implant, retaining pronation and supination, that was later passed on to Vasseur. Ultimately this implant did not make it to clinical trials and was abandoned. Lewis reported on the use of a cemented hinge design in ten clinical cases, which had little to no success. Lewis continued to revise his design arriving at a 3-component semi-constrained system but was never able to achieve consistent positive results. Conzemius begin clinical testing on the Iowa State Elbow, a cemented 2-component semi-constrained design, which eliminated pronation and supination and reduced the complexity of the joint to its fundamental motion, flexion and extension. The Iowa State Elbow was further refined through the early 2000’s and became the first commercially available TER in the veterinary market. In 2008, Acker reported satisfactory results on a biologically fixed 2-component design, known as the Tate Elbow™, on six (6) clinical cases with end-stage elbow OA. The Tate was also licensed by BioMedtrix and released in 2009 to a select group of surgeons. The instrumentation and implants of the Tate System have been continually improved and updated with a 3-component and unicompartmental design in development.

![Figure 1: (A) BioMedtrix/Vasseur, (B) Lewis Elbow, (C) Iowa State Elbow, (D) Tate Elbow™.](image)

As our understanding of OA in the elbow has advanced, attempts have been made to develop medial unicompartmental replacements in an attempt to deter the progression of OA from the initial onset. Cook and Schulz, working with Arthrex, developed the Canine Unicompartmental Elbow (CUE) which functions much like an Osteochondral Autograft Transfer System (OATS), but with metal and polyethylene implants substituted for...
osteochondral autograft. Another medial unicompartmental system is currently under development by Wendelburg and Tepic and is currently undergoing clinical testing (Wendelburg 2011).

A comprehensive understanding of the elbow anatomy entails not only an understanding of the articular surfaces but also the periarticular tissues; specifically, the ligaments, musculature, nerves and vasculature. The elbow can be described as a complex trochleoginglymoid joint encompassing three articulations: the humeroulnar, humeroradial and radioulnar. These articulations, comprised of the articular surfaces of the humeral condyle (e.g. trochlear and capitulum), the radial head and the cranially facing semilunar notch (e.g. trochlear notch, coronoid process and anconeal process) of the ulna are highly congruent and subtly complex (Figure 2). The elbow is further supported by the addition of a number of ligaments, the most important being the collateral ligaments for joint stability. Although the musculature, nerves and vasculature may not play an obvious role in the design of the articular surfaces of an implant, they can dictate the surgical approach and thus how an implant may be placed.

![Figure 2: Cranial and lateral views of the elbow joint.](image)

Understanding the biomechanical function of any joint is critical in order to design a dependable prosthesis. Until recently our understanding of the biomechanics of the canine elbow was quite limited, but that is slowly changing. Only recently have studies been done utilizing modern technologies, such as dynamic RSA and 3D reconstructions from CT scans, which allow for a focused analysis of the functional kinematics of the individual bones of the elbow.

Where veterinary research is lacking it is sometimes necessary to draw to draw correlations from research done in the human field within reason. The axis of rotation of flexion and extension has proven to be a critical feature in the human elbow as it exhibits very little variation through a complete range of motion. Therefore, any implant design concerned with balancing the surrounding soft tissues (e.g. semi-constrained joint replacements) must accurately and consistently replicate this axis in order to achieve a functional range of motion free of conflict. Another correlation can be made between the canine elbow which, like the human
knee, has a naturally occurring varus angulation^4. This inherently does not pose a problem unless one of the primary joint stabilizers (e.g. articular surfaces, lateral collateral ligament, anconeal process, etc.) is compromised at which point, there could be an excessive loading in the medial compartment.

Joint stability can be broken down into two different facets: intrinsic stability, which is provided by the shape of the articular surfaces and extrinsic stability, which is provided by the periarticular soft tissues. The intrinsic stability of the elbow is substantial compared to other joints such as the knee or shoulder due to the trochlear features of the humerus and ulna and specifically, the anconeal process. The primary extrinsic stabilizers in the elbow are the MCL, the LCL, and the anconeal process.

An ideal elbow replacement is designed to provide the patient with a pain-free joint that kinematically and mechanically replicates the original articulation. The veterinary community has seen designs ranging from fully-constrained, cemented, hinged prostheses to minimally invasive, biologically fixed, resurfacing implants. Every joint, in this case the elbow, has its own “window of acceptance.” To fall within that window, the designer must consider the following: the articular surface as it relates to motion and stability, available biomaterials, methods of fixation; how to reestablish the natural limb alignment; and how to design the implant to work in concert with the periarticular soft tissues.

The articulation of any joint replacement is a complicated balance between three intertwined factors: (1) joint kinematics, (2) intrinsic stability, and (3) implant wear potential. These are fundamentally accomplished through a compromise between conformity (how geometrically similar the two surfaces are) and constraint (how restrictive the two surfaces are in relative motion) (Figure 3). Furthermore, the relative motion of the prosthetic components are balanced with the surround soft tissues of the joint in order to minimize the stresses imposed on the bone-implant interfaces.

![Figure 3](image.png)

**Figure 3:** The image above depicts three different potential articular surfaces decreasing, from left to right, in constraint and conformity.

In an attempt to simplify the implant design, the articulation between the radius and ulna (i.e. pronation and supination) has been eliminated in several implant designs. While there are benefits to a radioulnar synostosis — the reduction from a three- to a two-component design and the resulting simplification of the surgery — there are also drawbacks. The decision to fuse the radioulnar articulation is a critical decision in the implant design process and is done with the knowledge of compromising motion for the simplification of the implant and the surgical technique.

Methods of implant fixation can be divided into two techniques: cemented fixation or biologic fixation. Biologically fixed implants have a provisional method for achieving the postoperative stability necessary to create an environment favorable to bone in-growth. For example, this is done through an interference fit, or press-fit, between the posts and the bone in the Tate Elbow, or by screw fixation in other designs. Due to the complexity and functional
demands placed upon the TER the veterinary community over the last 20 years has seen an array of different fixation methods: cemented, biologically fixed, cemented with biologic fixation, screw fixation, etc. Each method attempting to achieve the same goal, long lasting implant stability.

Reestablishing limb alignment is common procedure in many joint surgeries, in the elbow it is no different. The early stages of elbow osteoarthritis tend to be isolated or concentrated in the medial compartment. Ultimately, as a result of medial articular cartilage erosion, there is a resulting increase in the naturally occurring varus angle. This varus increase compounds the osteoarthritic changes in the medial compartment simultaneously offloading the lateral compartment, forcing the trochlea of the ulna to function like a fulcrum. This “snapshot” of the progression of elbow OA is what is now commonly referred to as, medial compartment disease (MCD). Correction of this angular deformity is necessary to achieve optimal limb function.

The supratrochlear foramen of the distal humerus creates a unique challenge for an implant design. Its role, as the opposing feature to the anconeal process as the elbow goes into full extension, functions as one of the primary stabilizers of the joint and adapting this critical to long term stability of TER. The veterinary community has seen this dealt with in a couple of different ways. Ultimately, if one of the primary stabilizers of the elbow is eliminated the remaining intrinsic and extrinsic stabilizers must compensate for this loss which could lead to a number of complications not short of luxation or implant loosening.

Although much remains to be learned, there have been great strides made in establishing a better understanding of elbow kinematics and biomechanics in recent years. With these advances will come a more suitable foundation for the development of prosthetic implants designed to manage not only end-stage but early OA (i.e. MCD) as well.

REFERENCES