The Rise of the Metal Elbow

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Abstract

Painful arthritis of the elbow joint has long been a challenging problem. Elbow arthroplasty has emerged as a viable treatment method for many patients. Implant design and surgical technique have evolved to provide more predictable symptom relief without compromising function. Elbow arthroplasty can now be used to treat a wide variety of conditions, including osteoarthritis, rheumatoid arthritis, and fractures. This review article presents historical and contemporary perspectives on elbow arthroplasty. A thorough discussion of implant design, surgical technique, and clinical outcomes is presented.

The evolution of the elbow can be traced back 20 million years. This evolution has led to a modified hinge joint that allows for motion in both the coronal and axial planes. These actions, along with the shoulder, allow the hand to be positioned in space for functional use. The elbow joint is comprised of three articulations: the radiocapitellar, proximal radioulnar, and the ulnotrochlear. While these articulations provide some intrinsic stability, the majority of the joint stability is reinforced by the surrounding soft tissues.

Complaints about the elbow are often secondary to trauma. The elbow is very susceptible to stiffness when injured, and even minor trauma can lead to serious consequences, such as permanent loss of motion. Primary osteoarthritis of the elbow, on the other hand, is a relatively uncommon problem. When present, it can be a challenge to treat. Similar to arthritis affecting other joints, pain is the predominant presenting symptom. Although not commonly considered a weightbearing joint, static loading forces about the elbow can equal three times body weight, and dynamic loading can equal six times body weight. Therefore, patients who are subjected to higher force loads, such as heavy machine operators, weightlifters, labors, and overhead athletes, are more prone to develop osteoarthritis of the elbow. Osteophyte impingement is the culprit for the initial symptoms often seen in osteoarthritis. Interestingly, the articular cartilage and the joint space may be preserved. In the later stages of osteoarthritis, the elbow loses more mobility, and pain is present even during the mid-arc of motion (Fig. 1). Primary osteoarthritis of the elbow constitutes less than 2% of all elbow arthritis cases. Therefore, the majority of the patients who have arthritis of the elbow are those with either rheumatoid or post-traumatic arthritis. About 20% to 60% of all patients with rheumatoid arthritis have involvement of the elbow. This usually presents within 5 years of disease onset.

Alleviation of pain with functional range of motion is the goal of treatment for patients with symptomatic arthritis of the elbow. When nonoperative treatments have failed, total elbow arthroplasty (TEA) may provide an effective treatment option. A study by Day and coworkers investigated the trends and projections of both shoulder and elbow arthroplasty within the United States for the year 2015. Surprisingly, they found the annual growth rates for total elbow arthroplasty to be comparable to total knee arthroplasty. They also noted that higher revision rates could put a financial strain on the population. Therefore, advancements in the design, indications for use, and surgical techniques of total elbow arthroplasty may be of greater emphasis in the near future.

Historical Perspective

Total elbow arthroplasty was developed in response to the failures of previous procedures in the treatment of elbow arthritis. This included resection arthroplasty (removal of the
Articular surfaces of the ulna and humerus) and interposition arthroplasty (placement of a soft tissue graft between the articular surfaces of the ulna and the humerus). Resection arthroplasty was originally performed as a salvage procedure for elbow infection (i.e., tuberculosis). Interposition arthroplasty with various autologous tissues (e.g., fat, muscle, tendon, or fascia) was initially described in 1893 by Schüller. This technique was popularized in the early 20th Century by Putti, among others. Both procedures yielded unpredictable results. Therefore, these procedures are currently used in only select patient populations.

From the late 1940s through the 1960s (before the use of methacrylate bone cement and polyethylene bearing surfaces), surgeons began implanting custom-made constrained hinged metal devices. These implants relied on both extracortical and intramedullary implant fixation. The outcomes were poor with unacceptable rates of loosening and instability. Recognition that constrained hinge designs were failing led surgeons to develop surface replacement hemiarthroplasty implants for the distal end of the humerus and the proximal ulna. These included designs by Venable and later by Barr and Eaton. Unfortunately, these early elbow designs were also marred by instability, loosening, recurrent pain, and overall poor function.

The “modern era” of total elbow arthroplasty started in the early 1970s. The “Dee” prosthesis had several modifications from the hemiarthroplasty device such as polyethylene bearing surfaces and modest degrees of constraint. The ground breaking feature, however, was the initial use of methacrylate bone cement. It was found that satisfactory pain relief could be provided to patients with arthritis by replacing the elbow joint with a hinged prosthesis. Unfortunately, the fully constrained hinge design transferred stress directly to the bone-prosthetic interface and in time, resulted in high rates of aseptic loosening and prosthetic failure.

Non-constrained prostheses were developed in an attempt to address this problem of early aseptic loosening. Dr. Roland Pritchard was one of the first surgeons to recognize the value of a loose hinge joint with a polyethylene bushing. This implant design aimed to reduce stresses on the bone cement interface and relied on the native soft tissue for stability. Perhaps due to difficulties in maintaining a competent soft tissue envelope during surgery, a relatively high incidence of postoperative instability was reported in some series.

In 1971, Dr. Ralph Coonrad developed a total elbow arthroplasty system with a focus on the coronal plane articulation. The design required less bone resection and placement of a collared polyethylene bushing. This design...
was further modified by Dr. Bernard Morrey, and the result was the Coonrad-Morrey implant (Zimmer, Warsaw, IN), which was a semiconstrained device that permitted 7° to 10° of laxity. In addition, an anterior flange was added to the humeral component to improve stability against the anteroposterior and rotational forces about the prosthesis. Newer designs of the Coonrad-Moorey prosthesis have notably decreased the previously reported high complication rate for total elbow arthroplasty. In addition, reports of total elbow arthroplasty in rheumatoid arthritis patients, regardless of the updated implant design, have shown a 92% survival rate at 10 years after replacement.

**Implant Design and Options**

There are a variety of total elbow arthroplasty implant designs currently on the market. The use and performance of these implants vary based on multiple factors, which include the nature of the arthritis, integrity of the surrounding soft tissues, residual bony deformity, and surgeon preference. Modern total elbow arthroplasty is generally separated into one of three designs: constrained, semiconstrained, or nonconstrained. In addition, the recently-developed “convertible” or “modular” prosthesis allows the option or conversion between semiconstrained and nonconstrained joints.

Constrained implants, such as the Swanson and the Gschwend prosthesis, impart coronal stability by limiting motion to flexion and extension. This design has fallen out of favor due its unacceptable rates of periprosthetic loosening and subsequent implant failure. As the prosthesis only allows motion in one plane, rotational and angular moments are believed to be transmitted as shear stresses to the implant bone interface. Severe bone loss often accompanies such loosening, making salvage and revision surgery difficult.

Semiconstrained implants have a “sloppy hinge” to provide inherent stability to the ulnohumeral articulation while allowing controlled laxity to varus and valgus and to internal and external rotation. The “sloppy hinge” allows the soft tissues to partially absorb the external stresses that would normally be concentrated at the bone prosthetic interface. The implants are coupled together with pins or snap-fit polyethylene bushings to provide some inherent stability. This stability, in turn, allows these implants to be used for a wide variety of elbow conditions when the soft tissues are deficient. Popular semiconstrained implants include the Coonrad-Morrey (Zimmer, Warsaw IN), Discovery (Biomet, Warsaw, IN), and the GSB III (Zimmer).

Nonconstrained prostheses rely on both the integrity of the surrounding soft tissues (capsule and ligaments) and the bearing surfaces for articular stability. There is no mechanical linkage between the humeral and ulnar components. Therefore, these designs require intact or repairable ligaments and normal bony anatomy for optimal outcome. The advantages include the preservation of bone stock, decreased polyethylene wear, and the preservation of physiologic elbow kinematics. Some examples of nonconstrained implants include the Kudo elbow (Biomet, Warsaw, IN), the Souter-Strathclyde elbow (Howmedica, Rutherford, NJ), the IBP elbow system (Biomet, Warsaw, IN), the Pritchard ERS (Depuy, Warsaw, IN), and the capitellocondylar (Ewald) implant (Johnson and Johnson, New Brunswick, NJ).

The convertible prosthesis allows the surgeon the flexibility to perform an isolated hemiarthroplasty, an unlinked nonconstrained, or a linked semiconstrained construct. This provides the versatility to address both intra- and postoperatively, the varying pathologic conditions of the elbow. The conversion can be done without the need to remove a well fixed components and maintaining bone stock. If late conversion is required, it can also be performed in a minimally invasive manner. Currently, there are several convertible implants that include the Latitude Elbow (Tornier, Edina, MN) and the Acclaim prosthesis (Depuy, Warsaw, IN).

**Indications**

Relief of pain is the primary goal of total elbow arthroplasty. Gallo and associates enumerated the following considerations in the preoperative evaluation for total elbow arthroplasty: 1. the condition of the skin envelope and previous surgical incisions; 2. osseous deformities, such as malunion, nonunion, and potential lack of bone stock; 3. location of ulnar nerve; 4. adequacy of ligamentous restraints, such as lateral collateral and medial collateral ligaments; 5. previously-implanted hardware; and 6. heterotopic ossification. These criteria will help determine the approach and implant used.

Advanced rheumatoid arthritis is the most common indication for total elbow arthroplasty. However, with the advent of disease modifying pharmacologic agents, the incidence of TEA in this group of patients may be decreasing. Other indications include comminuted distal humerus fractures, fracture nonunion, gross instability, tumors, and osteoarthritis (primary and post traumatic). In general, total elbow arthroplasty is indicated for the elderly patient for whom other treatment measures have failed and who are able to comply with the postoperative protocols. For the younger and more active patient, other salvage options, such as interpositional arthroplasty or elbow arthrodesis, may have to be considered. Interpositional arthroplasty, if needed, can then be converted to a TEA at a later time.

Contraindications to TEA include active or recent infection, inadequate soft tissue envelope, flaccid paralysis of the affected arm, non-restorable function of the biceps and triceps, and a neuropathic elbow joint. Poor patient compliance with activity and weight-lifting restrictions (such as avoidance of lifting objects greater than 10 pounds and repetitively lifting greater than 2 pounds) is also a primary contraindication. Furthermore, for the nonconstrained designs, competent soft tissues and adequate bone stock are required for optimal outcome.

**Surgical Techniques and Postoperative Rehabilitation**

A posterior skin incision, with large subcutaneous flaps, is commonly used to approach the elbow joint. Management
of the triceps tendon varies depending on implant design and surgeon preference. It can be reflected, split, or released. Regardless of the individual approach, the triceps must be mobilized to allow full exposure of the elbow joint. In addition, its function must also be restored at the end of the procedure for optimal outcome.40 Following triceps mobilization, the ulnar nerve is then identified and mobilized. There is no consensus in the literature regarding ulnar nerve transposition.41,42 Most surgeons recommend that the ulnar nerve be identified, mobilized, and transposed anteriorly prior to exposing the elbow joint.41,43

The factors that affect postoperative rehabilitation include the type of implant, condition of the soft tissues, and overall joint stability. Strict guidelines on lifting restrictions are emphasized throughout the rehabilitation course. The semi-constrained prosthesis tends to be more stable than its non-constrained counterpart, and therapy may proceed without any strict restrictions. Therefore, many patients require little or no supervised physical therapy after a semi-constrained TEA.44 Therapy following a nonconstrained arthroplasty is dependent on the integrity of the soft tissue constraints. If stability is a concern, patients are restricted from extending past 40° of elbow flexion initially; this restriction gradually is eased.44,45 If patients do not meet their prescribed goals for extension, then extension splinting can be considered. Regardless of the implant type, active forearm rotation exercises are performed with the elbow in 90° of flexion to protect the collateral ligaments.44 For the patient whose triceps had been detached and repaired during the surgery, active extension against resistance is avoided for the first 4 to 6 weeks.

Recent Clinical Outcomes

**Semi-constrained vs. Non-constrained**

There have been numerous publications reporting the clinical outcomes associated with a variety of total elbow arthroplasty designs. However, only a few studies directly compare the outcomes between specific designs of TEA. Prasad and Dent,46 for example, compared the results of the Souter-Strathclyde (nonconstrained) and the Coonrad-Morrey implant (semi-constrained) for the treatment of rheumatoid arthritis performed by a single surgeon. Both groups had similar postoperative Mayo elbow performance and patient satisfaction scores. However, the nonconstrained group had survivorship of 92% at 5 years and 76% at 10 years compared with 100% for the semi-constrained implant at 5 years. Similarly, Little and colleagues47 compared the results of three commonly used implants in patients with rheumatoid arthritis. The clinical performance of all implants was similar for pain relief and range of motion. However, the survivorship of the Coonrad-Morrey semi-constrained implant (90% at 5 years and 86% at 10 years) was better than the Kudo nonconstrained (85% and 81%) and Souter nonconstrained (93% and 82%) systems. Therefore, these investigators concluded that semi-constrained design provided joint stability without raising the risk of aseptic loosening.

**Convertible**

Literature evaluating the outcomes of the convertible elbow prosthesis is limited. Naqui and coworkers48 performed a retrospective review of the Acclaim (DePuy, Warsaw, IN) prosthesis in an elderly patient population with primary osteoarthritis. They found significant reductions in pain and improvement in motion and function after 57 months follow-up. Radiographic review demonstrated minimal rates of radiolucency around the components, and no components required revision. Bassi and associates also investigated the short-term outcomes of the Acclaim prosthesis.49 and reported that all but one patient had improved movement and function after 36 months of follow-up. No implant showed clinical or radiological evidence of aseptic loosening. Interestingly, 11 of the 36 patients (30.5%) sustained an intra-operative fracture of the humeral condyle. Though this complication did not seem to affect the overall outcome, the humeral resection guide has since been redesigned.

**Young Patients (Less than 40 Years Old)**

Celli and Morrey reported on 55 patients (mean age, 33 years) who underwent total elbow arthroplasty with a Coonrad-Morrey semi-constrained prosthesis for the treatment of either posttraumatic or inflammatory arthritis at a mean follow-up of 91 months.50 During this period, 12 (22%) of the elbows had undergone a subsequent surgical procedure: 4 due to loosening, three due to triceps weakness, 3 due to excessive wear, and 2 due to deep infection. Despite these complications, 93% of the patients had a good or excellent Mayo Elbow Performance Score at the latest follow-up. Demiralp and colleagues51 reported on the 8 to 12 year follow-up of total elbow arthroplasty (semi-constrained) in seven young patients (average age 23 years old) who were treated for open comminuted intra-articular elbow fractures due to gunshot injuries. Five of the 7 elbows had a poor result; two patients had prosthetic loosening from deep infection and another three patients had aseptic loosening that necessitated re-operation. The prosthesis was removed in all cases. These results suggest that total elbow arthroplasty in young patients must be considered with significant caution and thorough patient counseling.

**Distal Humerus Fractures**

Total elbow arthroplasty has recently gained popularity as a viable treatment option for acute, displaced, and comminuted intra-articular fractures in the elderly. Cobb and Morrey were the first to report on this indication.52 However, their study population included 48% of patients with rheumatoid arthritis who were likely to be suffering from degenerative changes to the joint even before the fracture.

Frankle and coworkers retrospectively compared outcomes after open reduction and internal fixation (ORIF) versus primary total elbow arthroplasty in the treatment of
distal humerus intra-articular fractures in the elderly. At 4.5 years follow-up, the investigators noted excellent results in 91% of the TEA patients compared to only 33% in the ORIF group. In a recent, level one evidence, prospective randomized trial, McKee and associates similarly reported that the Mayo elbow performance score and the DASH scores were better in the group of patients who were treated with TEA for their intraarticular distal humerus fractures. At 2 years of follow-up, this improvement in outcome was still noted for the TEA group, but the difference was no longer statistically significant.

**Complications**

Despite the relatively good clinical outcomes reported in the literature, there continue to be concerns about total elbow arthroplasty. This is not without reason, as complications have been reported to be as high as 20% to 45% in some long-term follow-up studies. Even in the short-term, a recent study by Krenek and colleagues reported inpatient complications to be over 10%, with almost 8% requiring reoperation within the first 90 days.

Deep infection is a potentially catastrophic complication following total elbow arthroplasty occurring in 1% to 12% of cases. Infection after elbow arthroplasty can be partially attributed to the use of immunosuppressive drugs in rheumatoid patients. Based on Morrey’s experience with infected TEA, the most common pathogens were Methicillin-sensitive *Staphylococcus aureus* (29.4%), multi-organism (19.6%), and *Staphylococcus epidermidis* (17.6%). For acute infections (less than 6 weeks), irrigation and debridement with retention of components and a 6 week IV antibiotic course may yield successful results. However, Yamaguchi and coworkers found that the virulence of the bacteria plays a large role in determining treatment. The majority of their patients whose elbows were infected by *Staphylococcus epidermidis* failed if they were treated with irrigation and debridement with retention of the components. For chronic infections, a two stage revision with removal of the prosthesis, insertion of a polymethylmethacrylate spacer, and replantation of a total elbow replacement after a 6-week intravenous antibiotic course and negative cultures is the current recommended treatment.

The most common long-term complication following TEA is aseptic loosening (Fig. 2). In comparison to other prosthetic joints, TEA may be more prone to catastrophic failure due to its smaller stem. The loosening rates appear to correlate directly with increasing constraint of the prosthesis. Thus, for example, the 5 year loosening rates for the constrained, semiconstrained, and nonconstrained implants are 25% to 51%, 6% to 17%, and 10% to 15%, respectively. Ulnar components fail in 2% to 5% of cases. Articulation failures, including pins or articular bushings, can occur in up to 5%. Humeral stem failures are believed to be less common because the distal humerus usually fractures before the stem fatigues.

Other complications of TEA include heterotrophic ossification, joint instability, triceps insufficiency, articular bushing wear or failure, and ulnar neuropathy. TEA instability is most often seen in the unconstrained prosthesis and rarely needs treatment if asymptomatic. Recommendations for avoiding instability include: 1. appropriate tension in the medial collateral ligament, 2. secure repair of the lateral collateral ligament, 3. preservation of the anterior capsule, and 4. preservation or reconstruction of the triceps. Revision to a semiconstrained prosthesis is an option for recurrent instability. Triceps insufficiency is a relatively common

![Figure 2](image-url) Anteroposterior and lateral radiographs of the elbow demonstrating aseptic loosening of a semiconstrained total elbow prosthesis.
complication and is probably under reported in the literature. In general, it can be tolerated by most patients but can be reinforced with an anconeus slide or Achilles tendon allograft if symptoms remain significant. The increased longevity of TEA has led to increasing incidence of polyethylene bushing wear. The bushing wear can be treated with isolated bushing exchange with good results. Ulnar neuropathy presents as a complication in 5% to 10% of total elbow replacements and usually manifests as paresthesias without motor weakness. Management can include neurolysis and transposition. Lastly, periprosthetic fractures are relatively uncommon complications following total elbow arthroplasty.

Revision Surgery and Salvage

Revision of a failed elbow implant is a technically difficult procedure. Patients generally fall into one of two categories: those with sufficient bone stock and those with bone deficiency. Removal of a well-cemented prosthesis is a challenge, and prosthetic re-implantation is only indicated when the residual osseous integrity is capable of maintaining a circumferential bone cement interface for stability. In cases with significant bone loss, several techniques can be used. These techniques include impaction grafting, allograft strut grafting, and incorporation of a semiconstrained prosthesis with multiple sizing options (Fig. 3).

Elbow fusion may be difficult to achieve after a failed TEA and is rarely indicated. Further complicating the issue, multiple studies have demonstrated that there is no ideal position for achieving fusion of the elbow. The loss of elbow motion cannot be effectively compensated by other joints, such as the shoulder, which further downgrades its utility. Furthermore, arthrodesis is not indicated for the patient with bilateral elbow disease as the functional limitations may be too great.

Elbow resection is a salvage procedure typically reserved for difficult cases where a prosthesis cannot be inserted (e.g., significant bony defect or residual infection). In 12 young patients with posttraumatic bone loss, Hahn and coworkers demonstrated that resection arthroplasty was associated with excellent outcome in 3 patients, good outcome in 6, fair outcome in 2, and poor outcome in 1 patient. Therefore, despite its limitations, these investigators recommended resection arthroplasty over arthrodesis even in young patients. The long-term effects of resection arthroplasty following failed TEA were similarly investigated by Zarkadas and colleagues. Their study involved 51 consecutive elbows that were treated with resection arthroplasty for a deep infection following TEA. Twenty patients had either died or refused follow-up. The remaining 30 elbows in 29 patients were contacted at an average of 11 years, and they found 8 had good results, 11 with fair results, and 11 with poor results. Therefore, the conception that elbow resection inevitably leads to a flail elbow with poor function is not supported by the results of these studies.

Conclusions and Future Considerations

Recent literature has better defined the performance and longevity of various total elbow arthroplasty designs. Overall, long-term outcome studies demonstrate satisfactory outcome in over 50% of cases 10 to 14 years after TEA. Most patients report good to excellent pain relief and good functional use of the joint. Nevertheless, further research is necessary to better refine surgical indications, implant de-

Figure 3 Anteroposterior and lateral radiographs of the elbow demonstrating revision of the failed semiconstrained implant from Figure 2. The construct has been augmented with allograft strut bone graft to provide additional structural support.
sign, and surgical techniques to improve the overall outcome and to minimize the rate of complications.

**Disclosure Statement**

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**References**