Arthroplasty of the Upper Extremity

A Clinical Guide from Elbow to Fingers

Graham J. W. King
Marco Rizzo
Editors

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I dedicate this book to my loving and supportive parents Ian and Ethelwynne; my beautiful wife and soul mate Denise; and my three amazing children Stephanie, Leanna, and Ian who provided me the opportunity, encouragement, and inspiration for this and many other projects that I have pursued during my "spare time." I am also grateful to my mentors Robert McMurtry, Cyril Frank, Bernard Morrey, and James Roth for their wisdom, guidance, and wise council.

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I would also dedicate this to my family: my wonderfully supportive and loving wife and daughter: Hope Marie and Hope Sol Rim without whom I would be lost. Thank you for encouraging and allowing me to pursue this work and the many others throughout my career. I remain indebted to your love, patience, and kindness. Special thanks also to my parents Nazario and Maria who've sacrificed so that I may have opportunities. Their love and example remain an inspiration. Thank you also to the mentors who've trained me: William Hardaker (1942–2015), teacher and mentor extraordinaire, who saw enough in me to give me a chance in orthopedics; James Urbaniak, for showing me the value and beauty of academic medicine; Richard Goldner, for demonstrating how dedicated, patient centered, and caring a surgeon can be; and Robert Beckenbaugh (1941–2020) for inspiring, teaching and nurturing my passion for arthroplasty.

Marco Rizzo, MD
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Preface

Arthritis of the upper extremity often results in significant pain and disability. Arthroplasty of the arthritic elbow, wrist, and hand relieves pain, preserves motion, and improves function. While the experience in upper extremity arthroplasty is less extensive than those of the hip and knee, when successful, these procedures can be very rewarding for patients. The aim of this book is to guide practicing upper extremity surgeons, trainees, and therapists on the contemporary arthroplasty management of arthritis of the elbow, wrist, and hand.

The genesis of this book dates back to 2018. We were invited by the program chairs of The American Society for Surgery of the Hand Annual Meeting to co-chair a pre-course titled Arthroplasty: Elbow to Fingertips. We divided each joint into three parts: (1) design considerations, (2) primary arthroplasty, and (3) revision/failed arthroplasty. We invited national and international experts to participate and were delighted at their positive responses and enthusiasm for this endeavor.

The pre-course was a great success and sparked the interest of the representatives from Springer to create a book related to this subject matter. Given the success we experienced with the pre-course, it made sense to have the book mirror the same outline. Thankfully, most of the meeting presenters were able to contribute chapters. Countless hours of effort from the authors have been put into the making of this book. We are greatly indebted to them and sincerely appreciate their sacrificing time from family and work obligations to share their expertise and experience.

Having a book dedicated to arthroplasty of the elbow, wrist, and hand is unprecedented and should prove very useful to upper extremity surgeons. In addition, the structure of the chapters with sections for each anatomic region will be efficient for the reader. The design considerations chapters will reinforce the underlying pathology and provide a greater understanding of the thought processes related to rationale and development of implants. It is our hope that this will inspire further creativity and insights to advance the designs of current implants. The primary arthroplasty chapters will guide surgeons on the current indications, technique, and outcomes of primary joint arthroplasty. The revision/failed chapters should help guide the reader through the often difficult and challenging options associated with treating patients who have failed primary arthroplasty.

We sincerely appreciate the invitation from Springer to lead this effort and for their support throughout these past 2 years. We would like to especially thank Ms. Abha Krishnan for her steady support and stewardship through this entire process.

Finally, to our devoted families, who have quietly and lovingly supported us through this (and many) academic endeavors, we are eternally grateful. Your love and support inspire us and have made this possible.

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Acknowledgments

Arthroplasty of the upper extremity remains considerably less developed than that of the knee and hip due to the perceived lack of opportunities for manufacturers, limiting investment in research and development. Arthritis and disorders of the upper limb are very common and are major causes of disability and loss of function for daily activities, work, and sports. There have been significant advances in upper extremity joint arthroplasty in recent years; however, there continues to be an unmet need for patients who could benefit from reliable and durable implants. This project began as an idea to highlight the advances in arthroplasty of the upper limb and to serve as a basis for future work.

A total of 52 authors volunteered their time to contribute to this book. Each is an acknowledged expert in their area of subspecialty. We express our deepest appreciation to all the authors who provided their expertise. We would also like to thank the editors and the publisher for their support of this project, particularly during the height of the COVID-19 pandemic. It is our hope that this book will be useful for those interested in advancing the surgical treatment of patients requiring upper limb joint arthroplasty.

Graham J. W. King and Marco Rizzo

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Part I

Total Elbow Arthroplasty

1 Total Elbow Arthroplasty: Design Considerations

Sebastian A. Müller, Graham J. W. King, and James A. Johnson

Introduction

The elbow is a complex tripartite joint, consisting of the ulnohumeral, the radiocapitellar, and the proximal radioulnar joints (PRUJ) [1] allowing for extension and flexion as well as forearm rotation. Compared to the joints of the lower limb, which are usually weight bearing, loading of the elbow is relatively low for many activities of daily living. However, forces transmitted across the elbow can be high for some activities exceeding three times body weight [2] and thereby challenging the longevity of total elbow arthroplasty (TEA). Several design considerations are necessary to restore the main motion of extension and flexion in the elbow as well as forearm rotation while respecting the high loading, which can occur. The overall goal of TEA is to achieve painless and stable motion for activities of daily living, vocations, and avocations [3]. The main indications for TEA include primary or posttraumatic osteoarthritis, rheumatoid arthritis, tumors, distal humeral fractures and nonunions, and dysfunctional instability. While the incidence of TEA continues to rise for acute trauma and posttraumatic sequelae, those for rheumatoid arthritis have decreased with the advent of more effective medical management [4–6]. TEA can be either linked transmitting higher forces along the implant or unlinked requiring intact ligaments and good bone stock. Convertible TEAs can be converted from an unlinked to a linked articula-

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tion if instability is problematic without having to revise the humeral or ulnar components [7–10]. They can also allow conversion from a distal humeral hemiarthroplasty to a TEA without removing the humeral stem.

Hemiarthroplasty of the distal humerus is an option for selected acute distal humeral fractures and nonunions, and likely require less weight restrictions than for TEA. However, the collateral ligaments must be repairable and a humeral component matched in size and shape to the native ulnar, and radial articulations are essential to reduce cartilage wear [11–13].

Basic Biomechanics

Kinematics of the Elbow

The primary function of the elbow is to position the hand in space for bimanual activities. The principal motions are flexion, extension, pronation, and supination. The flexion-extension motion has a full range of approximately 0–140 degrees, with an average 30–130 degrees needed for typical activities of daily living [3, 14, 15]. The flexion-extension axis passes through the center of curvature of the trochlear groove and the spherical center of the capitellum [16–20]. This axis varies slightly throughout the flexion-extension cycle, and hence the ulnohumeral articulation has been termed a "sloppy hinge" [16, 19]. This axis is approximately 3–5 degrees internally rotated from the medial and lateral epicondylar axis, and 4–8 degrees valgus relative to the humeral long axis [16, 17, 21]. An understanding of this relatively unique motion has led to the genesis of "loose hinge" TEA designs.

The carrying angle of the elbow, which differs from the aforementioned flexion axis, also has implications with respect to implant design [22]. The carrying angle is measured between the long axes of the humerus and ulna as measured in the coronal plane in full extension and supination. Carrying angles vary considerable among individuals, and are higher on average in women (10–15 degrees) than in men (7–12 degrees) [14]. Quite clearly, the establishment of this alignment is also important with regard to the design of the ulnohumeral articulation in implants.

Forearm rotation is governed primarily by the radiocapitellar joint, and proximal and distal radioulnar joints. The normal range is approximately 90 degrees of supination to 80 degrees of pronation, although 50 degrees in either direction is generally sufficient for most activities of daily living [3, 15]. The rotation axis runs from the center of the radial head to close to the fovea of the distal ulna [23, 24]. Reproducing the native forearm motion following implant reconstruction is primarily influenced by the shape and position of the radial head and capitellar surfaces for the total elbow replacement systems that replace both the ulnohumeral and radiohumeral articulations.

Joint Loading of the Elbow

Muscle loading has a profound impact on articular biomechanics. The compressive forces generated across the articulations of the elbow have been shown to markedly increase joint stability [25–30]. Biomechanical cadaver-based studies have clearly demonstrated that active loading achieved by simulating contraction of the elbow flexors and extensors results in more consistent and repeatable flexion-extension motion pathways relative to passive control (where the arm is guided by the investigator) [29].

An understanding of the loads that occur at the elbow is very relevant with regard to total implant design and performance. To date, direct measurements using instrumented implants and wireless telemetry in patients have yet to be developed for the elbow, and thus an exact measurement of joint loading is not available. However, it is well established from a variety of studies that these magnitudes are far from trivial. The quantification of these loads currently relies on computational approaches. Both simplified two-dimensional models and more complex approaches that account for the numerous load-bearing structures that cross the joint (i.e., the articulation, ligaments, capsule, muscles, and tendons) have been employed [2, 31, 32]. At the radiocapitellar joint, up to three times body weight has been estimated [2]. The resultant force on the ulnohumeral joint can also approach three times body weight during weight-training activities. Push-up exercises can generate forces approximating 45% of body weight [33]. Also, the direction of the joint reaction force varies markedly throughout the flexion-extension cycle, and this of course has a strong influence on the axial and bending loads that must be accepted by the implant and interfaces with bone. With respect to the relative load distribution between the ulnar and radial sides, this is very dependent on the activity and position of the joint (both for flexion and forearm rotation). Experimental and analytical studies have reported variable results, with approximately a 60:40 ratio for the radiocapitellar and ulnohumeral sides [31, 34, 35]. In light of the foregoing, it is logical to postulate that elbow implants are subjected to a wide range of significant loads that vary markedly in magnitude and direction in patients during routine activities.

Fig. 1.1 Custom-made linked TEA with anterior and posterior humeral flanges as well as a broken ulnar flange used for management of posttraumatic arthritis. The tip of the ulnar component has been implanted outside the intramedullary canal. A synostosis of the proximal ulna and radius is present. The olecranon is missing indicating poor triceps function

Current Total Elbow Arthroplasty (TEA) Principals

The first implantation of a TEA was documented in 1942 [36], but TEA was not routinely used before the early 1970s. These constrained TEAs had a fixed hinge (Fig. 1.1) with reported loosening rates of 26–68% of one or both stems at the bone-cement interface within 3 years after insertion, which is why this concept was abandoned [37–43]. Semi-constrained linked and unlinked implants were introduced in the 1970s and have continued to evolve over the last 50 years [37, 44, 45].

Improvements in linked implant durability were achieved with the development of semi-constrained implants incorporating a sloppy hinge. These implants permit 7–10° of varus-valgus laxity and some internal-external rotational laxity like that present in the native elbow. With this concept some of the forces are absorbed by the soft tissues reducing loading to the cement interface and thus loosening [7, 46–48]. In general, overconstraint results in higher loads being transferred through the bone-implant interface [49], which can lead to mechanical loosening, while underconstraint results in elbow instability [50, 51].

Unlinked implants transmit less force across the implant, which should theoretically reduce mechanical loosening. In the varus position, an unlinked TEA with intact ligaments transmits approximately half of the loads to the humeral stem when compared to a linked device [52]. This biomechanical advantage of unlinked TEA has yet to be confirmed with a reduction in wear and loosening in clinical studies [10, 30, 48, 53–55]. The stability of an unlinked device relies on secure ligament repair with strong healing, and good bone stock with no or little bony deformity [37, 44, 45, 53, 55–57] (Fig. 1.2). For an unlinked TEA, an intact or replaced radial head is important to improve stability [53, 58–60] (Fig. 1.3). If the aforementioned factors are lacking, a linked TEA is preferred [1, 46, 48, 52, 61–63]. However, forces on the implant increase for both linked and unlinked TEAs with insufficient ligaments in vitro, stressing the importance of ligament repair where possible for both design concepts [52] (Fig. 1.4).

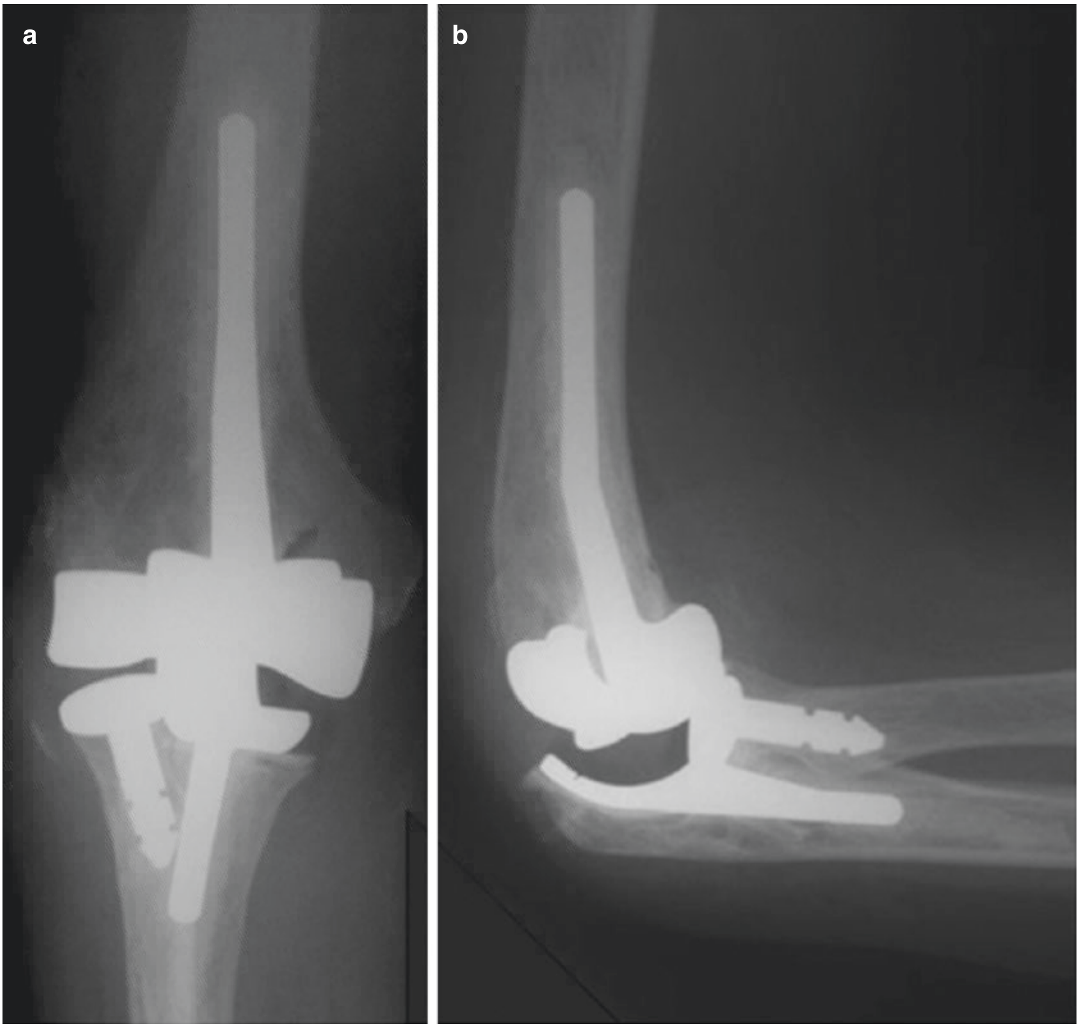

Fig. 1.2 (**a**, **b**) Joint subluxation in an unstable TEA with a radial head replacement (Sorbie, Wright Medical)

Traditional TEA designs were either linked or unlinked. In case of revision from an unlinked to a linked TEA to address instability, often well-fixed stems had to be removed, which means major surgery (Fig. 1.3). Modern convertible TEA designs can more easily be converted from unlinked to linked in a short surgical procedure [8–10]. Moreover, conversion from a hemiarthroplasty to TEA is possible without removing the humeral stem [8, 9] (Fig. 1.5).

The 10-year survivorship of linked and unlinked TEA is 83–90% with better results in high-volume institutions and in lower-demand patients [64, 65]. Instability, loosening, and material wear continue to be the most common causes of TEA failure [64–66]. Therefore, design considerations include joint stability in unlinked TEA, wear reduction in linked TEA, and implant fixation in linked and unlinked TEA.

Implant Fixation

Implants are usually fixed with acrylic bone cement into the distal humerus, proximal ulna, and proximal radius (if needed). Uncemented implants are not currently commercially avail-

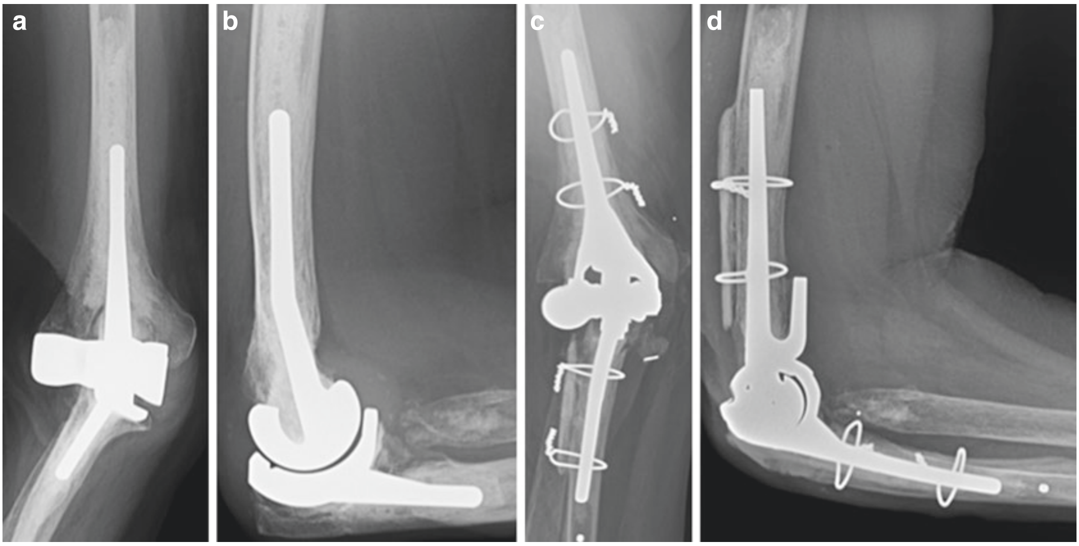

Fig. 1.3 (**a**, **b**) Fifteen years following an unlinked TEA for osteoarthritis (Sorbie, Wright Medical), valgus instability developed due to attenuation of the medial collateral ligament. (**c**, **d**) Revision to a linked implant (Latitude, Wright Medical). The well-fixed stems were removed and humeral and ulnar shafts augmented with allograft struts

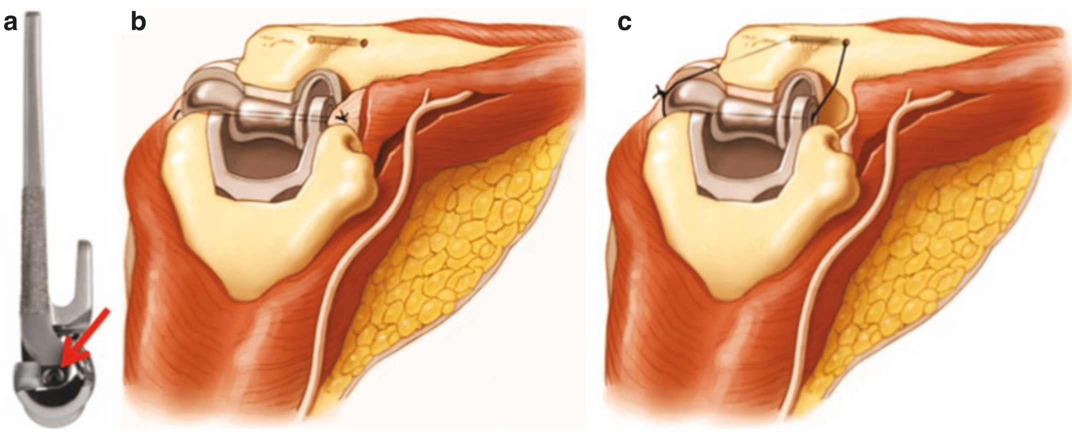

Fig. 1.4 Convertible implant (Latitude EV, Wright Medical) with (**a**) a hole in the humeral spool (red arrow) for (**b**) reattachment of the collateral ligaments and the flexor and extensor muscles, respectively. (**c**) Additional stability can be achieved by placing a strong suture through the spool and a tunnel in the ulna protecting the reattached ligaments from varus-valgus, distraction, and rotational forces while healing. (From Wright Medical Group, N.V., Memphis, TN, USA; with permission)

able for TEA but have had some success for humeral component fixation [45, 67–69]. Secure fixation of the cement interfaces with implant and bone is required to accept the significant axial, bending, and torsional loads that can be generated at the articulation. The stem should be inserted carefully into the intramedullary canal to achieve an optimal cement mantle around the implant [70]. Modern cementing techniques using cement guns and cement restrictors have further improved stem fixation [71].

Intramedullary Stem Design

Due to failures of early stemless or short-stem TEA designs (Fig. 1.6), intramedullary stem fixation has become standard in TEA [72, 73]. The

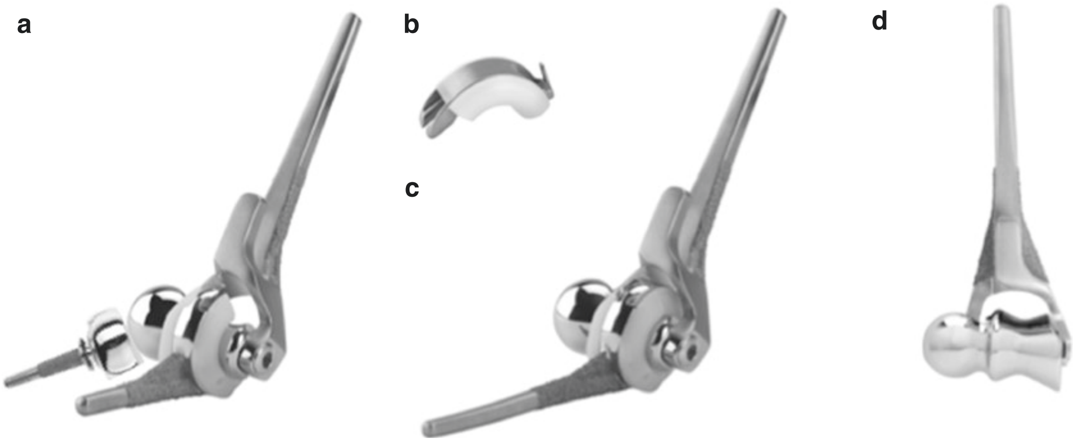

Fig. 1.5 Convertible TEA (Latitude EV System, Wright Medical). (**a**) Unlinked TEA with radial head replacement, (**b**) ulnar cap to link system, (**c**) linked TEA without radial head, (**d**) hemiarthroplasty of distal humerus with anatomical humeral spool. (From Wright Medical Group, N.V., Memphis, TN, USA; with permission)

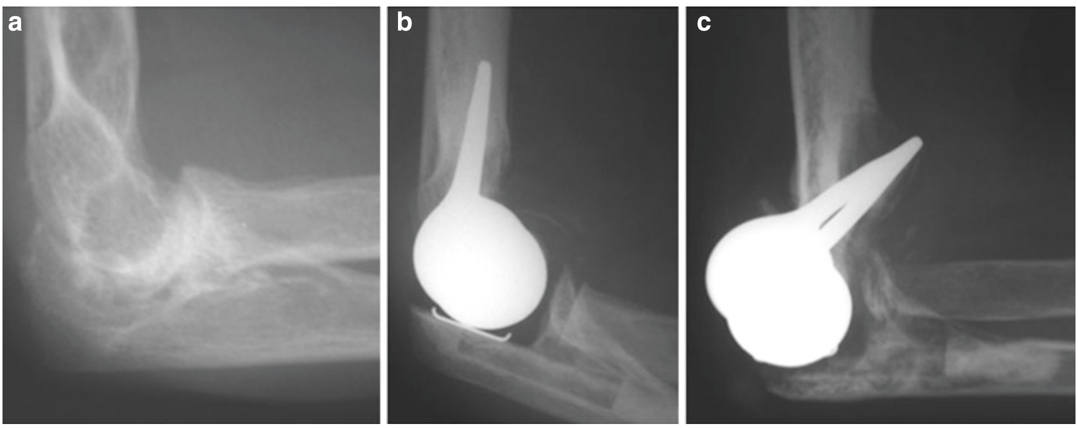

Fig. 1.6 (**a**) Lateral radiograph of a patient with rheumatoid arthritis, (**b**) postoperative radiograph after a short stem TEA (Souter-Strathclyde, Stryker), (**c**) humeral loosening with implant failure at 5 years

optimal stem length is unknown and requires further study.

Adding an anterior flange to the humeral component permits the insertion of a bone graft on the anterior humerus, which may enhance the bony support at a point where the maximum stress has been found to occur with some implant designs. The idea is to reduce rotational and posterior-directed forces potentially causing loosening [2, 34, 72, 74, 75]. While the anterior flange seems to reduce the forces for some implants (GSB, Sulzer Medical [76]; Coonrad-Morrey, Zimmer [7]), this may not be the case for other implants. The anterior flange of the Latitude TEA, Wright Medical did not change the load distribution for axial or bending moments in an in vitro study [77]. The authors of this study suggested two possible reasons why an anterior flange may not be needed in this implant. First, the Latitude humeral component has medial and lateral fins on the distal portion increasing the cross-sectional area and thus the fixation within the cement (Fig. 1.5). Second, the Latitude implant is made of cobalt chrome, and as such the forces may not be transmitted to the distal humerus to the same extent as they are with less stiff titanium implants.

Finite element and in vitro studies [78, 79] have shown unequal load distribution with greatly

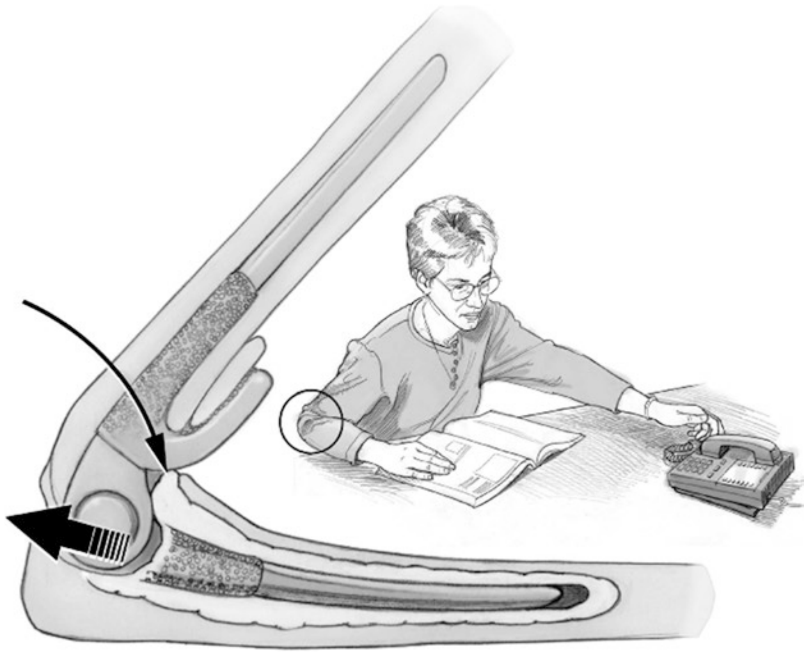

Fig. 1.7 Schematic of a TEA illustrating anterior impingement of the coronoid process on the anterior flange resulting in pullout forces being applied to the ulnar component. (From Cheung and O'Driscoll [80]; with permission)

increased strain adjacent to the implant tip, but strain reduction relative to the epiphysis of humerus and ulna. This may lead to stress shielding, bone resorption, and fatigue failure, particularly in the ulna where there is no flange on the stem. The ideal stem shape, length, and materials with respect to improving the load distribution of elbow arthroplasty require further study.

Unlike the loaded joints of the lower limb, pullout forces, so-called pistoning, may cause ulnar stem loosening, particularly in linked TEA (Fig. 1.7). Impingement of the anterior humeral component flange with a prominent coronoid process or excessive cement must be avoided. Moreover, the ulnar stem should not be implanted too far distally [80]. Anterior flexion impingement should be reduced in future TEA designs allowing for high flexion angles regardless of the presence of an anterior flange.

Smooth stems favor debonding of the implant-cement interface and should be avoided in TEA. In vitro studies showed the highest axial load resistance was found for stems with rough surface treatment when compared to smooth stems. Titanium stems showed significantly higher load resistance compared to cobalt chrome stems for sintered beads, but similar results between materials with plasma spray coatings [81]. Shedding of sintered beads was of concern in these in vitro studies as well as the known weakening of the stem substrate in the course of their application (Fig. 1.8). Titanium plasma spray surface treatments are likely preferred for TEA.

In a laboratory setting, the ideal stem cross section was shown to be rectangular because it resisted the highest rotational forces when compared to triangular, oval, or round [82] (Fig. 1.9). Sharp rectangular stems, while providing the greatest resistance to torsion, should probably be avoided due to the concern about stress concentration in the cement mantle. To date, in vitro studies testing surface treatment and cross section have used straight stems with a constant cross section throughout the entire length, which does not reflect the anatomic situations with

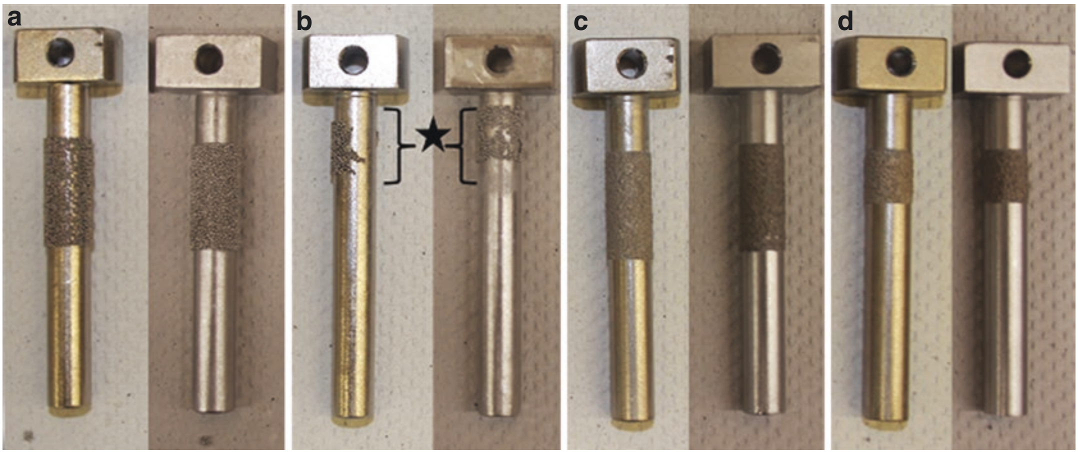

Fig. 1.8 Titanium (left) and cobalt chrome (right) stems after in vitro testing. (**a**) 20 mm and (**b**) 10 mm beaded stems. (**c**) 20 mm and (**d**) 10 mm plasma spray-treated stems. Note debonding of the surface treatment in 10 mm beaded stems (star; B). (From Hosein et al. [81]; with permission)

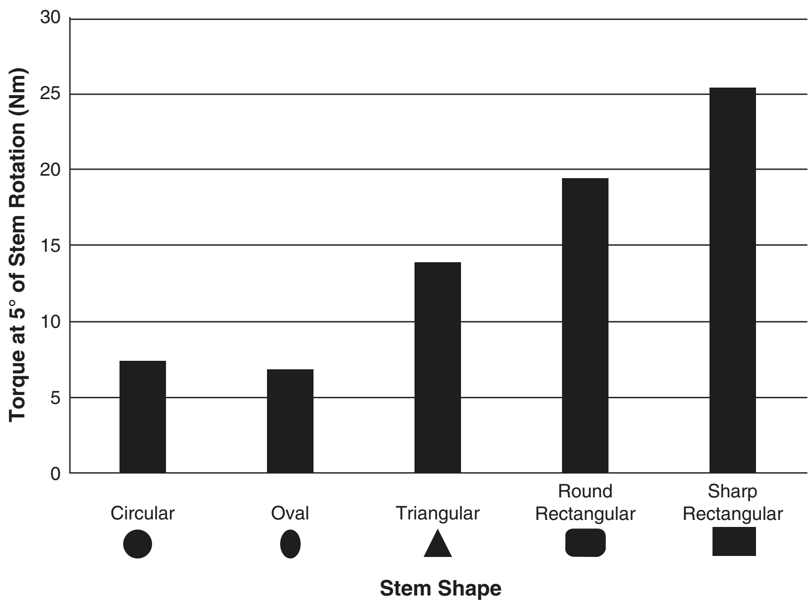

Fig. 1.9 Resistance to rotational force in this in vitro study was found to differ depending on stem cross-sectional shape. The highest torque resistance was found for a rectangular cross section with sharp edges [82]

curved and tapered implants. Nevertheless, plasma spray-coated stems with a rectangular cross section are most likely favorable in vivo as well. Curved stems are more anatomic however; their removal is problematic relative to straight-tapered stems in the setting of infection. Further studies are needed to compare the durability of these two design concepts.

Implant Positioning

Restoration of the extension and flexion axis is essential in TEA. Implant malpositioning alters ligament and capsular tension, muscle moment arms, and lines of action. This may increase wear of the articular surfaces and increase stresses in the implant-bone construct, possibly leading to component loosening or mechanical failure. It has been shown in an in vitro biomechanical study that the resultant load is significantly increased if the humeral component is positioned in anything but an anatomic location [83] (Fig. 1.10).

Correct positioning of the humeral stem relies on the accurate reproduction of the anatomic extension-flexion axis, which is determined by the vector through the centers of the capitellum and the trochlea. However, using visual cues to estimate the axis, alignment errors up to 10° in both directions occur even in the hands of subspecialty trained orthopedic surgeons [84] (Fig. 1.11). Improved surgical cutting guides or navigation systems may help to improve accuracy.

Among five methods for intraoperative determination of the extension-flexion axis from the proximal forearm, the most accurate is to use the ridge of the greater sigmoid notch in combination with the center of the radial head [85]. Modern TEA designs use surgical guides for joint axis determination and likely improve the accuracy of

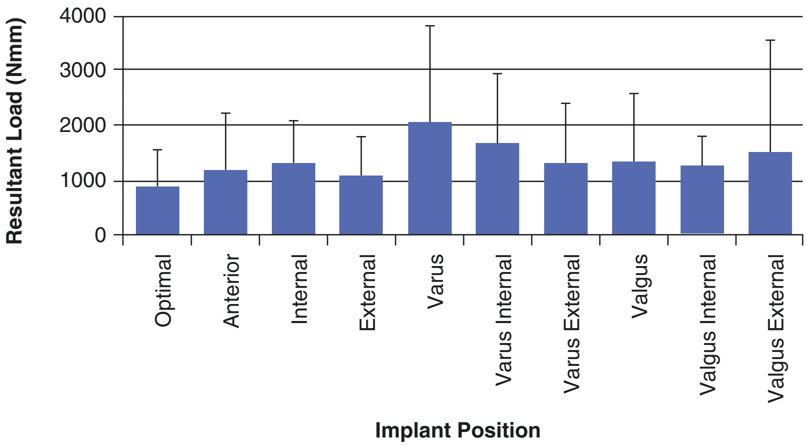

Fig. 1.10 Mean bending load in the humeral stem of an instrumented TEA using a cadaver biomechanical model and an in vitro joint motion simulator. The resultant bending load (mean + SD) of the entire flexion range is shown. Malpositioning of the humeral component resulted in an increase in forces in the humeral stem. (From Brownhill et al. [83]; with permission)

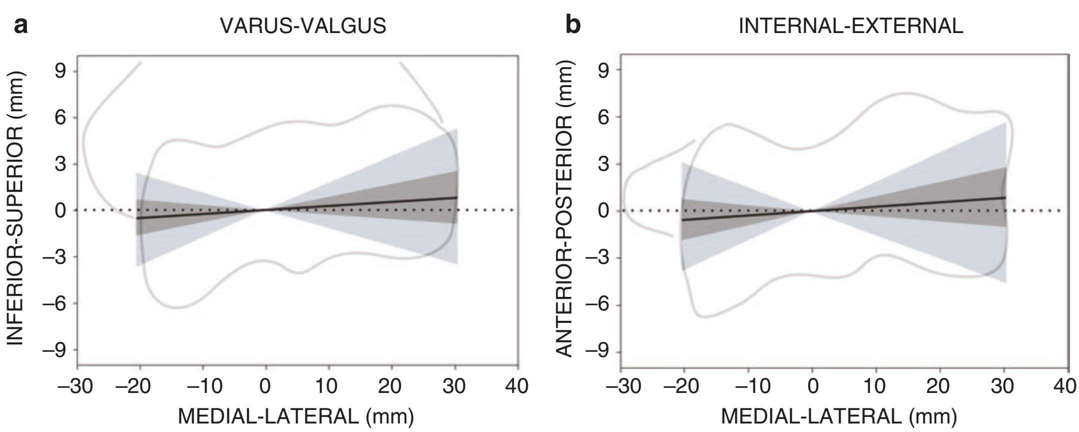

Fig. 1.11 (**a**, **b**) Error in determination of extension-flexion axis of the elbow for varus-valgus and internal-external rotational alignment, respectively. The solid black line indicates the mean extension flexion axis. The dark gray area represents errors within one standard deviation of the mean line and the light gray area the remaining errors. (Adapted from Brownhill et al. [84]; with permission)

ulnar component positioning when the radial head is available.

More anatomic stem designs are required to improve alignment within the intramedullary canal as shown for the proximal ulna and distal humerus [86, 87]. Modular systems or custom-designed implants reverse engineered from CT imaging could be an option in cases of an altered intramedullary canal due to previous fractures, if long stems are needed [86], or to better accommodate the natural shape of the humerus and ulna, which varies between individuals [86, 87].

Computer navigation has been clinically used for spinal surgery as well as knee and hip arthroplasty but not for TEA so far. There are some in vitro studies evaluating navigation approaches using a laser scanner [88] also in combination with CT data from the diseased elbow [89] or CT data from the contralateral distal humerus [90], in order to define the correct implant position. Using this technology, commercially available humeral stems were found to impinge within the intramedullary canal in some cases causing alignment errors in rotation and translation. Impingement was not observed when shorter (more anatomic) stems were used. It was concluded that humeral stems with a fixed valgus angulation are difficult to implant correctly and more variability in varus-valgus stem angulations is needed to improve the accuracy of implant positioning [91]. Navigated implant placement was found to be superior to surgeon placement using standard mechanical instruments, particularly evident in the setting of distal humeral bone loss or deformity. Further work is needed to translate these in vitro findings into improved TEA designs and implantation techniques.

Implant Wear

Wear of ultrahigh molecular weight polyethylene (UHMWPE) may induce osteolysis, which favors implant loosening [92–95]. Implant fatigue fractures may occur at the junction of a well-fixed and loose stem due to osteolysis (Fig. 1.12) as well as substrate weakening from the sintering of beaded surface treatments (Fig. 1.8) [96].

Whereas early TEA designs used metal on metal bearings, all current linked TEAs feature a

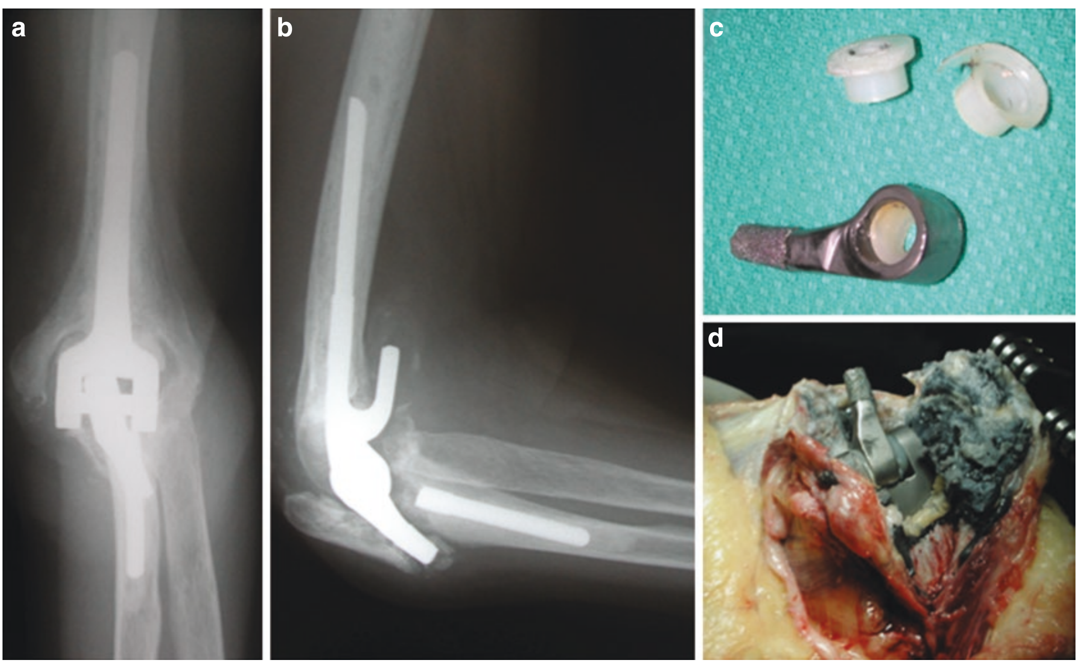

Fig. 1.12 (**a**, **b**) Cantilever bending failure of the ulnar stem with periprosthetic fracture of the proximal ulna in a linked TEA (Coonrad-Morrey, Zimmer). (**c**, **d**) Bearing wear, osteolysis, and massive metallosis was noted at surgery

cobalt chrome surface that articulates against an UHMWPE bearing. Once the UHMWPE bearing surface is worn completely, the bushings need to be replaced to avoid metal on metal contact resulting in metallosis (Fig. 1.12). Some TEA designs use a "cylindrical" linking mechanism with a straight cobalt chrome pin [97–99]. Others use an "hourglass" or "concave cylinder" linkage designs with greater surface area of contact (Fig. 1.13). In a computational finite element analysis [51], the hourglass and concave cylinder linkages showed a significant decreased edge loading compared to a traditional cylindrical linkage design (Fig. 1.14). While edge loading

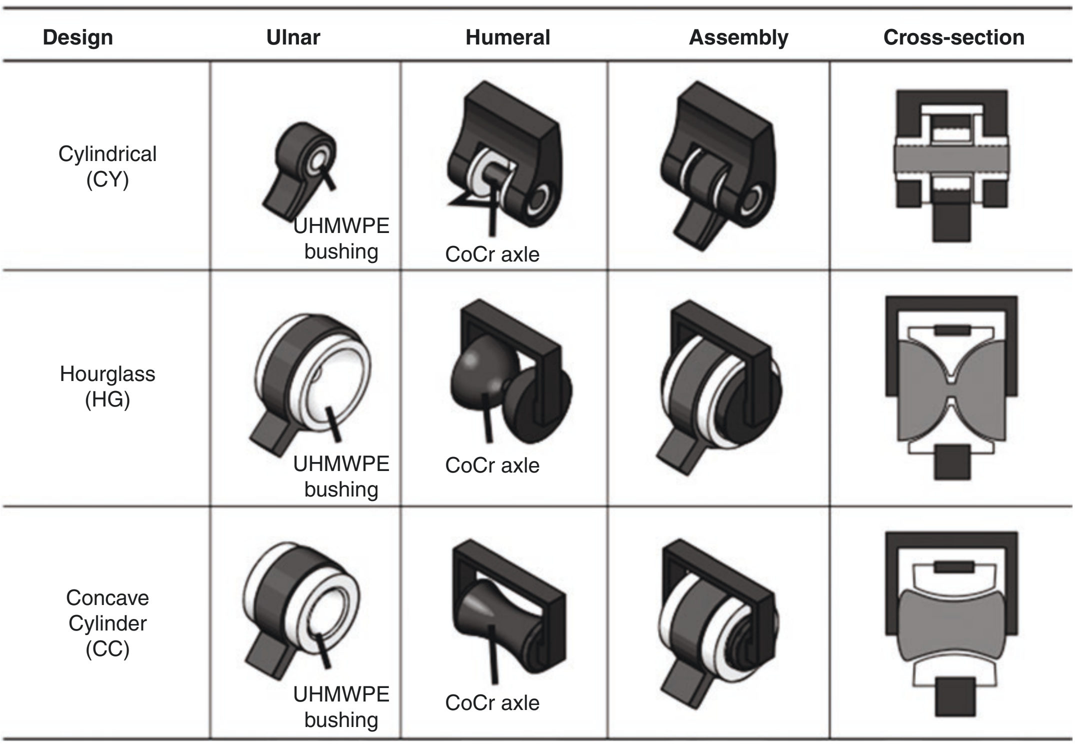

Fig. 1.13 Schematic drawing of three different linkage mechanisms types. (From Willing et al. [51]; with permission)

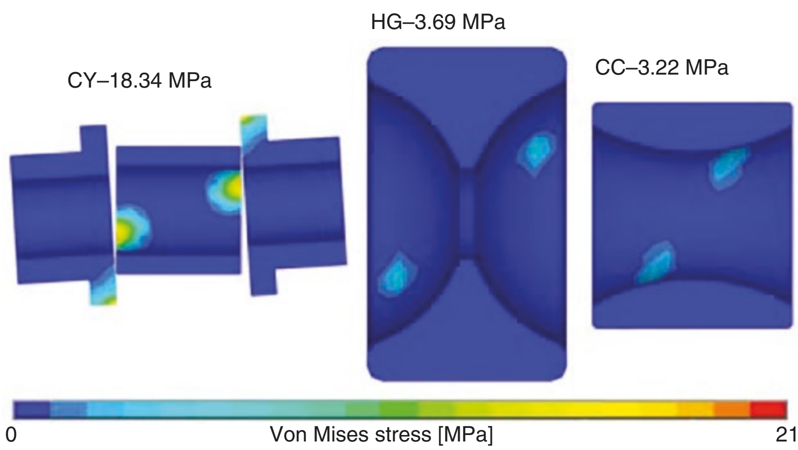

Fig. 1.14 Significantly higher edge loading occurred for the cylindrical linkage design compared to hourglass and concave cylinder shapes. (From Willing et al. [51]; with permission)

was comparable for hourglass and concave cylinder designs, the concave cylinder design provided better varus-valgus stability and thus may be best suited for TEA with respect to reduction of wear, osteolysis, and implant failure [96].

Design Considerations for Distal Humeral Hemiarthroplasty

Overview

The first reported hemiarthroplasty of the distal humerus was implanted in 1925, which was made of aluminum and bronze with a protective rubber coating [100]. Other early implants composed of acrylic, nylon, or Vitallium were reported in case reports or small case series between 1947 and 1990 [101–105]. A series of ten elbows treated with a stemless stainless-steel or titanium hemiarthroplasty for posttraumatic conditions, rheumatoid arthritis, or ankylosis due to hemophilia was published in 1974. While elbows with posttraumatic conditions were stable, were painless, and had a functional range of motion in posttraumatic conditions, the results for inflammatory arthritis or hemophilia were unpredictable or poor [106].

The main treatment of distal humerus fractures remains ORIF in younger patients with reconstructable fractures and TEA for older patients with osteoporosis and unreconstructable fractures. There has been recent interest in distal humerus hemiarthroplasty for comminuted capitellar-trochlear and supracondylar fractures in patients too young for a TEA due to the lifelong activity restrictions required with these devices and concerns about implant longevity. The indications for distal humeral hemiarthroplasty also include failed ORIF, malunion or nonunion, and avascular necrosis of the capitellum or the trochlea [13, 107–110]. Some authors do not recommend distal humeral hemiarthroplasty in the younger population with distal humeral fractures due to a concern about long-term cartilage wear. These studies reported the outcome of nonanatomic distal humeral components where the contact with the native joint was likely suboptimal unlike newer anatomically shaped designs [11, 12].

The advantages of distal humeral hemiarthroplasty over TEA are the absence of polyethylene bearing wear and periarticular osteolysis from particulate debris. This may lower the risk of component loosening likely requiring less activity restrictions than for TEA [111]. With the introduction of commercially available, anatomical (Sorbie, Wright Medical; Latitude, Wright Medical) and nonanatomical (Kudo, Biomet) implants, outcome studies of hemiarthroplasties have increased over the last two decades [111]. The convertible Latitude EV system (Fig. 1.5) is the only available implant with a hemiarthroplasty option as most of the aforementioned implants are no longer marketed. It can be converted to a TEA by adding an ulnar stem and replacing the anatomical humeral spool with a differently shaped TEA spool. Hemiarthroplasty implants are currently not approved for use by the Food and Drug Administration for the United States but are available in many other countries.

Design considerations for distal humeral hemiarthroplasty stems are comparable to TEA. Stable soft tissue constraint is as important for a distal humeral hemiarthroplasty, similar to unlinked TEA. While a lack of polyethylene wear means osteolysis-mediated aseptic loosening is unlikely, cartilage degeneration of the proximal ulna and radial head is an important concern that requires further study.

Joint Stability

Ligament repair and fixation of fractured epicondyles or condyles are necessary for joint stability, which can be challenging in the setting of comminution. An olecranon osteotomy surgical approach was commonly employed in early clinical series; it has fallen out of favor [108–110, 112, 113]. While allowing excellent exposure of the distal humeral articular surface and preservation of the collateral ligaments, nonunion, prominent hardware, and conversion to TEA were problematic [111]. Other approaches include triceps-splitting [114], triceps-reflecting (Bryan-Morrey)

[115, 116], medial or lateral epicondyle osteotomy [117, 118], and subperiosteal lateral collateral ligament release [107]. The authors prefer a triceps-preserving para-olecranon approach for acute fractures. It gives appropriate exposure, can be used for conversion to TEA as well, and does not require postoperative restrictions for the triceps repair with greater extension strength [119]. While comminuted parts of the joint surface need to be removed, fractured condyles and epicondyles with their attached collateral ligaments must be preserved for repair [111]. Determination of correct humeral component positioning may be challenging if both epicondyles are fractured, which may result in incorrect joint alignment and altered joint biomechanics. Using the superior aspect of the olecranon fossa to position the anterior flange and evaluating the tension of the soft tissues with a triceps-on approach are recommended to estimate the correct depth [111]. The humeral stem should be internally rotated 14° relative to the posterior humeral cortex [120].

Epicondyles can be fixed using sutures, K-wires, or small plates, and torn ligaments can be repaired with sutures through the hole in the humeral spool as for TEA (Fig. 1.4) [111]. A secure repair and healing of epicondyles and collateral ligaments is essential for joint stability, which is why strengthening should not be started before 8–12 weeks postoperatively [111]. Once the epicondyles are radiographically healed and the elbow is clinically stable, no specific weight restrictions such as recommended for TEA are required. However, the patient should be educated about the need to protect the hemiarthroplasty [111].

Cartilage Wear Reduction

Nonanatomic TEA implants that have been used for hemiarthroplasty (Kudo; Biomet) lead to substantial cartilage attrition and are no longer on the market [12]. Degenerative radiographic changes have also been reported with anatomically shaped implants, more commonly for the Sorbie than for the Latitude; however, the clinical results have been favorable [13, 110].

An in vitro study found that the best joint congruity of the Latitude hemiarthroplasty with highest contact area was found if the humeral spool optimally fitted the greater sigmoid notch, followed by oversized implants. Undersized implants had the least congruity. Moreover, congruity was greater for active motion than passive motion indicating joint reduction due to muscle loading [121]. Compared to the native elbow, the mean contact area of an optimally sized implant decreased 44% for the ulnohumeral joint but only 4% for the radiocapitellar joint [122]. Altered varus and valgus angulations were found for optimally and undersized implants, whereas the oversized implants best reproduced native elbow kinematics. Based on this in vitro data, when choosing between two implant sizes, the larger one should be selected [111]. However, regardless of implant size, alterations in elbow biomechanics were found with abnormal articular contact, tracking, and loading and thus may result in cartilage degeneration over time [123]. Possible design modifications of the humeral spool could improve joint congruity and biomechanics. The stiffer nature of the metallic implant relative to the native cartilage of the distal humerus most likely wears the cartilage of ulna and radial head over time. Hence, future consideration should be given to more compliant implant materials, which should be more cartilage friendly. Long-term data regarding cartilage wear and distal humeral hemiarthroplasty durability is not yet available [111].

Summary

TEA can be either unlinked or linked. Good bone stock, repaired ligaments, and an intact or replaced radial head are required for unlinked TEA. In cases of unstable unlinked TEA, convertible designs have the advantage to be converted to a linked status in a short surgery without the need of revising well-fixed stems. Wear and loosening is more often seen in linked TEA. Improvement of implant designs includes more anatomic stems with rectangular cross section and surface roughening. Modern concave cylinder-shaped UHMWPE linkage designs reduce wear and provide good stability. Precise surgical guidance for correct implant alignment and fixation is preferable.

Distal humeral hemiarthroplasty for nonreconstructable distal humeral fractures is a good option in selected patients with good short- to mid-term results. Likely less weight restrictions are required than for TEA. Repair of epicondyles, condyles, and collateral ligaments is essential. Joint stability and wear of the ulnar and radial joint surfaces remain challenging. More anatomic implants using more compliant articular materials may improve long-term results.

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