Elbow Arthroplasty

Current Techniques and Complications

Filippo Castoldi
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SICSeG
Società Italiana di Chirurgia della Spalla e del Gomito

Springer

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To Prof. Randelli and Prof. Perugia, founding fathers of the Italian Society for the Shoulder and Elbow Surgery.

To our beloved families whose love, patience and support for us never wavered despite our continual absence.

Foreword

Two years ago, at the beginning of my mandate as President of the Italian Society for the Shoulder and Elbow Surgery (SICSeG), I decided, together with the Executive Committee, that the Society should tangibly demonstrate its mission to spread knowledge about shoulder and elbow surgery by publishing two monographs: one on reverse shoulder prosthesis and the other on elbow arthroplasty.

The project seemed ambitious, but at the same time achievable since the Society would have made use of the most experienced Italian shoulder and elbow surgeons. Finally, the two monographs have been realized.

The monograph on the elbow is unique in the international scenario since it was not written by a single author, or by several authors belonging to the same group, but by surgeons of different Italian backgrounds. Therefore, the work does not spread a single line of thought dictated by individual cultural background, commercial relationships, or personal insights, but the experience of an entire nation on a difficult subject.

The topics of biomechanics, pathophysiology, and surgical technique, which currently cause heated debates in various congresses, have been slavishly addressed in the chapters.

I wish this work an international success, and I am sure that it will be a milestone not only for those who want to approach this surgery but also for expert surgeons who will find useful information for comparison and reflections.

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Preface

Elbow prosthetic surgery has evolved greatly over the years: the materials used have changed, as have the approaches used to preserve soft tissues. A greater knowledge of the anatomy and biomechanics of the elbow, and more generally of the elbow itself, among orthopedic surgeons has led to the treatment of increasingly acute cases and of complex sequelae with elbow prosthesis. This book is dedicated to every aspect of the prosthetics of the elbow and provides a state-of-the-art summary for surgeons who deal with the disorders of this joint.

The expertise and widely acknowledged reputation of the authors who have contributed to this text are such that this book may be considered a manual that is indispensable to the professional growth of the elbow surgeon.

Turin, Italy — Filippo Castoldi
Rome, Italy — Giuseppe Giannicola
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Contents

About the Editors

Filippo Castoldi, MD is Chief of the Department of Orthopedics and Traumatology at the University of Turin, Italy, and currently Chief of the Orthopedics and Traumatology University Clinic at the San Luigi University Hospital, Turin. His main interests are shoulder, elbow, and knee pathologies and their treatments-areas in which he undertook training during prolonged periods of study in Europe and the United States. Prof. Castoldi is the lead author of a number of scientific papers that have addressed the development of new techniques and clinical and basic science research. He is the winner of several international awards and has been a faculty member of national and international meetings and courses.

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Roberto Rotini is Director of Shoulder and Elbow Unit and is responsible for the research program titled “Orthopedic Clinical Pathology” of Rizzoli Orthopedic Institute of Bologna. From 2002 he has been teaching, with the role of Professor on contract, shoulder and elbow matters at the Orthopaedic Post-graduate School of Bologna University. He is a member of ESSSE/SECEC (European Society for Surgery of the Shoulder and the Elbow) from 2002; he is part of the Board of Italian Society for Shoulder and Elbow Surgery (SICSeG) from 2005 and was the President of this Society in 2013–2014. He is part of the Editorial Board of Musculoskeletal Surgery.

Part I

Basic Science

History and Evolution of Elbow Arthroplasties

1

Luigi Murena, Gianluca Canton, Antonio Moretti, Guido Maritan, and Pasquale Punzetto

1.1 Introduction

Prosthetic replacement of the elbow is performed especially as a response to degenerative or inflammatory disease. Osteoarthritis, both primary and secondary to trauma, and rheumatoid arthritis have historically been the most common indications. In recent years, acute fracture has also caught on as a recommended indication, although it had already been proposed in the past.

The development of elbow surgery was closely associated with the treatment of rheumatoid arthritis and tuberculous arthritis. The main causal factor at the end of the nineteenth century and at the beginning of the twentieth century was tuberculosis. The incidence of tuberculous joint disease decreased considerably at the end of World War II, because of the introduction of effective antibiotics. Nowadays, primary causes of osteoarthritis of the elbow constitute less than 2% of all elbow arthritis cases. Therefore, the main causes are rheumatoid arthritis or post-traumatic arthritis. The involvement of the elbow is common in rheumatoid arthritis, with about 20–60% of all patients affected. Elbow involvement usually appears within 5 years of disease onset.

In recent years the indications have changed. According to the Norwegian Arthroplasty Registry [1], the national Scottish arthroplasty register [2], and the SPARCS database from the New York State Department of Health [3], the trend has seen a decrease in total elbow arthroplasties performed on patients with rheumatoid arthritis and a concomitant increase in arthroplasties performed for trauma cases. Certainly, the utilization of disease-modifying antirheumatoid drugs (DMARDSs) has played a part in this change [4]. Furthermore, the use of elbow arthroplasty to treat acute trauma cases has gained popularity in the last decades, although it was introduced earlier in the mid-twentieth century. Before elbow arthroplasty introduction, many procedures to treat elbow diseases were described. Elbow arthroplasty was developed mainly as a response to the high failure rate of these procedures. However, some of these interventions are still being used and represent an alternative to arthroplasty in selected cases. Non-prosthetic interventions for severe articular elbow diseases include resection arthroplasty (removal of the articular surfaces of the ulna and humerus), interposition arthroplasty (placement of a soft tissue graft between the articular surfaces of the ulna and the humerus), elbow arthrodesis, and others.

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The first recorded surgical procedure in the elbow was performed by Ambroise Paré in the sixteenth century [5]. It represents the first documented case of resection arthroplasty. He resected the humeral and ulnar bone in an infected elbow joint together with the affected soft tissue to prevent amputation. Evolution of this technique saw the attempts of Park and Moreau in the late eighteenth century who made an extraperiosteal excision of the elbow joint which often resulted in gross instability [6]. A century later, Ollier described a subperiosteal, subcapsular excision of the joint, which he used successfully in 106 cases, mainly of tuberculous arthritis [6]. In the nineteenth century, with the development of more advanced surgical and postoperative care, isolated resection of the distal humerus was proposed. At the end of the nineteenth century, more conservative attempts were described by Wolff, who proposed to remove all the exuberant tissue to treat elbow ankylosis, obtaining scarce success [7].

In the same years interposition arthroplasty was developed. Schüller performed it in 1893 for the first time in a patient with rheumatoid arthritis [8]. The use of fascia as interposition material was introduced by MacAusland in 1921 [9] and popularized in the first half of the twentieth century, thanks to Vittorio Putti, Director of Rizzoli Orthopaedic Institute of Bologna [10]. The description of one of his cases of interposition arthroplasty using the fascia lata can be found in the *Journal of Bone and Joint Surgery* in a 1923 edition.

Through the years interposition arthroplasty reports in the literature resulted to be good in terms of pain relief but only fair in terms of joint mobility and stability.

Interposition arthroplasty is still today a valid option for selected cases, especially in young active patients with severe joint damage, although elbow arthroplasty is currently recognized as the gold standard treatment for severe elbow joint disease. This intervention preserves bone stock and motion; hence it can be converted to a total elbow arthroplasty after the patient has reached a more advanced age or a minor functional demand.

1.2 Total Elbow Arthroplasty

The first prosthetic replacement of the elbow joint was made by Robineau in 1925. He inserted an unconstrained elbow prosthesis in a 20-year-old patient after distal humerus resection. The prosthesis consisted of metal and vulcanized rubber. In the following years, different types of prosthesis made of various materials have been introduced. In 1941 Boerema used a hinged elbow prosthesis made of metal [5]. In the same years (1947), hemiarthroplasty was introduced by Mellen and Phalen as a response to distal humerus non-union and malunion cases [11].

In the 1950s Venable and MacAusland were the first to use an elbow hemiarthroplasty for acute fracture cases. Venable implanted a Vitallium hemiarthroplasty in a man who shuttered the distal end of the humerus after a fall [12]. A few years later, MacAusland reported the use of a hemiarthroplasty made of the same material in four cases of acute fracture. He obtained good results in terms of pain relief and function, but one prosthesis required replacement because of rupture [13].

Later, in 1965, Barr and Eaton designed and used a stem-type hemiarthroplasty to treat a case of post-traumatic arthritis in a 30-year-old man who suffered an open, comminuted, supracondylar T-fracture of the right humerus 3 years before. Four years after the patient had a 30-degree flexion contracture, with active flexion to 125 degrees. Pronation and supination were full. There was no instability or discomfort in the elbow [14].

The main problem of the prosthesis designed before 1970s consisted in frequent loosening and instability. Street and Stevens, who used a resurfacing stemless prosthesis made of stainless steel or titanium to replace the trochlea and capitellum in 1967, represent an exception. They obtained poor results in patients with inflammatory arthritis or hemophilia, while they achieved a painless, stable elbow with a functional range of motion in most patients with post-traumatic lesions [15].

In an attempt to address stem fixation-related complications, Dee started to use cement fixation [16]. Bone cement use in orthopedic surgery had

not reached widespread popularity yet; hence implant fixation represented a serious problem. This technique had indeed been recently introduced (1959) by Sir John Charnley with the aim of anchoring the femoral head prosthesis to the shaft of the femur. In the 1970s, the US Food and Drug Administration (FDA) approved bone cement for use in prosthetic fixation [17]. In previous years, most elbow stemmed implants were fixed with transfixing screws through the stems.

In the early 1970s, the prosthesis of Dee signed the beginning of the "modern" era of prosthetic elbow replacement. Dee designed and produced a fully constrained hinged prosthesis and used methacrylate bone cement. In 1972 he reported the results of the first 12 arthroplasties, with an average follow-up of 14 months. The results, considering the range of movement and pain relief, were excellent in 10 patients [16]. According to his example, different kinds of fully constrained elbow prosthesis were designed, like the GSB (Gschwend, Scheier, Baehler) I system which was used from 1971 [18]. In 1972 Albert B. Swanson designed a prosthesis with Vitallium humeral and ulnar components fixed with methacrylate [19]. Two years later, Schlein used smooth cemented stems [20]. These implants initially consisted of metal-on-metal coupling. Unfortunately, many researchers, such as Weiss in 1970, Souter in 1973, and Gschwend and Nederpelt in 1975, reported poor results with total arthroplasties [21]. Although pain relief was achieved with most of the prosthesis, there were still high rates of loosening of one or both stems at the bone-cement interface as well as prosthetic failure. This failure modality was interpreted to be mostly related to the high bone-prosthetic interface stress, due to the fully constrained design. In response to these failures, three design concepts developed over the years: linked or semi-constrained, unlinked, and convertible prosthesis.

Both Dee and Swanson changed their designs, resulting in a semi-constrained prosthesis. Hence, the semi-constrained coupled implant was developed in the mid-1970s. The aim of the polyethylene-metal loose-hinged device was to provide inherent stability and decrease the rate of loosening.

Roland Pritchard was one of the first surgeons to propose a "loose hinge" and a polyethylene bushing trying to reduce the incidence of aseptic loosening [22]. The stability of this design would have relied on the native soft tissues. Unfortunately, at that time surgical technique was not good enough to guarantee ligaments preservation. Therefore, a relatively high incidence of postoperative instability was reported [23].

Considering the high rates of different complications, the purpose was to create a design able to guarantee a stable joint, ensure solid fixation with acrylic cement, have low friction, replace all the elbow joint (both the ulnohumeral and the radiohumeral articulation), and sacrifice as little bone as possible.

The Mayo prosthesis and the Coonrad one tried to follow these considerations.

The original Mayo prosthesis, firstly used in 1973, was composed of humeral, ulnar, and radial head components, all secured to bone with methyl methacrylate. The position of the stainless-steel humeral component, angulated anteriorly, corresponded to the locus of the anatomical axis of rotation. The ulnar and the radial head components were both made of high-density polyethylene. The result was a low-friction, stable design, with only slight varus-valgus motion throughout the flexion-extension range of motion. Similarly, the Coonrad prosthesis, designed in 1971, consisted of a polyethylene bushing at the humerus and a polyethylene insert at the ulna, but did not provide for replacement of the radial head [24].

However, the aimed goal was still far from being reached. In fact, among the 80 Mayo or Coonrad total elbow arthroplasties performed at the Mayo Clinic from 1973 to 1977, revision was required in 19 implants (24%), 11 of which because of loosening, and the complication rate was 55% [24]. The high incidence of loosening was thought to be related to poor understanding of essential joint design features, to deficiencies of surgical technique, to poor knowledge of elbow biomechanics, and to mistakes in patient selection.

After biomechanical studies and on the basis of clinical experience, the design was modified to allow approximately 7–8° of varus-valgus laxity

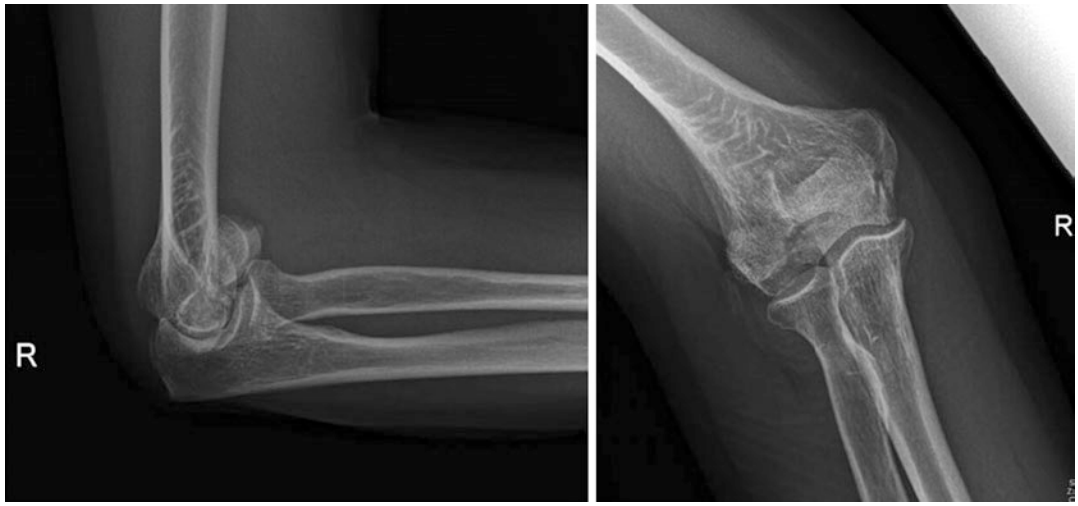

Fig. 1.1 Distal humeral comminuted coronal shear fracture of the right elbow in a 72-year-old woman. Preoperative X-rays, lateral view and anteroposterior view

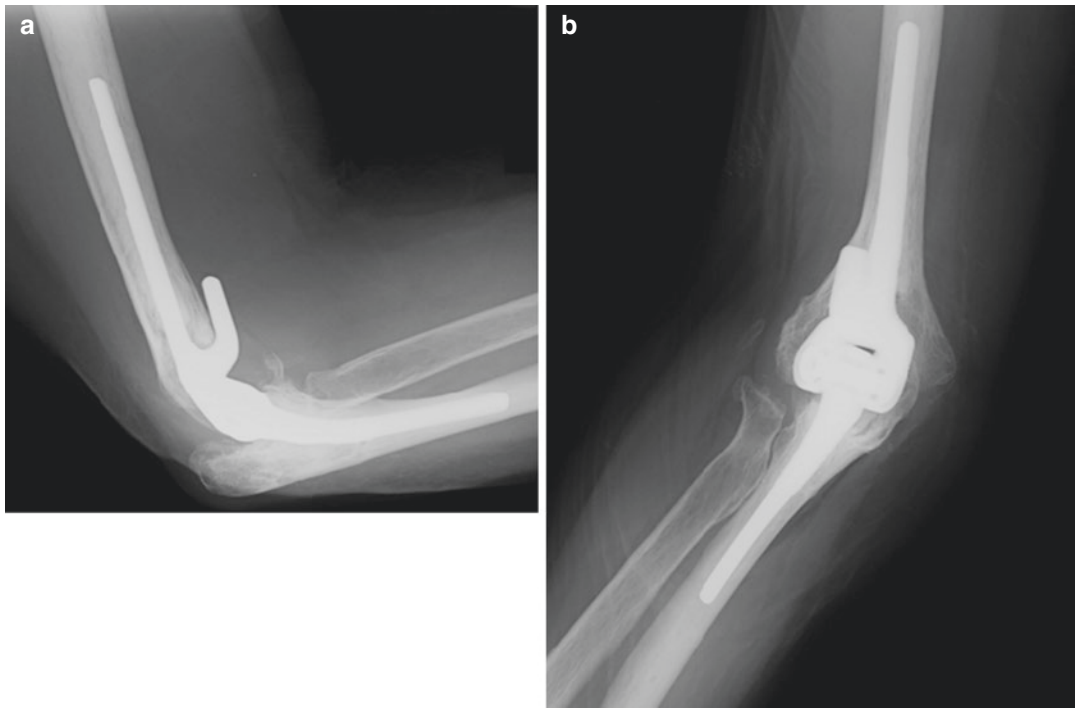

Fig. 1.2 X-rays obtained at 1-year follow-up: (**a**) lateral view and (**b**) oblique view from total elbow arthroplasty with a Coonrad-Morrey type III implant

and 8° of internal and external rotation (the Coonrad II).

In 1981, to further decrease the incidence of loosening and to resist posterior displacement and axial rotation stresses imparted to the humeral stem, the prosthesis was changed again to type III Coonrad-Morrey (Figs. 1.1 and 1.2): a long humeral stem, an anterior humeral flange to be

coupled to autologous bone graft, and a porous coating to provide components of metaphyseal integration were the main innovative features [25].

Among the semi-constrained prosthesis, also the GSB system evolved from the original design in 1971. The final result is a semi-constrained prosthesis, the GSB III, which was introduced in 1978 and essentially remained unchanged since then. The humeral component has large supporting surfaces for humeral condyles and a wide stem for transference of rotational stress. Distinctive is the oval loose link connection between the humerus and the ulna that allows 5° of abduction, adduction, and rotational movement. The coupling articular surfaces are coated with polyethylene, and the metal components are made of Protasul alloy. The outcome in terms of pain relief and ROM improvement is reported to be good in the midterm period in most studies, although the results seem to deteriorate with time because of loosening, which remains the main concern [18, 26].

Alongside semi-constrained prosthesis, from the 1970s the unlinked prosthesis was developed, including the Kudo, the Souter-Strathclyde, the IBP, and the Capitellocondylar prosthesis. Common advantages of these designs include the preservation of bone stock, decreased polyethylene wear, and the preservation of normal elbow kinematics. Since there is no mechanical linkage between the humeral and ulnar components, implant stability resides on the integrity of surrounding soft tissues (capsule and ligaments). Therefore, the main concern of all unlinked prosthesis was postoperative instability.

The Kudo prosthesis underwent several changes since its introduction in 1972. Type I consisted of a stainless steel non-stemmed humeral implant and a polyethylene ulnar component with a short stem for intramedullary fixation [27]. For type II the surface of the humeral component was modified from a cylindrical to a saddle-shaped surface. The main problem with these designs was proximal subsidence of the humeral component. To address this complication, the humeral component was redesigned to a stemmed component, changing the material to titanium with a polyethylene surface [27]. Hence, type III was used from 1980 to 1987, when the humeral and ulnar stems were changed to a porous-coated stem (Kudo type IV, 1988) [28]. The aim was to obtain a stable uncemented implant. However, the contact of titanium alloy against the high-density polyethylene led to metallosis and a high rate of ulnar polyethylene wear in many cases. Therefore, the humeral component was modified in 1990, with a cobalt-chrome alloy covered of plasma spray titanium for implant integration. The resulting Kudo type V implant is still being used, with good long-term results [17].

The Souter-Strathclyde prosthesis was first implanted by Souter in 1977. The humeral component was made of Vitallium and the ulnar component of polyethylene. The theoretical advantage consisted in the small amount of bone that had to be removed to implant the short stemmed humeral component. However, because of high loosening rates, a long-stemmed humeral component has been used more often, undermining the advantage of this implant [28].

The Capitellocondylar total elbow prosthesis is a non-constrained cemented prosthesis that has been used since 1974, and it is still widely used. The humeral components are made of cobalt-chrome alloy, while the ulnar component is made of polyethylene [17]. Reported clinical experience of 202 prosthesis implanted from 1974 to 1987 demonstrated the major complication to be postoperative dislocation of the implant. The authors noticed that anterior capsulotomy, performed to correct a flexion deformity, could be partly responsible for postoperative instability [29].

Nowadays, many studies report good results for both linked and unlinked total elbow arthroplasties, in particular in low-demand patients with rheumatoid arthritis [30, 31]. However, despite evolution of different elbow prosthesis designs, concerns regarding loosening at long-term follow-up and arthroplasty use in a younger, higher-demand patient population still remain. The latest technical evolutions of elbow implants are trying to solve these problems through implant modularity, instrumentation, and surgical technique development. The result is the convertible elbow prosthesis, which includes the

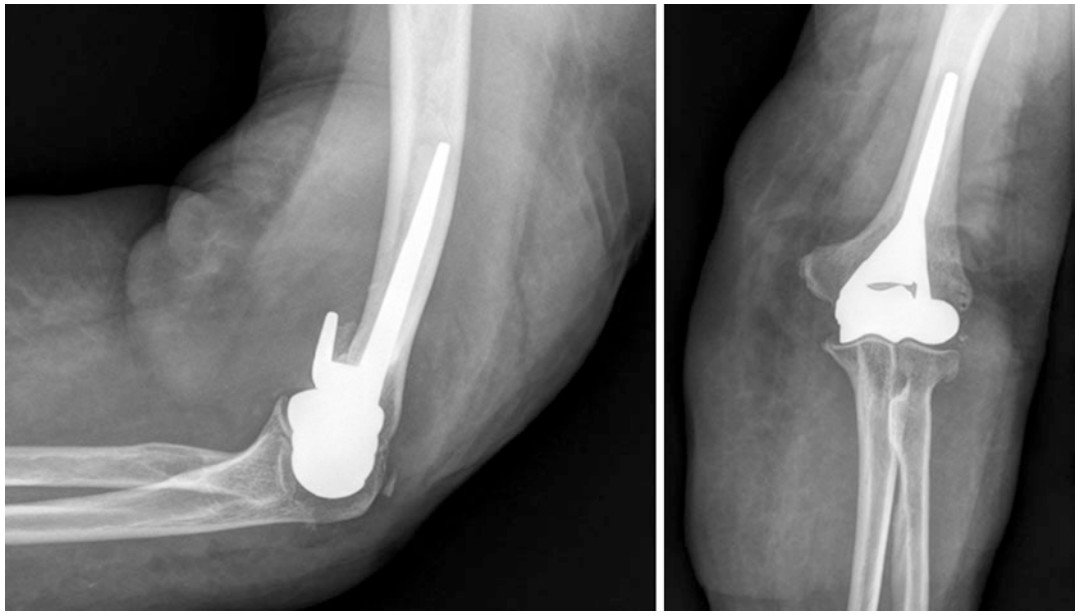

Fig. 1.3 One-month follow-up X-rays (lateral and anteroposterior views) of a hemiarthroplasty with a convertible implant in a distal humeral fracture case of the left elbow in an 80-year-old woman

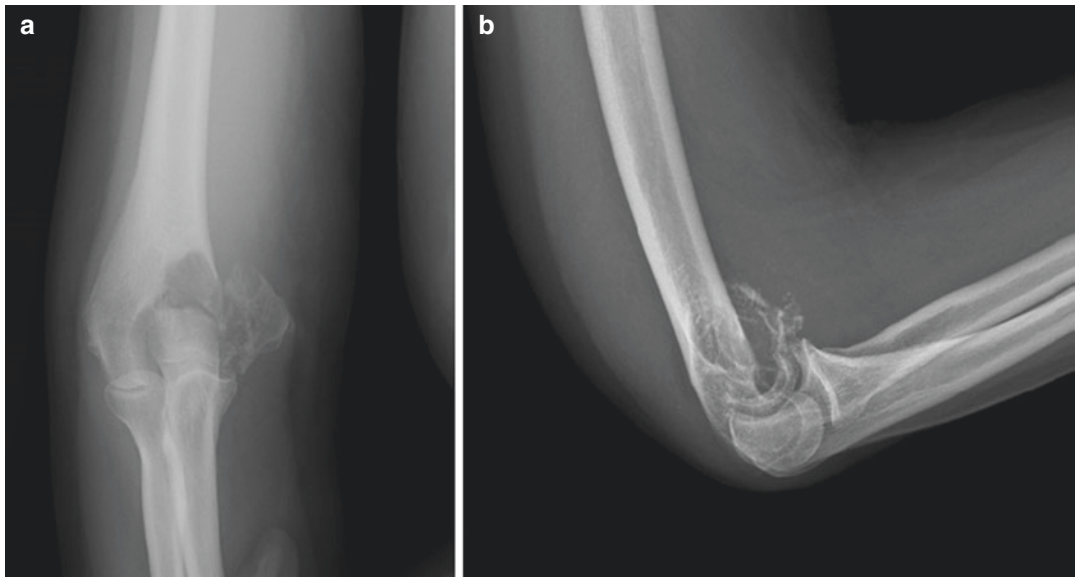

Fig. 1.4 Distal humeral comminuted fracture of the right elbow in a 69-year-old woman. Preoperative X-rays, (**a**) anteroposterior view and (**b**) lateral view

Latitude, the Acclaim, and the K-NOW total elbow systems. With these designs hemiarthroplasty (Fig. 1.3) and unlinked or linked (Figs. 1.4 and 1.5) elbow arthroplasty are all possible and can be chosen according to the conditions of the patients elbow. The conversion from a design to another can be performed at any time, without the compulsory removal of stable components.

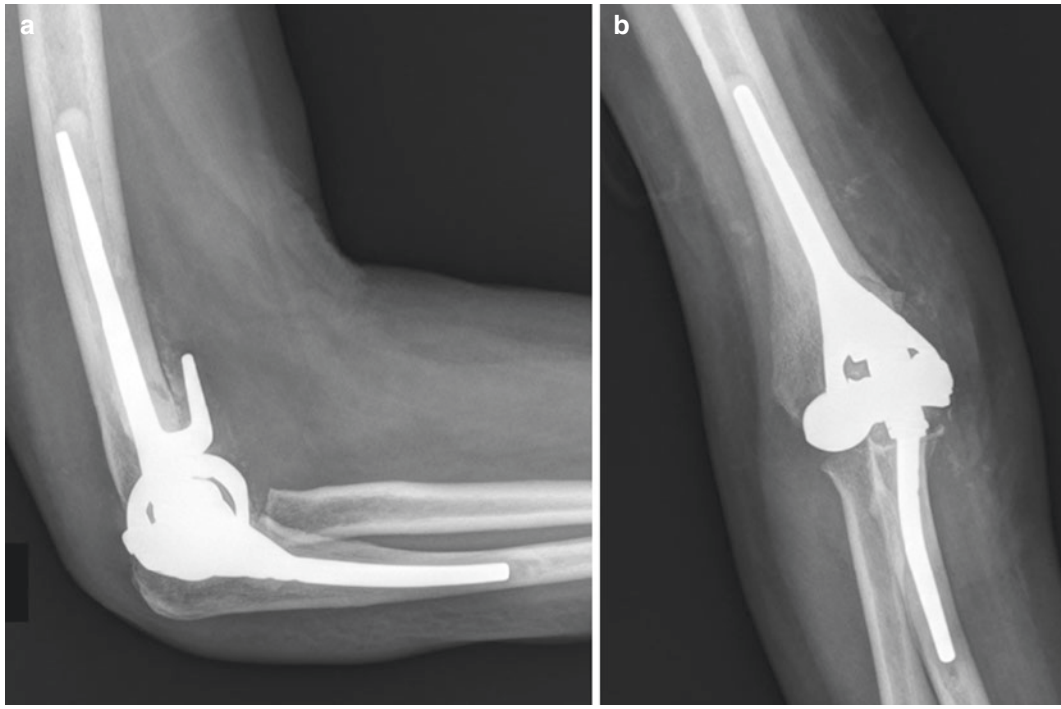

Fig. 1.5 X-rays obtained at 1-month follow-up: (**a**) lateral view and (**b**) anteroposterior view from total elbow arthroplasty with a Latitude convertible implant

1.3 Radial Head Arthroplasty

The radial head prosthesis is nowadays recommended to treat comminuted radial head fractures, complicated by ligamentous injury or other associated fractures at the elbow.

It was firstly described in the 1940s. In previous years, radial head resection was the treatment of choice, although new bone formation after resection, proximal migration of the radius, elbow or wrist pain, and elbow instability were common complications.

In the literature the treatment of comminuted fractures non-amenable to internal fixation without elbow instability is still a matter of debate. The influence of radial head resection in elbow stability with ligament integrity is indeed controversial. Biomechanical studies show that radial head resection alters the elbow kinematics, increasing the varus-valgus instability even with intact ligaments, facilitating the appearance of long-term complications as proximal radial migration, persistence pain, decreased strength, and degenerative osteoarthritis [32]. However, long-term studies with satisfactory results of radial head resection in selected patients have been published in the literature [33]. Nonetheless, a role for radial head replacement in radial head fractures with elbow instability and with forearm instability is demonstrated in the literature [32]. Therefore an evolution of radial head implants has been observed in the last decades and is still being observed.

The first radial head implant was described in 1941 by Speed to prevent heterotopic bone formation after radial head resection. He used a ferrule cap to cover the radial neck. Carr in 1951 was the first to use a radial head prosthesis to restore elbow stability. The introduction of Mason classification of radial head fractures in 1954 had an important role in giving more reproducible indication. In the first decades, a variety of materials including acrylic (Cherry), Vitallium (Carr and Howard), and silicone

rubber (Swanson et al.) were used for prosthetic radial heads [34–36].

In the 1960s different studies were conducted on previously implanted radial head prosthesis, reporting better joint motion and less pain and underlining its role in preventing proximal migration of the radius compared to capitellectomy [34].

In 1969 the Swanson Silastic radial head prosthesis became available. Although it was very popular at the beginning, in 1979 the first structural complications were reported. Fatigue failure in the treatment of Essex-Lopresti fractures, giant cell synovitis secondary to particulate debris, and intramedullary chronic inflammatory changes were noted [34]. Therefore, in the early 1980s, metallic implant was proposed again, as found in the papers of Harrington and Tountas in 1981 [37] and of Pribyl in 1986 [38]. In 1993 Knight et al. described a new Vitallium prosthesis, reporting the results of a clinical trial. They concluded that metallic prosthesis restored axial stiffness and had a role in the acute management of severely displaced fractures of the radial head associated with dislocation or ulnar fracture.

All radial head implants described and used until the late 1980s were unipolar. However, differences in stem fixation could be found and should be remarked. The majority of these implants had a symmetric head with a smooth stem, not fixed with cement (loose stem). The lack of head asymmetry in these implants should be compensated by the little movement of the stem within the radial neck. This should also improve the congruency of the articular surface of the implant with the capitellum and the proximal part of the ulna. Several authors reported that the role of metal spacer provided by these implants leads to satisfactory results and was useful in the treatment of traumatic elbow instability [37]. On the other hand, fixed stem implants aimed at anatomic reproduction of the radial head; therefore design was important as well as implanting technique. This is especially true for monoblock unipolar prosthesis, which were used in those years. Yian et al. have shown that malalignment of unipolar implants can lead to decreased radiocapitellar contact area and increased cartilage wear due to stress concentration [38]. Biomechanical and anatomical studies have shown the importance of an accurate reproduction of the size and orientation of the radial head to restore the complex articular movements of the elbow. Moreover, an axial understuffing or overstuffing of the radiohumeral joint by >2.5 mm alters indeed both elbow kinematics and load transfer. The consequences are the decrease of ROM and pain, followed by erosion of the capitellum, necessitating prosthesis removal in some cases.

To overcome these complications and to maximize radiocapitellar congruency and contact forces, Judet et al. introduced a bipolar prosthesis in 1988. The “floating” radial head prosthesis was made of cobalt chrome, had a collared stem with a 15° neck shaft angle, and consisted of two parts connected by a spherical joint allowing to telescope or rotate in all planes. The radial head was symmetric, composed of metal or pyrocarbon, and bridged to the radial neck by a mobile polyethylene on chromium bearing at the head-neck junction. Theoretically, the purpose of this design was to reduce stress at the implant-bone interface, to increase the contact area of the radiocapitellar joint, and to permit a full contact with humeral surface during elbow movements [35]. However, because of this increased motion, there is greater potential for osteolysis, particle disease, and osteoarthritis at the radiocapitellar joint space. In 1996, Judet et al. reported their promising results with the floating radial head prosthesis. The floating articulation and concave surface of the implant allow continual full contact to be maintained against the convex humeral condyle during flexion/extension and supination/pronation of the elbow [35]. During the same period, Judet et al. introduced a new implant with a radial head composed of pyrocarbon. This is a biocompatible material introduced in medicine in 1969 for artificial heart valves. Apart from being very biocompatible and mechanically similar to the bone, pyrocarbon has also high wear resistance and superior polishing with respect to other materials, allowing minimal wear [35].

Nonetheless, in 2009 O’Driscoll reported some disadvantages of the Judet bipolar prosthesis: the tilt of radial head under unbalanced or

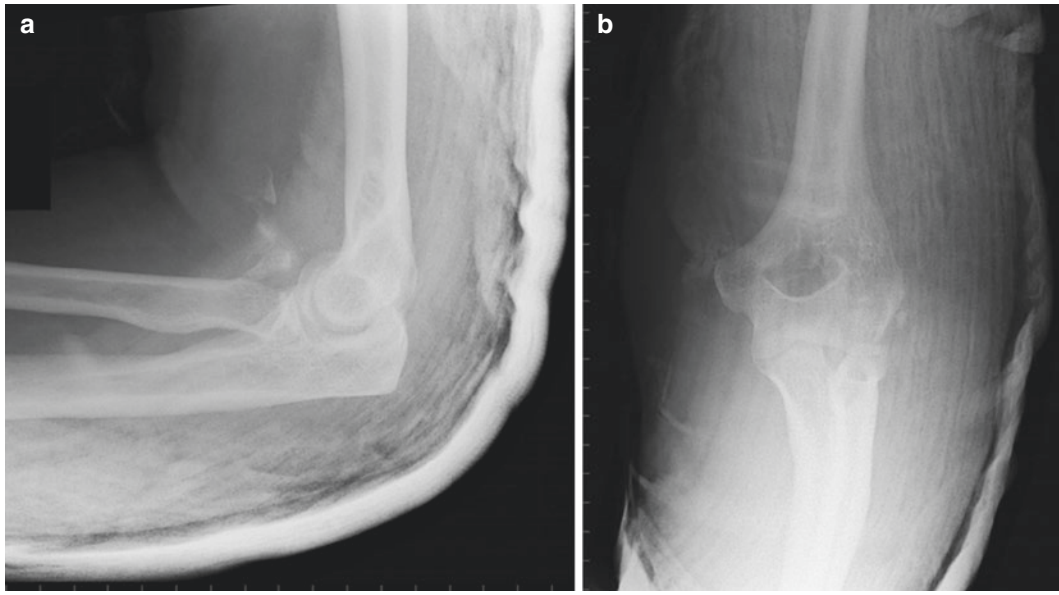

Fig. 1.6 Left elbow dislocation with comminuted radial head fracture in a 43-year-old man. Preoperative X-rays, (**a**) lateral view and (**b**) anteroposterior view, obtained after dislocation reduction and cast immobilization

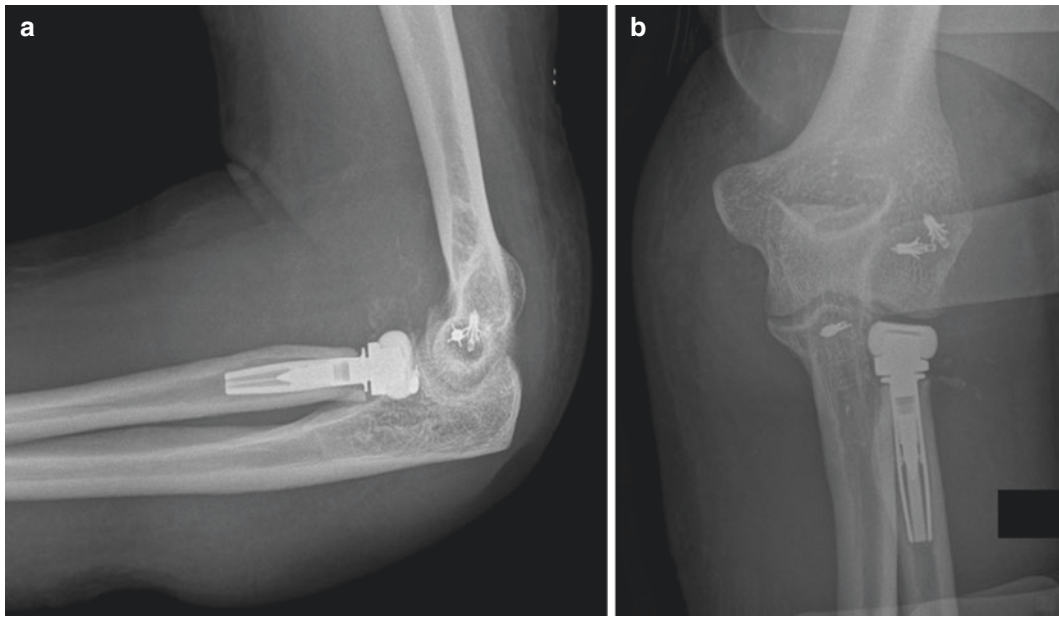

Fig. 1.7 X-rays obtained at 1-month follow-up: (**a**) lateral view and (**b**) anteroposterior view from radial head arthroplasty with a modular implant and capsular and ligamentous reconstruction

eccentric load and the possible disassociation of the head from the stem [39].

The most recent evolution of radial head prosthetic designs leads to modular implants (Figs. 1.6 and 1.7), able to restore the anatomy and the radial head kinematics [40]. In 2012 Sarris et al. proposed the modular pyrocarbon (MoPyC) radial head prosthesis. It consists of a radial head

made of pyrolytic carbon and an anatomic neck with an angulation of 15° and a fixed stem, both made of titanium alloy [41].

Nowadays, radial head prostheses may be categorized according to material (silicone, polyethylene, pyrocarbon, metal), modularity (monoblock versus modular), polarity (unipolar or monopolar versus bipolar), or fixation (cemented, uncemented press fit, intentional loose fit, or fixation with an expandable stem).

Although modern radial head replacements have largely improved in recent years considering their designs and materials, complications are still present. Although failure of the prosthesis is rare, loosening and dislocation of the prosthesis have been described. The main concern is the mismatch in sizing the prosthesis with the native radial head and the difficulty in reproducing precise functional anatomy of the radial head, unless a simple spacer is used. Thus, clear superiority of a prosthetic design still has to be determined, in particular comparing anatomical implants and loose-fit spacers.

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2 Epidemiology and Demographics of Elbow Arthroplasties

L. Tarallo

Abbreviations

DMARDs	Disease-modifying anti-rheumatic drug
TEA	Total elbow arthroplasty

2.1 History of Elbow Arthroplasty

Total elbow arthroplasty (TEA) was developed in response to the failures of previous procedures in the treatment of elbow arthritis. This included resection arthroplasty and interposition arthroplasty. Resection arthroplasty was originally performed as a salvage procedure for elbow infection (i.e. tuberculosis) [1]. Interposition arthroplasty with various autologous tissues (e.g. fat, muscle, tendon, or fascia) was initially described in 1893 by Schüller [2]. This technique was popularized in the early twentieth century by Putti [3], among others. Both procedures yielded unpredictable results.

From the late 1940s through the 1960s, surgeons began implanting custom-made constrained hinged metal devices. These implants relied on both extracortical and intramedullary implantation [4]. The outcomes were poor with unacceptable rates of loosening and instability [5, 6]. 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 [7] and later by Barr and Eaton [8]. Unfortunately, these early elbow designs were also complicated by instability, loosening, recurrent pain and overall poor function [9, 10].

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 [11]. 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 linked prosthesis. Unfortunately, the fully constrained hinge design transferred stress directly to the bone-prosthetic interface and resulted in high rates of aseptic loosening and prosthetic failure [12–14].

Non-constrained prostheses were developed in order to solve the problem of early aseptic loosening. Roland Pritchard was one of the first surgeons to recognize the value of a loose hinge joint with a polyethylene bushing [15]. This implant design aimed to reduce stresses on the

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bone cement interface and relied on the native soft tissue for stability. Perhaps a relatively high incidence of postoperative instability was reported in some series, due to difficulties in maintaining a competent soft tissue envelope during surgery [16, 17].

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 semi-constrained device that permitted 7–10° of laxity [18]. In addition, an anterior hinge was added to the humeral component to improve stability against the anteroposterior and rotational forces about the prosthesis. The designs of the Coonrad-Morrey prosthesis have notably decreased the previously reported high complication rate for total elbow arthroplasty, and nowadays it appears to be the most implanted model [19, 20].

2.2 National Arthroplasty Register

The chance to analyze the demographics and the epidemiology of prosthesis implants is possible, thanks to joint replacement registries established in some countries in the last decades of the twentieth century. First national registries that were established considered only knee and hip implants [21], but inspired by the experiences with hip and knee registration, shoulder and elbow replacement have been added to existing joint replacement registries or have been established as individual registries in the first decades of the twenty-first century.

Although little is known about current surgical utilization of TEA, we can perform a descriptive analysis of demographics in some countries whose national arthroplasty databases are free to consult.

Considering the records reported in Norwegian Arthroplasty Register [22], the number of prostheses performed per year from 1994 to 2016 decreased in that specific country. In fact primary TEA performed in 2000 was 36, while the same procedure performed during the year 2016 decreased to 26 operations in all the country (Fig. 2.1).

In Australia and Great Britain, the trend is different: according to available data of Australian Joint Registry and NJR, the English registry of arthroplasty, the number of procedures is increasing.

In fact, in Great Britain, while the number of lateral resurfacing procedures has almost disappeared in the last years, the total number of

Fig. 2.1 The trend of elbow arthroplasty implantations from 2000 to 2016 in Norway

implants, especially taking into account total elbow arthroplasties performed, has increased from 243 per year in 2012 to 439 per year in 2015 [23].

In Australia, whose registry of arthroplasty allows to check the number of procedures performed in every State of the Country, we can see that the biggest number of TEA performed per person is implanted in Victoria, the most urbanized state in all the island, probably because of the surgery cost, while the number of arthroplasties implanted is lower in the poorest states of Australia [24, 25].

According to RIAP, the Italian registry of arthroplasty, the number of primary total elbow arthroplasties has increased in our country too, going from 361 in 2001 to 499 operations in 2014.

Day et al. reported the number of TEAs performed in the United States increased at a rate of 6.4% in annual procedural volume and 7.6% in annual growth between 1993 and 2007 [26] (Fig. 2.2).

The increase in the number of total elbow arthroplasties performed in the last years seems to be due to the change of indication: in fact, while in the past the main indication for total elbow arthroplasties was represented by patients affected by rheumatoid arthritis with a long story of pain and stiffness in both elbows, actually good results can be obtained implanting total elbow prosthesis to treat elbow fractures, especially in osteoporotic patients [27].

Meanwhile the number of patients with inflammatory arthritis who demand for elbow replacement is decreasing, thanks to the great clinical results obtained by medical management which went through great development during the last years, especially taking into account the introduction of immune-suppressing and immune-modulating drugs.

On the other hand, the possibility of replacing elbow joints who appeared hardly disrupted by comminuted fracture in elder and in low functional demand young patients appears to be a good solution to allow trauma victims to get a good quality of life.

Unfortunately total elbow arthroplasty is still an uncommon procedure in comparison with the prosthesis implanted in other joints so the availability of data and information is limited.

For example, no federal TEA registry has been established in the United States despite calls for such a registry. Previous analysis of TEA utilization rates in the United States has been carried on by regional or national databases which allows to consult just limited information [28].

However, even in the United States, recent trends report an increase in the number of TEA procedures performed per year to treat trauma than to solve pain and stiffness due to inflammatory arthritis [29].

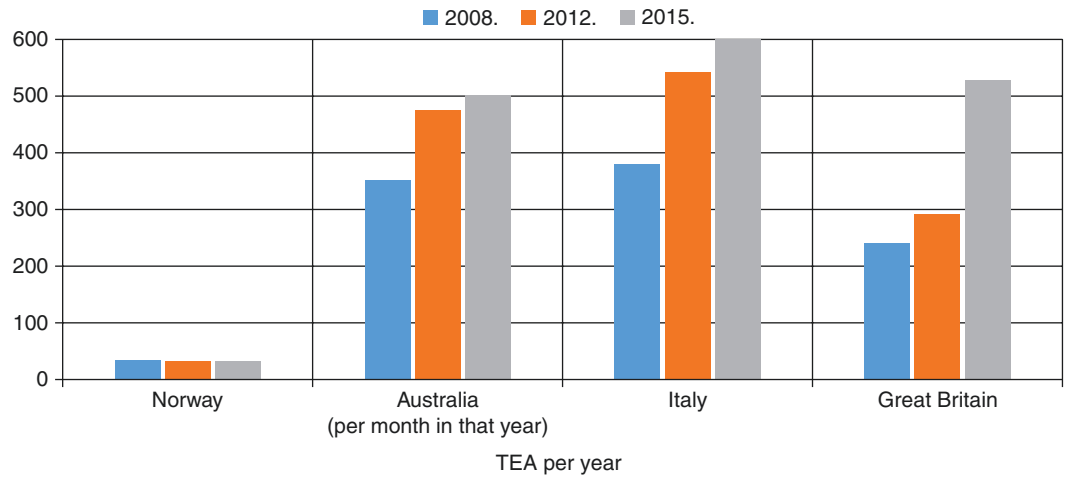

Fig. 2.2 The trend of elbow arthroplasty implantations in Norway, Australia, Italy and Great Britain in 3 different years

2.3 Aetiology Trend of Elbow Arthroplasty

However, if we study a trend according only to aetiology, until 2001, the majority of TEA were performed to the management of rheumatoid elbows [30]. Over the last 20 years, the natural history of inflammatory elbow arthropathy has changed. It is hypothesized that the common use of disease-modifying anti-rheumatic drugs (DMARDs) in the medical management of rheumatoid patients changes the management of RA to other indications, as just highlighted. This data was demonstrated in a study conducted by Jacob J. Triplet [31] who reviewed TEA trends in the Medicare population from 2005 to 2012 and compared utilizations for the most common indications, including acute distal humerus fracture, osteoarthritis, post-traumatic arthritis, rheumatoid arthritis and distal humerus nonunion. This analysis showed a significant decline in TEA use for rheumatoid arthritis. Surprisingly, there was also a decline in TEA use for distal humerus nonunion. These findings may be explained secondary to the prevalence of DMARDs for rheumatoid arthritis and the greater comfort of surgeons with improved fracture fixation options in managing distal humerus nonunion. Nevertheless, best results have been recorded in inflammatory arthritis patients and in elder distal humerus fractures' patients [32–34], while the satisfaction of young patients whose prosthesis was implanted after acute trauma is worse [35]. This is probably due to the lower functional demand of the first group. The same trend incidence over time among inflammatory arthropathies and trauma treatments is underlined in another national study: Jenkins et al. [36] use Scottish National Arthroplasty register to highlight an increase in TEA for osteoarthritis and trauma, but the overall numbers were low (Fig. 2.3).

The Norwegian registry reported similar results on 562 TEA procedures over a 13-year period [32]. Rheumatoid arthritis was the most common diagnosis, and the data showed a similar reduction in rate over time (Fig. 2.4).

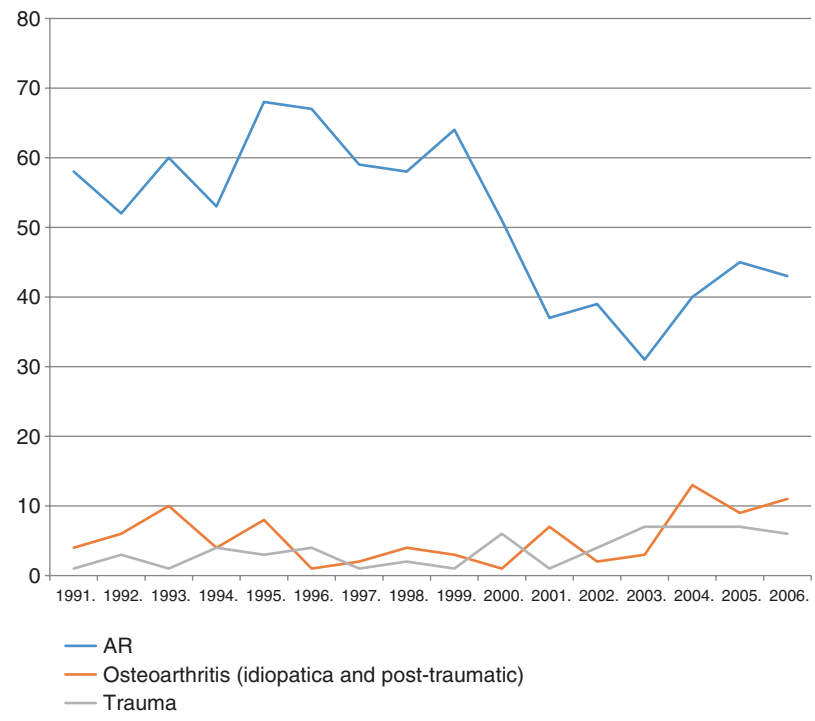

Fig. 2.3 The aetiology trend in Scottish National Arthroplasty from 1991 to 2006

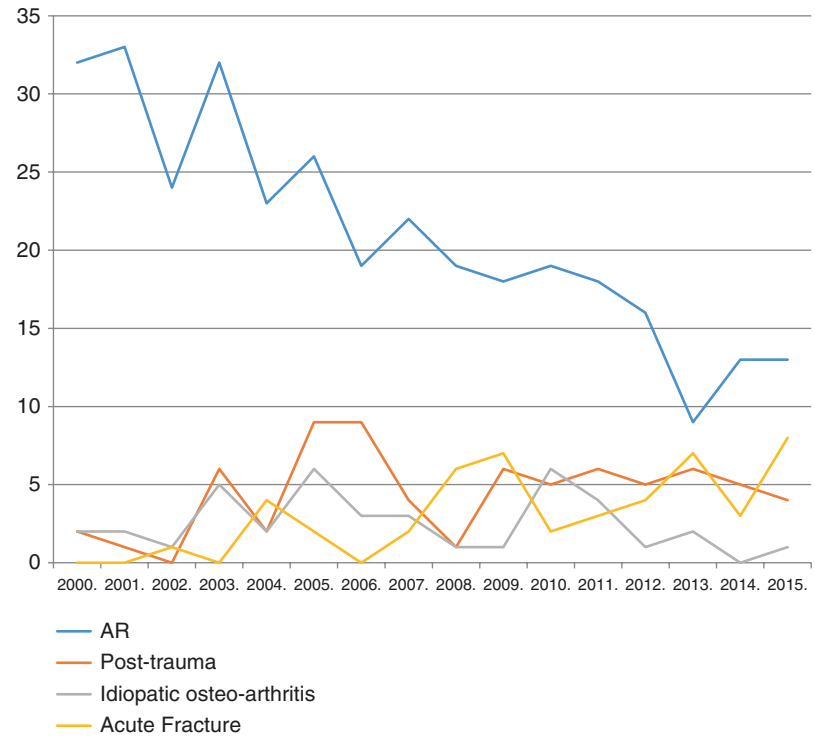

Fig. 2.4 The aetiology trend in Norwegian National Arthroplasty from 2000 to 2015

2.4 Sex Trend of Elbow Arthroplasty

Several interesting observations could, also, be linked to sex features. TEA procedure rates were higher for women than men during 1993–2007 in the United States [37] (Fig. 2.5).

Jasvinder et al. highlighted the mortality rates were lower in females, which is consistent with findings from a recently published systematic review of post-arthroplasty mortality [38]. One previous study focused on sex differences in knee arthroplasty outcomes using Pennsylvania database reported higher mortality in males compared to females, consistent with results of previous study [39]. Jasvinder A. Singh et al. extend this finding to TEA and to a US representative sample. The females had a shorter index hospital stay compared to males, despite the fact that females were older [40]. It is important to underline that females can often be free from work for a longer time than men, influencing clinical and functional results after the surgery [41]. On the contrary, the social support to females is lower compared to males [42]. Social support is a strong predictor of the possibility of discharging in job duties and home setting [43–45]. Dependence on family member increases the likelihood of successful discharge to home [46].

On the other hand, complications after TEA did not seem to worsen over time, in both females and males. This is an important observation, indicating that careful preoperative and postoperative management and the implementation of a more efficient post-arthroplasty discharge planning and care coordination [47] might be helping prevent higher health care utilization and costs that are anticipated due to increasing complexity of patients undergoing TEA.

2.5 Racial Trend of Elbow Arthroplasty

Using National Inpatient Sample, it is possible to analyze also incidence and outcomes of TEA implantation based on racial features. Zhou et al. [29] underlined that the most

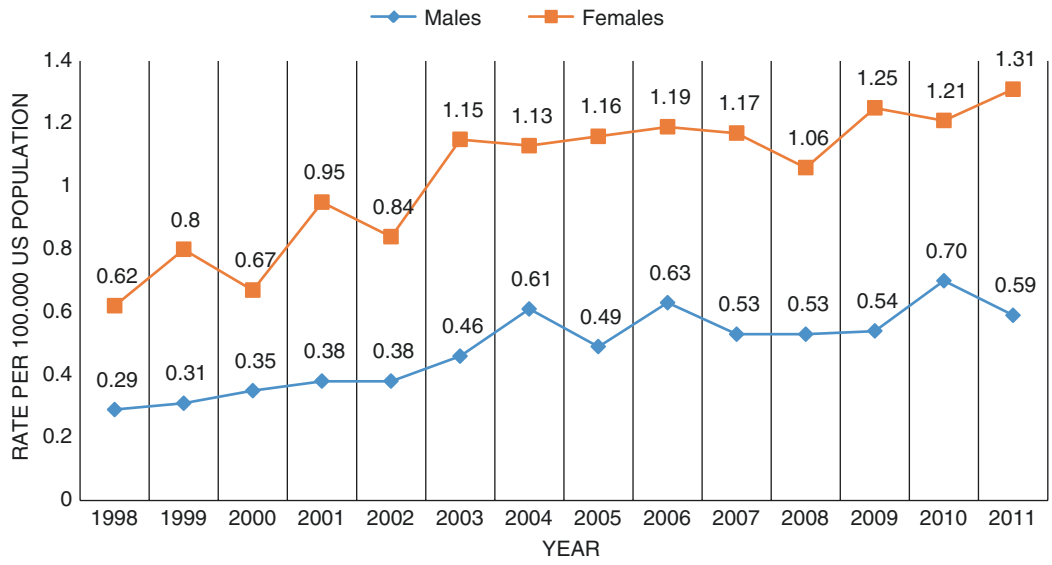

Fig. 2.5 Time trends in TEA utilization by sex

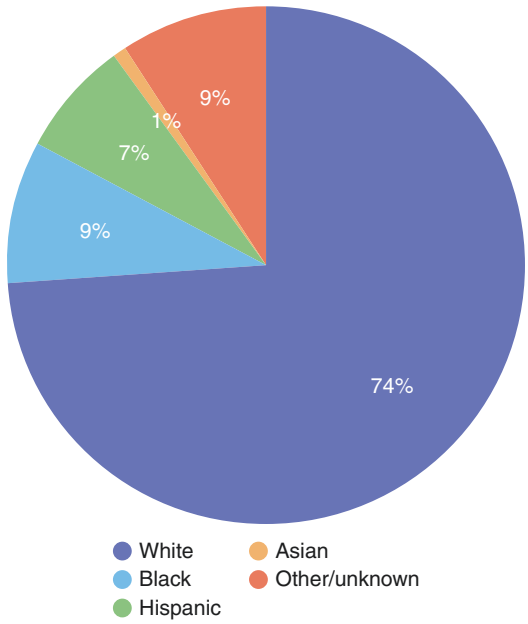

Fig. 2.6 Racial trend in United States in 2016

common group of patients undergoing total elbow arthroplasty is primarily White females in US population, which is consistent with previous epidemiological studies (Fig. 2.6) [48] This is likely related to increased number of osteoporotic traumatic elbow fractures seen in this patient population.

Singh et al. [30] in a recent study assess racial disparities in utilization rates and outcomes after primary total elbow arthroplasty. There were 3471 Whites and 308 Blacks who underwent primary TEA in our NIS sample from 1998 to 2010 (Fig. 2.7). Compared with White patients, Black patients undergoing TEA were younger, less likely to be female and more likely to have rheumatoid arthritis as the underlying diagnosis. Mortality was rare in both populations. Considering work-discharging, in adjusted analysis, it's reported that White people have access to inpatient facility more easily than Black people, but in studies adjusted for age, sex and Deyo-Charlson index, the chances are the same in both groups. Finally, the length of hospital stay appears to be longer of the average in 31.2% of Black people and in 29.8% Whites, demonstrating the fastest clinical resolutions in the second group. No White-Black disparities were noted in TEA outcomes, except slight differences in discharge disposition.

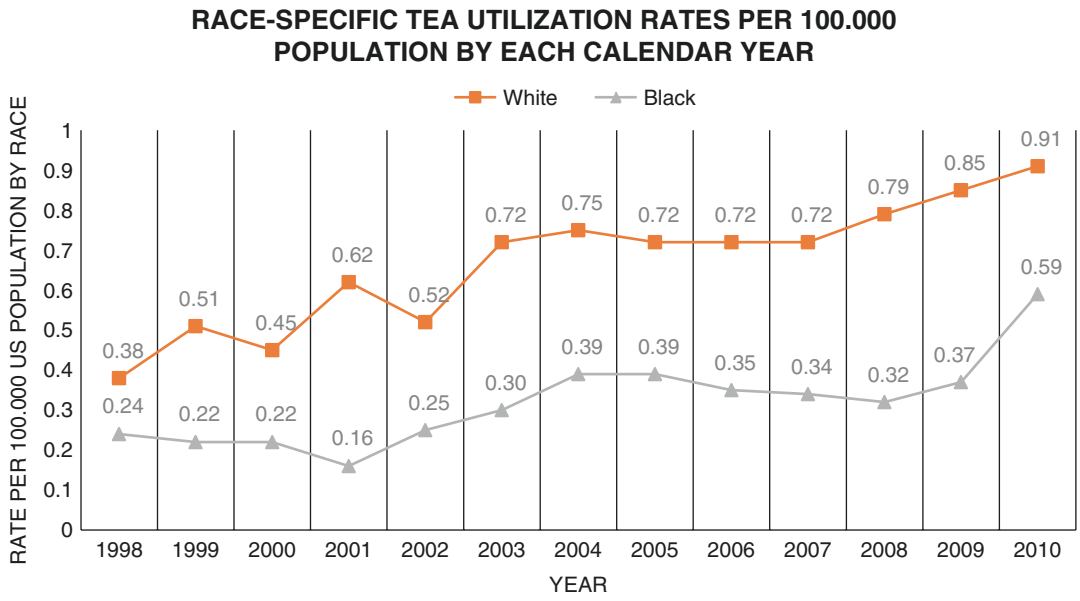

Fig. 2.7 Race-specific TEA utilization rates from 1998 to 2010 in United States

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3 Anatomy of the Elbow and How It Affects Implant Design

D. Polimanti and G. Giannicola

3.1 Distal Humerus

The distal humerus is triangular in shape, with an articular surface that represents its base and lateral and medial columns that represent the other two sides. The articular surface of the distal humerus is divided in two parts by a slight ridge: the humeral capitellum laterally and the trochlea medially (Fig. 3.1).

3.1.1 Capitulum of the Humerus

Although capitellar implants have recently become commercially available, the morphology of the capitellum has not yet been fully characterized. Few articles have been published in the literature on this topic. An understanding of the morphology of the capitellar articular surface is of paramount importance in ensuring optimal joint biomechanics when undertaking arthroplasty reconstruction of one or both sides of the radiocapitellar joint.

The capitulum of the humerus was routinely assumed to be spherical. However, McDonald et al. [1] suggested that the shape of the capitellum is more complex than is generally believed. Sabo et al. [2] analyzed its morphology in 50 cadaveric human elbows using CT scanning. The authors' aim was to provide a detailed description of the morphology of the humeral capitellum to assist in the development of an optimal capitellar implant design. They reported a mean height of 23.2 mm (range, 18.3–29.5), a mean width of

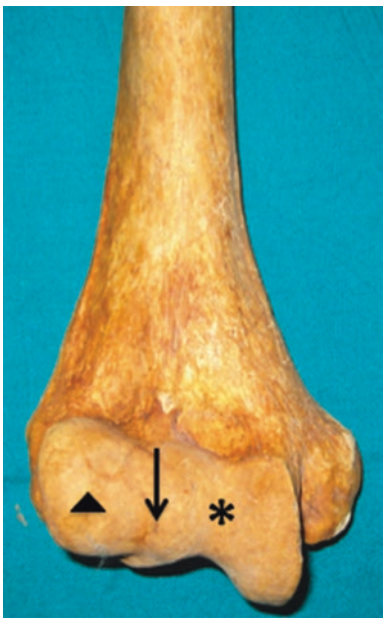

Fig. 3.1 Anterior aspect of the distal humerus: *, humeral trochlea; arrowhead, capitellum; arrow, trochleocapitellar sulcus

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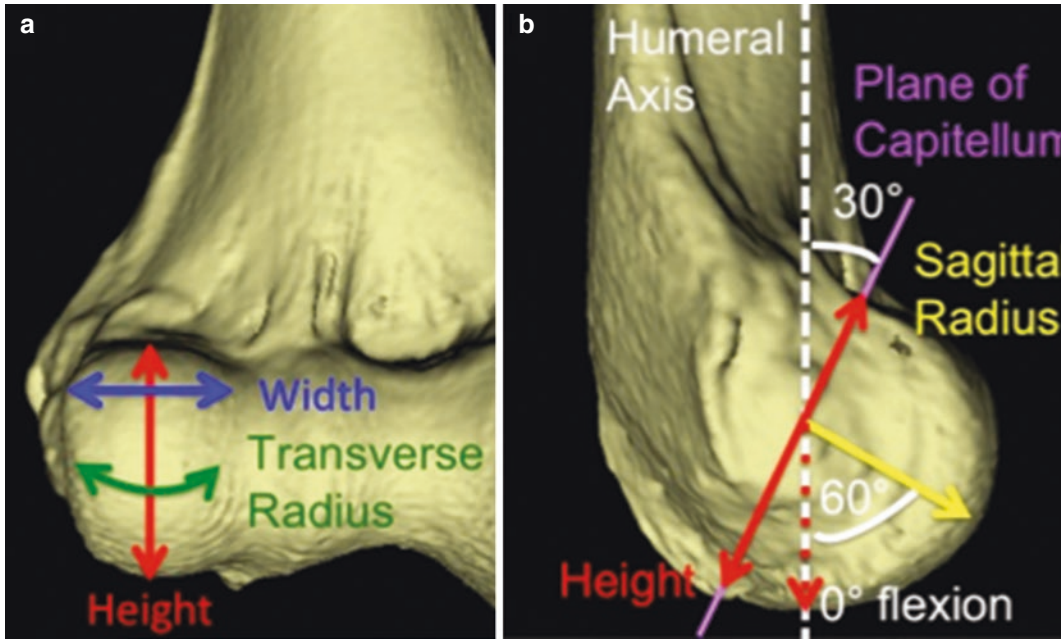

Fig. 3.2 Parameters used to describe the capitellum. (**a**) Anterior-posterior view of the capitellum showing the height, width, and transverse radius. (**b**) Lateral view showing the orientation of the plane of the capitellum in relation to the humeral shaft and the measurements used to determine the height and sagittal radius. Source: Sabo et al. [2]. Reproduced with permission from Elsevier

13.9 mm (range, 9–19), a mean transverse radius of curvature of 14 mm (range, 9.6–20.9), and a mean sagittal radius of curvature of 11.6 mm (range, 8.7–14.8) (Fig. 3.2).

The study by Sabo et al. [2] definitively demonstrated that the capitellum is not spherical but somewhat ellipsoid, with a greater radius of curvature in a medial-lateral direction. Therefore, despite being conceptually simple and easy to manufacture, a spherical capitellar implant would not articulate with the native radial head in the same way as the native capitellum. Indeed, the spherical surface, which underestimates the transverse radius of curvature, might alter the contact stresses on the center of the radial dish and apex of the capitellum. Furthermore, the authors reported a moderate correlation between height and width as well as a strong correlation between the sagittal and transverse radii of curvature, thereby suggesting that it should be possible to develop a commercially viable, off-the-shelf, capitellar implant that fits the majority of patients.

Future works, based on kinematic testing and the assessment of the contact area with both the native and reconstructed radial head, are needed to assess the viability of these proposed implant designs prior to their utilization in patients.

3.1.2 Trochlea

The trochlea forms the medial portion of the articular surface of the distal humerus. It consists of a deep depression, called the trochlear groove, between two well-marked borders, i.e., the medial and the lateral ridge, that perfectly match the sigmoid notch of the ulna and form the ulnohumeral joint of the elbow. A thorough knowledge of this articular surface is of paramount importance to the development of a distal humeral hemiarthroplasty because an altered contact pattern results in premature wear of the ulnar and radial cartilages, which in turn causes pain and functional impairment and may lead to a total elbow arthroplasty conversion [3–5].

However, few studies have investigated the characteristics of the articular surface of the trochlea. Goldfarb et al. [6] studied the osseous anatomy of the elbow using standard anterior-posterior and lateral radiographs in 178 subjects. They subjectively evaluated the surface contour and identified three different patterns: a flat contour, defined as type 1 (20.8%); a small ridge with shallow adjacent sulci, defined as type 2 (61.2%); and a prominent ridge with deep sulci, defined as type 3 (18%) (Fig. 3.3).

When Giannicola et al. [7] subsequently studied the variability of the bony and cartilaginous trochlear notch angle (TNA) on the MRI scans of 78 healthy elbows, they reported a mean TNA of 142° but also found that this angle varies considerably (range, 124–156°). This marked difference results in significant anatomical variations in trochlear shape, which may be less or more concave regardless of the size of the bone or gender of the subject (Fig. 3.4). Moreover, the cartilaginous layer does not affect this angle at the level examined. These findings may be relevant to anatomical implant design for distal humeral hemiarthroplasty.

In another study, Giannicola et al. [8] reported that the cartilage thickness modifies the morphology and diameter of the distal humeral articular surface. Indeed, they found that the cartilage thickness varied considerably (range, 0.4–1.8 mm), it being thinner at the medial and lateral edges but thicker at the level of the trochleocapitellar and trochlear grooves, the lateral trochlear ridges, and the center of the capitellum.

The importance of the variability of the cartilage layer emerges from two recent biomechanical studies that analyzed the effect of anatomical distal humeral hemiarthroplasty (DHH) on articular contact of the elbow [9, 10]; both studies detected significantly altered contact patterns at the proximal radial and ulnar joints. These studies concluded that the main reason for the altered contact patterns might have been that the prosthe-

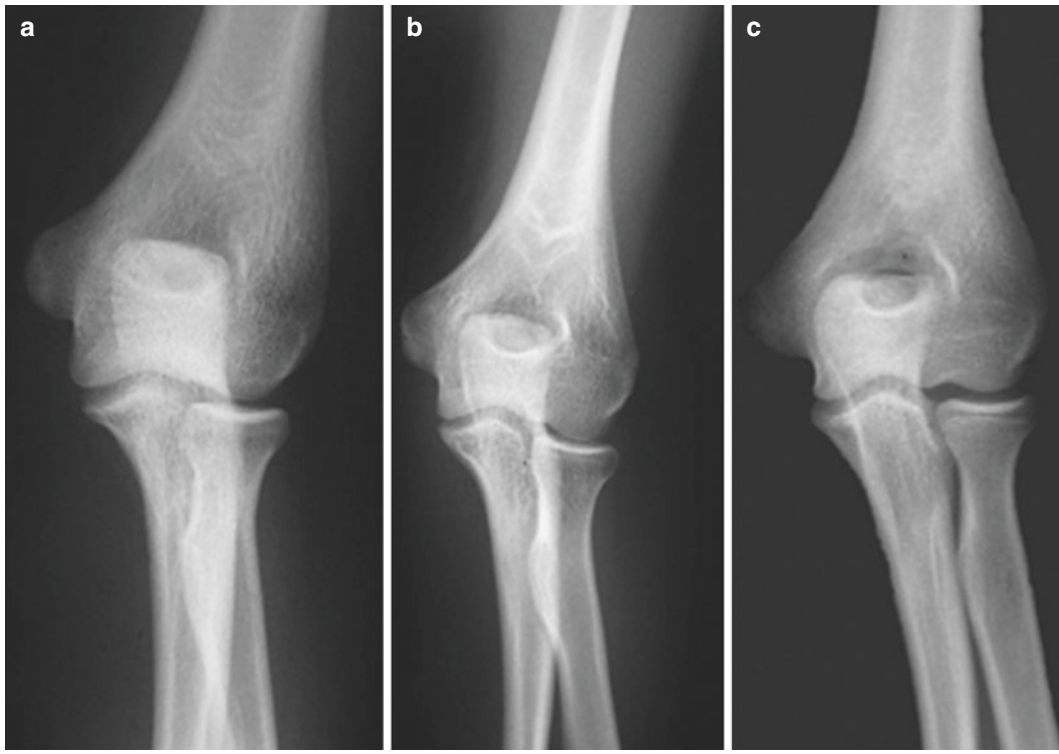

Fig. 3.3 Examples of (**a**) type I distal humerus contour; (**b**) type II distal humerus contour; and (**c**) type III distal humerus contour. Source: Goldfarb et al. [6]. Reproduced with permission from Elsevier

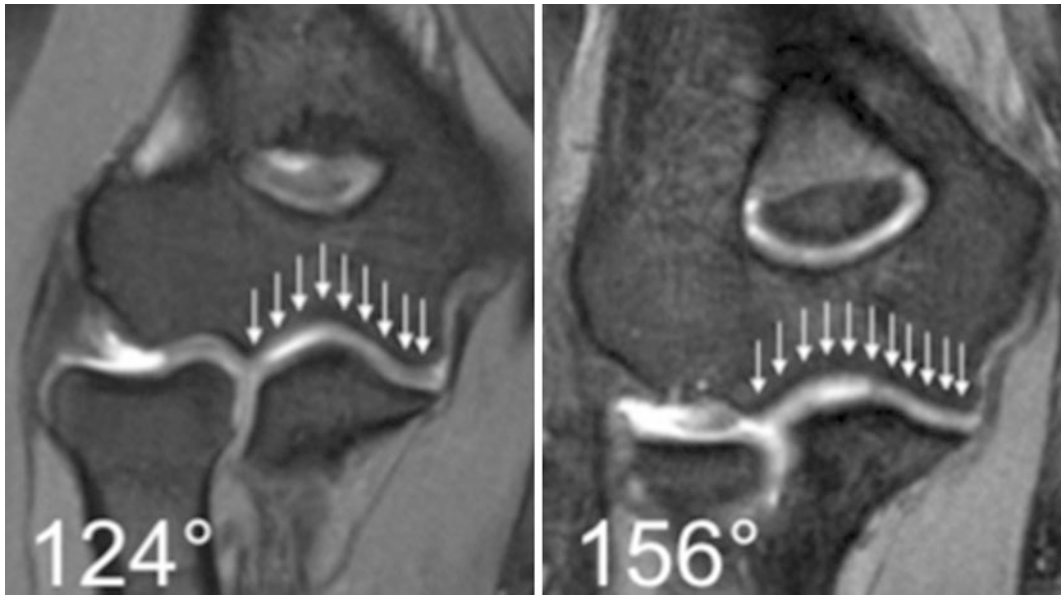

Fig. 3.4 Two extremes of the shape spectrum of the trochlear notch angle. Source: Giannicola et al. [7]. Reproduced with permission from Springer

ses were designed on the basis of the distal humeral osseous anatomy, without taking into account the effect of the cartilage thickness.

When Willing et al. [11] compared different models of a reverse-engineered distal humeral hemiarthroplasty with and without the cartilage layer in a subsequent study, they observed that the latter yielded the largest contact areas and lowest contact stresses.

In conclusion, the morphological shape and diameter of the trochlea may vary depending on the osseous contour and cartilage thickness; the design of anatomical prosthetic devices should thus not only be based on different sizes of the humeral spool, but different shapes of this component should also be made available.

3.1.3 Morphology of the Distal Humerus

The orientation of the articular surface of the distal humerus on the lateral plane is commonly reported to be rotated anteriorly by about 30° in relation to the long axis of the humerus (Fig. 3.5a). On the frontal plane, it is tilted approximately by 6° in valgus (Fig. 3.5b), while on the transverse plane, the articular surface and rotation axis are rotated inward by approximately 5° [12] (Fig. 3.5c).

Brownhill et al. [13] determined the relationship between the medullary canal axis and the flexion-extension axis of the distal humerus as they are relevant to implant design and selection for total elbow arthroplasty. Computed tomography scans of 40 fresh-frozen cadaveric specimens were analyzed using computer-aided design software. The authors calculated the anterior offset, the cubital angle, and the anteroposterior curvature of the distal humeral canal (Fig. 3.6). The results showed that the anterior offset varies significantly (range, 6.6–11.1 mm), with higher values being observed in males, and that it is directly proportional to the length of the medullary canal; furthermore, it does not correlate with articular size. The mean cubital angle was 87.3° ± 2.8°, with no differences emerging between males and females, while the radius of curvature of the humeral canal (anatomical bow) was typically apex posterior and increased in more proximal sections. Brownhill et al. [13] suggested that, when humeral components for total elbow replacement are being designed, the anterior off-

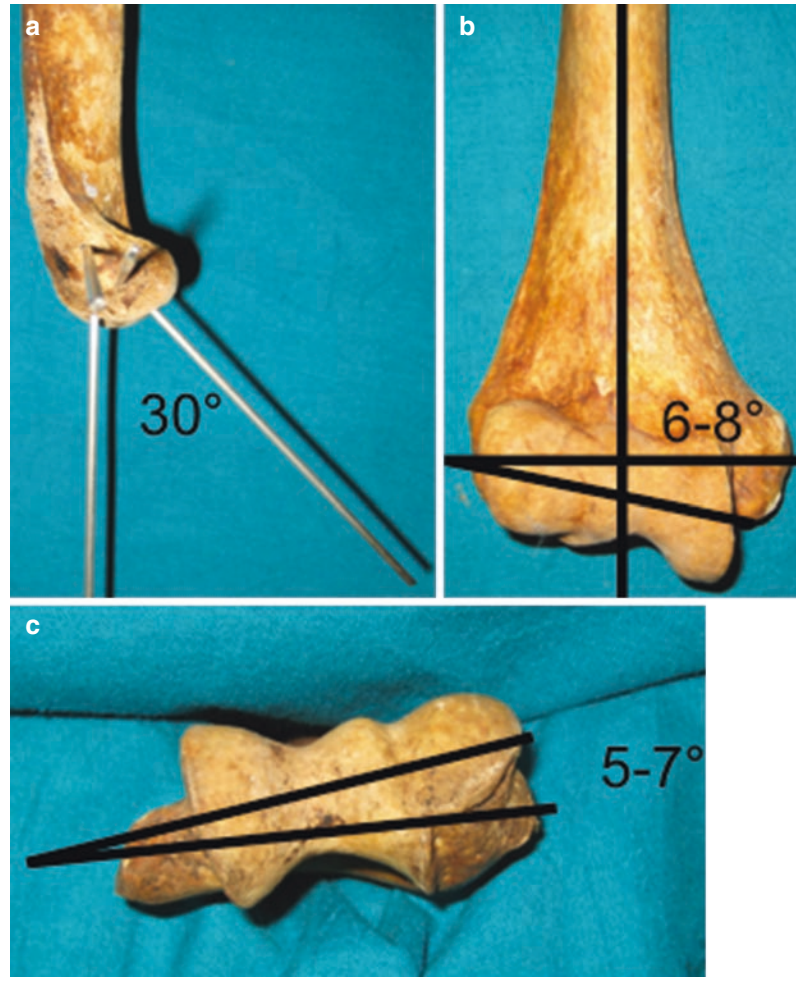

Fig. 3.5 Sagittal (**a**), coronal (**b**), and axial (**c**) view of the distal humerus. See the text for the explanation

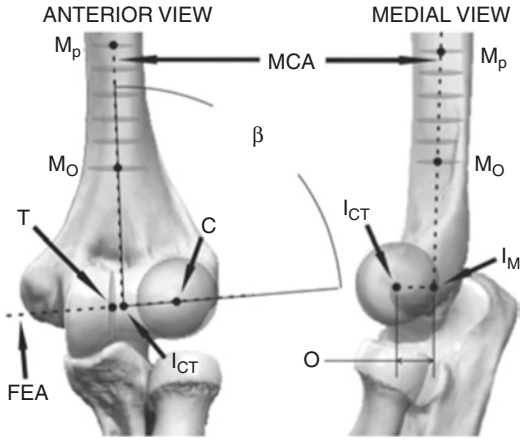

Fig. 3.6 The anterior offset (O) of the flexion-extension axis (FEA) defined as the offset of the trochlea from the medullary canal axis (MCA) on the sagittal plane. The cubital angle (β) was measured between the MCA and the FEA on the frontal plane. Source Brownhill et al. [13]. Reproduced with permission from Elsevier

set should be proportional to a straight stem's length, be larger in men than in women, and be considered separately from the width of the articular component. The increased offset is likely to be a result of the anteroposterior curvature of the distal third of the humerus (i.e., anatomical bow), which causes longer straight stems to be angled more posteriorly. By designing stems with a slight apex posterior curvature in the distal portion and a straighter proximal section, implants may be better aligned with the center of the canal, thereby allowing the design of press-fit uncemented stems or a more uniform cement mantle around cemented stems [13, 14].

Lenoir et al. [15] conducted a CT scan study of 22 elbows in 21 patients to evaluate the effect of morphological features of the elbow on variations in the alignment of components of the Discovery Elbow System (Biomet, Warsaw,

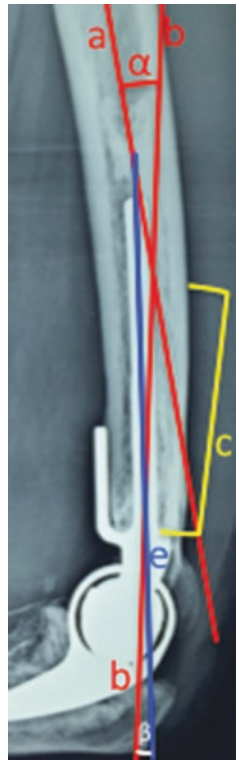

Fig. 3.7 Sagittal plane of distal humerus: *a*, axis of proximal humeral shaft on the sagittal plane; *b* axis of the distal humeral shaft on the sagittal plane; *α* humeral anterior angulation; *c* distance of humeral anterior angulation from distal humerus resection; *e* axis of the humeral implant on the sagittal plane; *β* version of humeral implant

Indiana) (Fig. 3.7). The design of the components in this system theoretically takes into account the anatomical characteristics of the elbow; indeed, the humeral stem is curved to reflect the anterior angulation of the humerus. Despite this, the authors found that the anterior offset and version of the humeral components were significantly affected by variations in the anatomical bow. The anatomical bow was inversely correlated with the anterior offset and version of the components. The conflict between the tip of the stem and the inner surface of the cortex, at the point of deformity of the bone, is greater when deformities are significant or close to the joint. The authors concluded by recommending stems with a variable anterior angulation because of the marked anatomical variations at the distal aspect of the humerus. An alternative solution might be the use

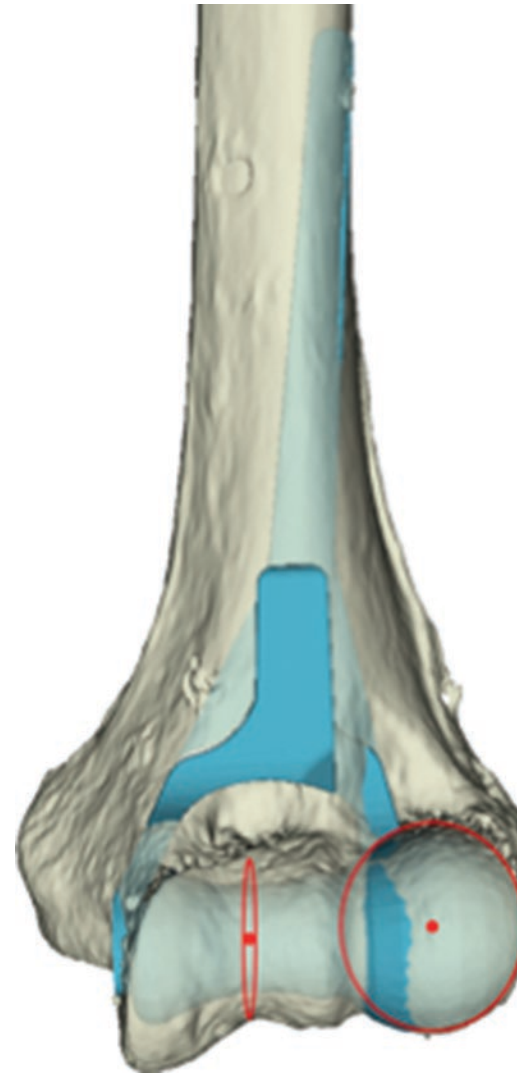

Fig. 3.8 Varus-valgus angulation of the distal humerus affects the stem implant alignment. Source: McDonald et al. [16]. Reproduced with permission from Elsevier

of shorter stem components, though this is likely to be unfeasible because it may compromise the fixation and stability of the implants.

McDonald et al. [16] performed a CT scan study on 13 cadaveric humeri to determine the humeral geometry and facilitate the computer-assisted implant alignment of total elbow prostheses (Latitude, Tornier, Stafford, TX). The results of their study show that anatomical variations in varus-valgus angulation of the distal humerus significantly affect the implant alignment (Fig. 3.8), whereas those in anterior-posterior offset result in

fewer implant alignment errors. The medial-lateral offset of the distal humerus was not closely associated with medial-lateral alignment errors in the implant tested in their study. The authors concluded that a humeral component with a fixed valgus angulation cannot be accurately positioned consistently without sacrificing the alignment of the FE axis. Moreover, their study suggests that the accuracy of the implant placement may be improved by introducing greater modularity of the humeral components, with three valgus angulations of 0°, 4°, and 8°.

To our knowledge, no studies have yet analyzed how anatomical variations in the inward rotation of the distal humerus affect implant design.

3.2 Proximal Ulna

The proximal ulna consists of two curved processes, the olecranon and the coronoid, which form the greater sigmoid notch (Fig. 3.9). The greater sigmoid notch is joined to the humeral trochlea, thereby forming the main articulation of the elbow that provides its inherent stability. A better understanding of the morphology of the proximal ulna should permit the development of ulnar component designs that fit the native bone more closely and consequently lead to more accurate implant positioning. However, there is scanty information in the literature on the anatomy of the ulna and how it affects implant designs. What information is available comes from forensic studies, which focus on size variations of the proximal ulna [17, 18].

Some ulnar morphological parameters are relevant to implant design and positioning, particularly the proximal ulna varus angulation (Fig. 3.10) and proximal ulna dorsal angulation (PUDA) (Fig. 3.11). Grechenig et al. [19] recorded a mean value of the PUDA of 4.5° (range, 1–14°) and a mean proximal ulna varus angulation of 17.5° (range, 11–23°). In a radiographic study performed by Rouleau et al. [20], the PUDA yielded a mean value of 5.7° (range, 0–14°) and was reported to be placed a mean of 47 mm (range, 34–78 mm) distal to the olecranon tip.

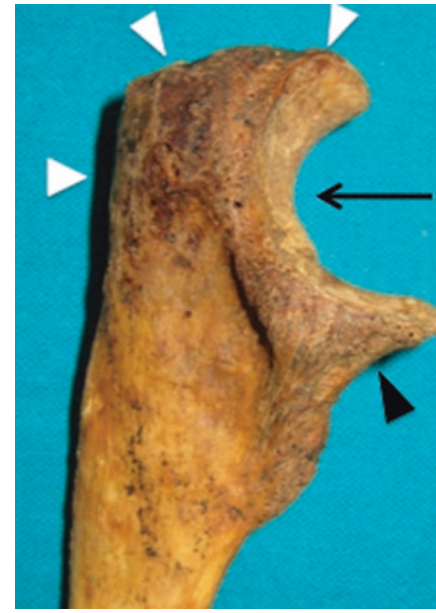

Fig. 3.9 White arrowheads, olecranon process; black arrowhead, coronoid process; arrow, greater sigmoid notch

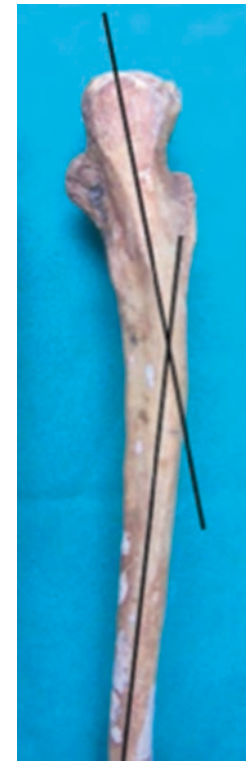

Fig. 3.10 Proximal ulna varus angulation, posterior view. Source: Giannicola et al. [7] Elbow joint; Bergman's Comprehensive Encyclopedia of Human Anatomic Variation

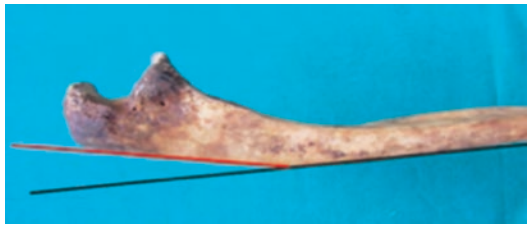

Fig. 3.11 Proximal ulna dorsal angulation (PUDA) lateral view. Source: Giannicola et al. [7] Elbow joint; Bergman's Comprehensive Encyclopedia of Human Anatomic Variation

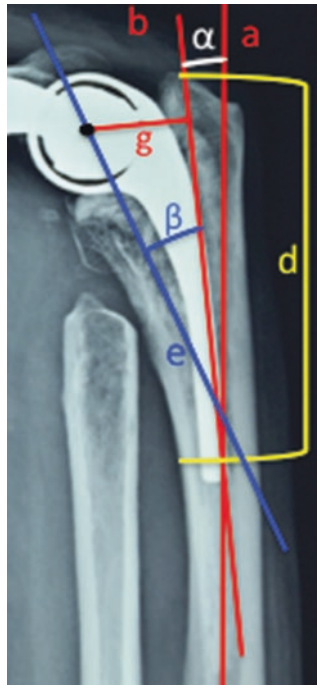

Fig. 3.12 Sagittal plane of proximal ulna. *a* axis of distal ulnar shaft; *b* axis of proximal ulnar shaft; *α* ulnar anterior angulation; *d* distance between the vertex of the anterior angulation of the ulna and the tip of the olecranon; *e* axis of ulnar implant with the systematic correction of 23°; *β* version of ulnar implant; *g*, ulnar anterior offset

Lenoir et al. [15] analyzed the effect of the morphological features of the proximal ulna on alignment variations of the ulnar components of total elbow arthroplasty (Fig. 3.12). The anterior offset and version of the ulnar components were inversely correlated with the PUDA; Moreover, the distance from the tip of the olecranon to the point of anterior angulation of the ulna also affected these parameters: the closer the anterior angulation of the ulna was to the joint, the lower the ulnar anterior offset and version of the ulnar component. Abutment of the stem when introducing either component might explain these results, with a conflict arising between the tip of the stem and the inner surface of the cortex at the point of deformity of the bone. This conflict is greater when deformities are significant or near the joint.

Brownhill et al. [21] assessed, by means of CT scans, the shape of the medullary canal in 31 cadaveric proximal ulnae. The diameter, curvature, and coronal and sagittal angulation of the ulnar canal were calculated in relation to the center of the greater sigmoid notch. The authors reported that the anatomy of the ulnar canal varies significantly and observed that its posterior and lateral offsets increase distally from the articulation center (Fig. 3.13). At 50 mm distal to the articulation center, the posterior offset reaches a plateau distally, thus indicating that a constant posterior angulation of 0° for the distal section would likely be suitable in most cases. Unlike the posterior offset, the lateral offset does not reach a plateau of 0° distally (Fig. 3.13). On the basis of these data, the authors suggested that shorter stems between 40 and 60 mm in length should be angled approximately 8° in valgus and 5.5° posteriorly. For longer stems, such as those used in revision surgery, a transition from the steeper proximal section to the less curved distal section should be considered. It may be necessary to angle the distal section for these longer stems approximately 5° in valgus in relation to the greater sigmoid notch, with no anterior-posterior angulation. Furthermore, the diameter of this stem would taper from 8–12 mm to 4–6 mm at the transition point (60 mm distally to the center of the greater sigmoid notch); the stem diameter should instead remain constant distal to the transition point.

To sum up, multiple factors should be considered in future designs of proximal ulna implants. The key requirements for these designs should be the alignment with the ulnar flexion axis and central positioning of the stem throughout the medullary canal. Owing to the variable nature of

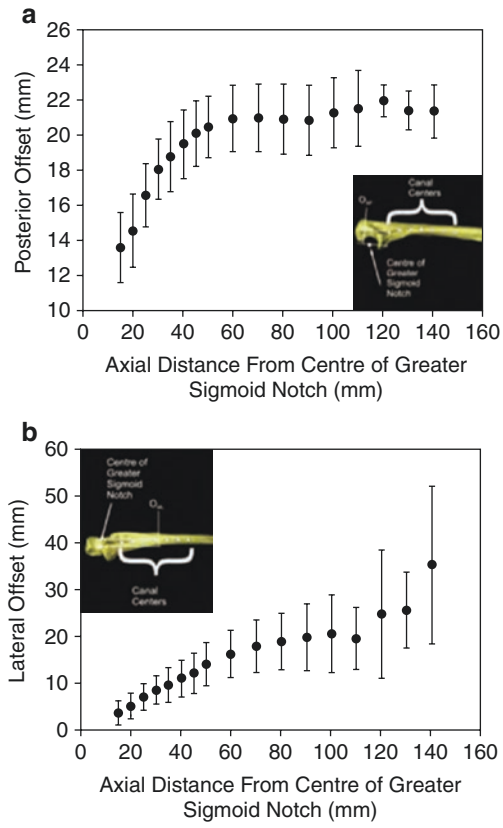

Fig. 3.13 (**a**) Average posterior offset of canal centers versus axial distance from center of greater sigmoid notch. (**b**) Average lateral offset of canal centers versus axial distance from center of greater sigmoid notch. Note that the scales for the two axes are different. Source: Brownhill et al. [21]. Reproduced with permission from Elsevier

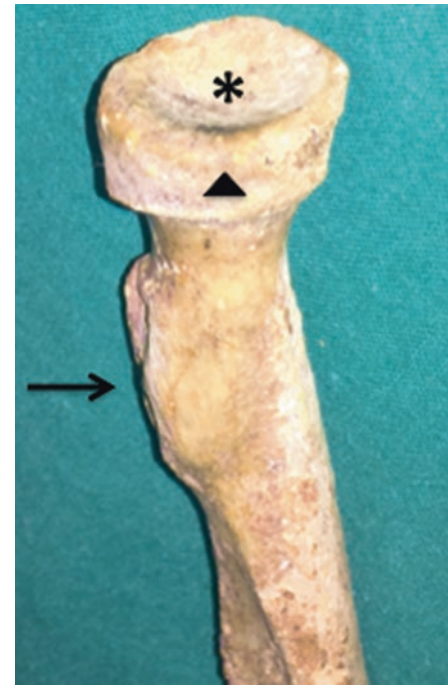

Fig. 3.14 3D CT scan images showing the proximal aspect of the radius. Arrowhead, radial head; (*) fovea radialis; *arrow*, tuberosity; the radial neck expands from the head-neck border to the proximal edge of the bicipital tuberosity

the ulnar anatomy, modular or custom designs may be needed to achieve these goals.

3.3 Proximal Radius

The proximal radius consists of two main elements: the head and the neck. The radial head is cylindrical in shape with a depression in the midportion, referred to as the fovea radialis, that accommodates the capitellum. The circumference of the proximal radius has an articular surface for the sigmoid notch of the ulna. Distally, the radial head continues with the radial neck, which expands from the head-neck border to the proximal edge of the bicipital tuberosity (Fig. 3.14).

The anatomy of the radial head is complex owing to its irregular shape. In recent decades, several authors have performed morphometric studies designed to analyze the shape and size of the proximal radius with a view to improving the design and biomechanics of radial head implants. Nevertheless, the description of the exact geometry of the proximal radius, including its shape and size, is still a matter of debate, and the anatomy of the radial head has yet to be fully defined.

In this regard, some authors [22, 23] who performed a cadaveric study found that the radial head is generally circular, with little difference between the two diameters. Captier et al. [24] instead reported that 57% of their specimens were elliptical and 43% were circular. In addition, Van Riet et al. [25] reported that the radial head was not circular in 27 cadaveric elbows; they found a mean maximum diameter (*x*-axis) of

25.1 mm (range, 22.1–29.7) and a mean minimum diameter (*y*-axis) of 23.4 mm (range, 19.9–27.8), as well as a strong correlation between these two axes [25] (Fig. 3.15). The noncircular shape of the proximal radius is supported by the findings of other authors [26, 27]. Koslowsky et al. [28] definitively demonstrated that the radial head is not circular. The authors studied the anatomy of the radial head on 18 pairs of elbow bone specimens that were fixed with formalin and included the covering cartilage. Optosil imprints of these proximal radii were taken, and 3 mm slices were obtained (Fig. 3.16). The radial head was measured in six different positions of rotation per slice, ranging from full supination to 60° of pronation, with the margo interosseous acting as a reference point (Fig. 3.16). The authors demonstrated that the shape of the radial head is complex, with its size increasing from the radiocapitellar joint surface to the middle of the proximal radioulnar joint surface. Indeed, the diameter increases from the first slice (0 mm) to the third slice (6 mm) before once again decreasing. The maximum head diameter was observed at 30° of supination (mean 24.13 mm, range, 21.18–27.31), while the minimum head diameter was located perpendicular to this position (60° pronation) (mean 22.67 mm, range, 20.00–25.97). Differences between the maximum and minimum diameters were significant in all the slices ($P < 0.001$). The authors also found that the height of the radial head was significantly greater

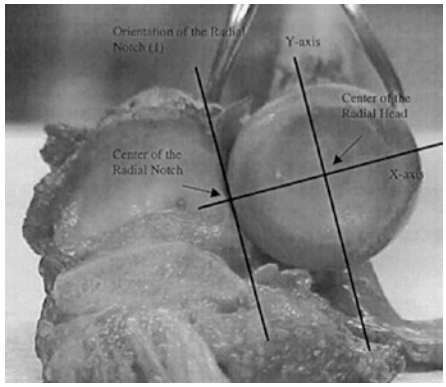

Fig. 3.15 *X*-axis and *y*-axis of the radial head. The *x*- and *y*-axes of the radial head were defined in relation to the radial notch of the ulna, with the forearm in neutral position. Source: Van Riet et al. [25]. Reproduced with the permission from The Journal of Hand Surgery

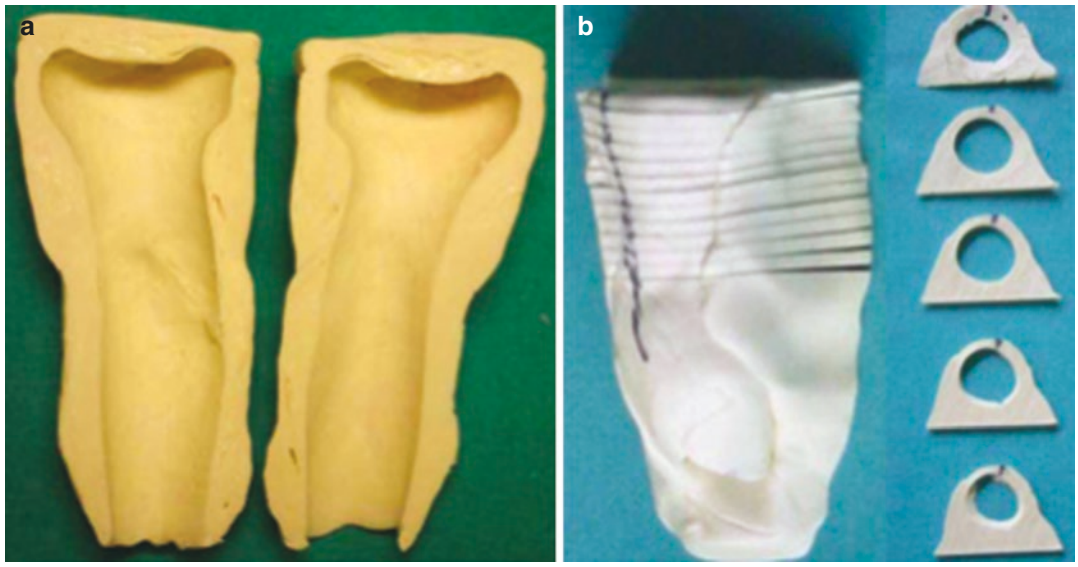

Fig. 3.16 (**a**) Optosil imprint of the radial head. The complete block was opened and the cadaveric radius was removed. (**b**) The optosil imprint was cut into 3 mm slices. The left side of the picture shows the optosil imprint cut in 3 mm horizontal slices. The right side of the picture shows optosil slices from 0 to 12 mm from the radiocapitellar joint level. The position of the margo interosseous is marked on the slice in order to facilitate the imitation of different rotation positions. Source: Koslowsky et al. [28]. Reproduced with permission from Springer

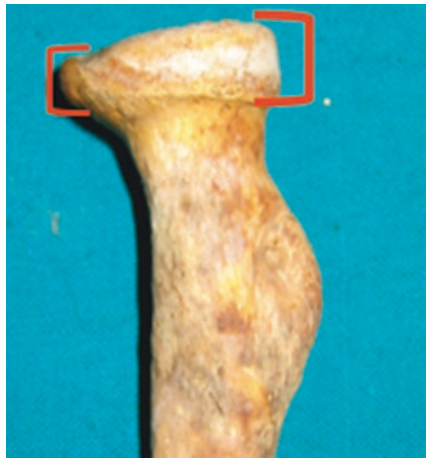

Fig. 3.17 The radial head circumference is higher on the ulnar side than on the radial non-articulating side

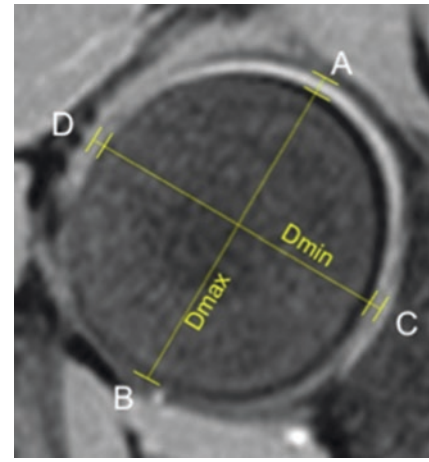

Fig. 3.18 The method adopted to measure the maximum diameter (D_{max}) and minimum diameter (D_{min}) and the cartilage thickness at four different points: A, at the level of the articular surface of the maximum diameter; B, at the level of the non-articular surface (safe zone) of the maximum diameter; C, at the level of the medial side of the minimum diameter; D, at the level of the lateral side of the minimum diameter. Source: Giannicola et al. [7]. Reproduced with permission from Elsevier

on the ulnar side (mean, 11.04 mm; range, 14.76–8.41) than on the radial non-articulating side (mean, 10.02 mm; range, 12.95–7.89) (Fig. 3.17). They also reported that the mean depth of the fovea was 1.95 mm (range, 1.18–2.97) and that the mean diameter of the fovea was 16.7 mm (range, 13.63–21.02). Other studies designed to assess the diameter and the depth of the fovea radialis have yielded similar results, with mean values of, respectively, 15.56 mm and 2.17 mm, being reported [22, 24, 25, 27]. However, it is not yet clear whether the shape of the fovea radialis is circular or elliptical. Captier et al. [24] demonstrated that the fovea is not in the center of the radial head circumference, but offset, with the axial view revealing that the fovea radialis was backward eccentric in complete supination and forward eccentric in complete pronation. Prosthetic implants that mimic the normal radius of curvature and the maximum depth of the articulating dish are more likely to ensure radiocapitellar stability [29].

Giannicola et al. [30] more recently investigated how much cartilage covers the articular surface of the proximal radius and how this affects the morphology of the radial head. The study was performed on magnetic resonance imaging scans of 78 healthy elbows. The maximum and minimum diameters of the radial head both with and without cartilage were calculated (Fig. 3.18). The mean maximum and minimum bone diameters without cartilage were 22.2 mm and 21.5 mm and mean maximum and minimum total diameters with cartilage 24.0 mm and 23.2 mm, respectively. All the differences between diameters were statistically significant. The study showed that the cartilage surface significantly increases the maximum and minimum diameters of the radial head and thus modifies its shape; furthermore, the cartilage thickness varies in different subjects and does not correlate with bone radius size, thus suggesting that the exact diameters of the radial head cannot be inferred from indirect measurements on dry bones or by radiography. This finding is relevant when an anatomic implant is used.

Yeung et al. [31] also analyzed regional variations in cartilage thickness around the radial head on 27 cadaveric radii, which they scanned using CT in a neutral position and processed through a computer program to obtain cartilage and subchondral bone surface models. At the periphery of the radial head, cartilage thickness in the posteromedial (0–90°) quadrant was significantly thicker than in all the other regions of the radial head

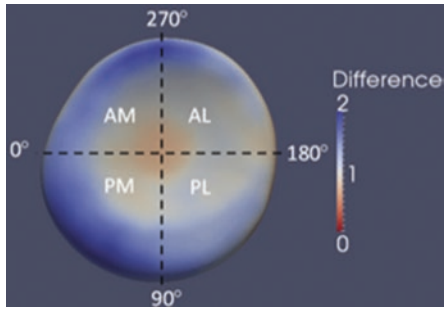

Fig. 3.19 Topographic representation showing thicker cartilage in the posteromedial quadrant (blue), which gradually becomes thinner (red) around the periphery of the radial head. Source: Yeung et al. [31]. Reproduced with permission from Elsevier

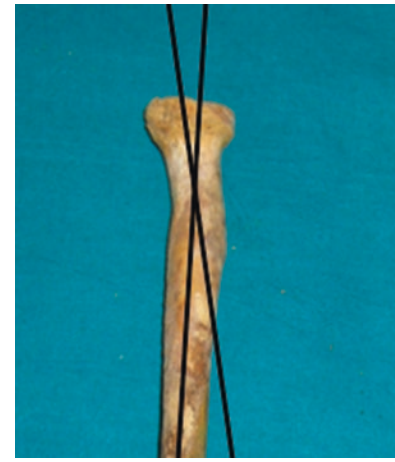

Fig. 3.20 Radial neck to shaft angle

(Fig. 3.19). Cartilage thickness gradually decreased from this region. Thickness values within the articular dish were similar (0.96 ± 0.18 mm) but increased toward the rim (Fig. 3.19). The authors concluded that cartilage thickness around the rim circumference affects the depth of the articular dish of the radial head, which is in turn involved in radiocapitellar congruency and stability owing to concavity compression.

Few studies have provided details of the morphometric parameters of the radial neck. Knowledge of the size and shape of the proximal radius is essential for prosthetic design purposes. When Koslowsky et al. [28] studied 40 macerated proximal radii, they reported a mean neck length 13.4 mm (range, 8–20); the proximal, middle, and distal intramedullary diameters of the radial neck were 11.6 mm (range, 6.6–18.6), 10.5 mm (range, 5.5–16.3), and 9.8 mm (range, 6.0–16.9), respectively; the authors also reported a mean radial neck to shaft angle of 167.8° (range, 160.5–178°) (Fig. 3.20) when measured at a rotation angle of 58.6° (range, 50–70°) supination. This radial neck to shaft angle data is comparable to that reported in one study by Van Riet [25], in which the mean angle was found to be 163° (range, 152–174), and in another study by Captier [24], in which the mean angle was found to be 168° (range, 160–175). These data demonstrate that the length and diameter of the radial neck vary considerably, thus complicating attempts to make a standard prosthetic design.

Only one study has evaluated the angle between the head and neck of the proximal radius. This morphological study, performed using a coordinate measuring machine on fresh radius bone, revealed a mean head-neck angle of 2.5° (0.41° SD) in the front view and of 9.5° (0.52° SD) in the side view [22].

In summary, the morphology of the proximal radius varies markedly. The most critical points are:

1. The shape of the radial head is noncircular, and the maximum and minimum diameters of the bone not only vary but are increased significantly by the cartilage, whose thickness is independent of the bone radius.
2. The height of the radial head is not constant, it being greater at the level of radioulnar joint surface than on the radial non-articulating side.
3. The depth and diameter of the fovea also vary, and the fovea does not lie in the center of the radial head circumference.
4. The intramedullary canal of the radial neck is conical, its narrowest part being found at the end that is proximal to the radial tuberosity.
5. The measurement of the head-neck and neck-shaft angles is mandatory to ensure the planes between the capitulum and the prosthetic joint surface fully correspond.

Most radial head prostheses do not appear to respect these anatomic data. Indeed, biomechanics studies have shown that commercially available prostheses result in altered kinematics and radiocapitellar/radiohumeral contact areas caused by an insufficient degree of congruency; these problems are significantly greater in circular prostheses than in anatomic designs [32, 33]. Although bipolar radial head prostheses have been designed to compensate for these problems, such prostheses have been found to have adverse effects on the stability of the radiocapitellar joint.

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4 Kinematics and Biomechanics in Normal and Replacement Elbow

Marco Paoloni, Francesco Agostini, Alessandra Bettinelli, Nicolò Scappatura, and Rossella Scatozza

The elbow has a significant importance in terms of the functionality of the upper limb. It is located as a connecting point between the arm and the forearm contributing to modify the relationship between these segments to correctly position the hand in the three-dimensional space.

Because of its specific role in linking two body segments, as well as in orienting the hand during everyday activities, it is of particular importance to understand which are the kinematic requirements needed to perform activities of daily living. The issue has been object of researches, and recently Sardelli and colleagues [1] have calculated the functional range of motions required for the elbow to act during some ADL tasks. In 25 subjects evaluated with a stereophotogrammetric device, the range of motion for elbow flexion during positional tasks has been calculated between a minimum of 27° ± 7° of flexion and a maximum of 149° ± 5° of flexion. Forearm rotation ranged from 20.0° ± 18° of pronation to 104° ± 10° of supination. Varus and valgus angulations ranged between 2° ± 5° of varus and 9° ± 5° of valgus.

The maximum flexion arc during functional tasks was 130° ± 7°, with a minimum value recorded as 23° ± 6° and a maximum value recorded as 142° ± 3°. The task requiring the maximum flexion range of motion is speaking with cellular telephone.

The range of motion for pronation–supination has been calculated as 103° ± 34°, and it is needed for activities performed using a fork. Typing on a keyboard requires the maximum pronation of forearm (65° ± 8°), while maximum supination is needed for opening a door (77° ± 13°).

As regards varus–valgus arc of motion, it is actually calculated as 11° ± 4°. Minimum valgus (0° ± 6°) can be found with cutting with a knife, while maximum valgus (13° ± 6°) is needed with opening a door [1].

Due to the interest to regain pre-morbidity quality of life in nowadays' medicine, also in the field of elbow surgery, the abovementioned functional range of motion, as well as the fundamental biomechanics needed to achieve them, must be taken into account when approaching elbow reconstructive surgery.

4.1 Humeral-Ulnar and Humeral-Radial Joints

The elbow has two degrees of freedom allowing to perform movements on sagittal plane, i.e., flexion/extension, and on transverse plane, i.e., pronation/supination. It is often treated as a single joint, but it is possible to recognize three distinct joints with a single capsule and a single joint cavity [2]:

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1. Humeral-radial joint: between the lateral condyle of the humerus and the head of the radius—It allows prono-supination movements.
2. Humeral-ulnar joint: between the medial condyle of the humerus and the semilunar incision of the ulna—it allows flexion and extension movements.
3. Proximal radial-ulnar joint: between the head of the radio and the radial incision of the ulna—it allows prono-supination of the hand.

The structural stability of the elbow is mainly provided by the relationship between the humeral trochlea and the ulnar joint surface. The humeral-ulnar joint is sometimes classified as a "ginglymus" or "hinged joint" owing due to the fact that it is mainly characterized by flexion–extension movements. Recently, the term "modified hinge" seems more appropriate, because the movement of the ulna during flexion–extension is characterized by a rotation around its axis and a translation. This is a very important feature of the prosthetic implant site [3].

4.1.1 Normal "Valgus Angle" of the Elbow

The elbow can be considered as an asymmetric joint, if represented on the frontal plane. This asymmetry, partly due to the distal extension of the medial lip of the trochlea, helps to create a lateral deviation of the ulna related to the humerus. The related angle is known as "normal cubitus valgus" or "carrying angle" (Fig. 4.1) [4, 5].

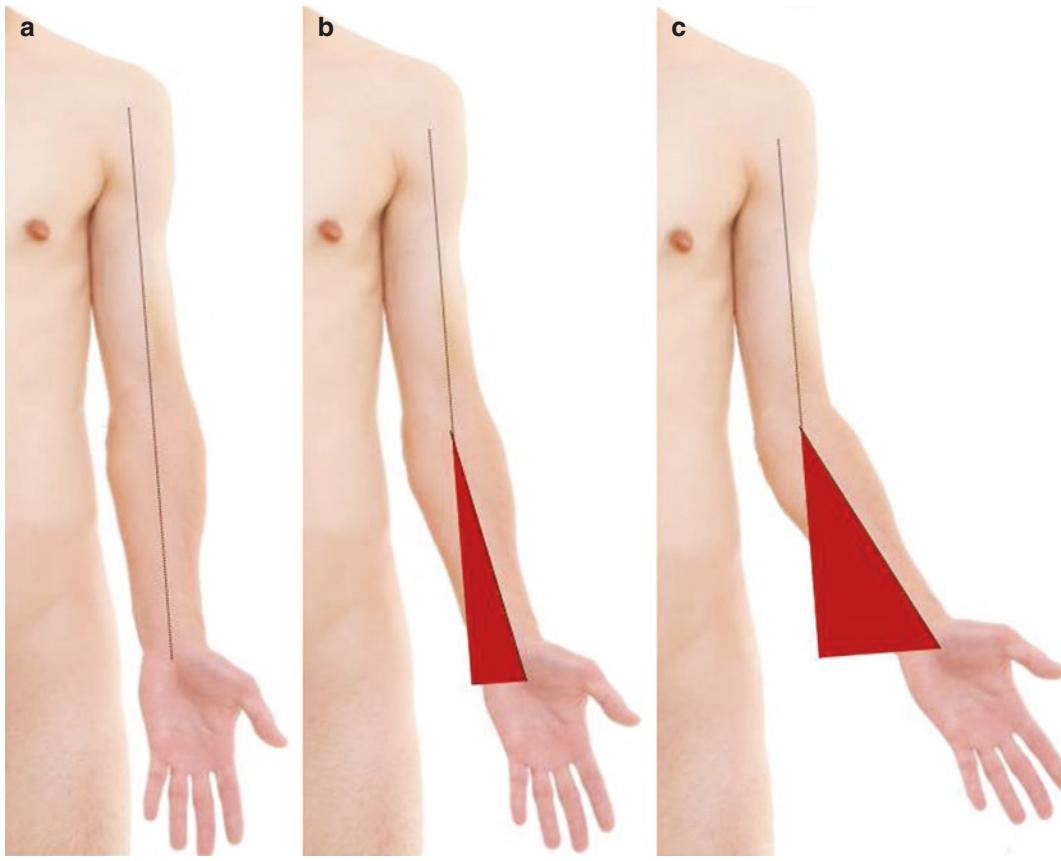

Fig. 4.1 Variability of cubitus valgus angle. (**a**) Cubitus varus ±5°. (**b**) Normal cubitus valgus represented by 15° from the longitudinal axis of the humerus. (**c**) Excessive cubitus valgus ±30°

4.1.2 Periarticular Connective Tissue

The capsule of the elbow contains the humeral-ulnar, the humeral-radial, and the proximal radio-ulnar joints. It is thin and reinforced anteriorly by oblique bands of fibrous tissue and medially and laterally by collateral ligaments, providing a relevant contribution to joint stability.

The medial collateral ligament is composed by bundles of anterior, posterior, and transverse fibers. The anterior ones are characterized by greater strength and represent the most important contribution against a valgus force. Some fibers of the anterior bundles, those originating from the anterior face of the medial epicondyle, are inserted in the medial part of the coronoid process of the ulna, extending on both sides of the axis of rotation during the movement of the sagittal plane. Thus they contribute to providing stability throughout the range of motion. The posterior fibers of the medial collateral ligament, mostly considered capsular thickening, originate from the posterior part of the medial epicondyle and are inserted into the medial margin of the olecranon process. They offer resistance during valgus and the flexion movement. The transverse fibers, on the other hand, originate and are inserted on the same bone, from the olecranon to the coronoid process of the ulna, and for this reason they are not considered to be stabilizing articular structures. Currently, in addition to the medial collateral ligaments, the proximal fibers of the flexors of the wrist muscles and of the group of pronator muscles are considered to be uselessly used as dynamic stabilizers of the elbow.

The lateral collateral ligament complex is the main structure that guarantees varus stabilization. It originates from the lateral epicondyle and divides after its origin into two bundles. The first, the radial collateral ligament, merges with the ring ligament that surrounds the head of the radio. The second, the ulnar collateral ligament, instead, is inserted caudally on the ulna, "distally to the supinator crest." These fibers are stretched during the complete bending movement. The ulnar collateral ligament, in addition to the anterior fibers of the medial collateral ligament, provides medial-lateral stability due to their ulnar insertion [6].

4.1.3 Center of Rotation

Many authors in the past have dealt with the theme of the elbow's center of rotation with more or less contrasting results both about its displacement and the actual amount of displacement. The deviation of the joint's center of rotation is minimal, and the variation reported is probably due to limitations in experimental design. Thus, in terms of significance, it can be stated that the humerus-ulnar joint is uniaxial except at the extremities of both flexion and extension and that the axis of rotation passes through the center of the arches formed by the trochlear groove and the capital. It has also been demonstrated that up to 5 mm alterations in the four directions of the space had only a slight effect on elbow kinematics, therefore being negligible from a biomechanical point of view [7].

4.1.4 Arthrokinematics at the Humeral-Ulnar Joint

The humeral-ulnar joint is composed by the humeral trochlea which is articulated with the ulnar trochlear fossa. During extension, the anterior fibers of the medial collateral ligament are stretched. During flexion, the surface of the trochlear fossa rolls and slides on the trochlea, and the posterior fibers of the medial collateral ligament are then tensioned (Fig. 4.2).

4.1.5 Arthrokinematics at the Humeral-Radial Joint

The humeral-radial joint is located between the radial head and the humeral condyle. During the flexion–extension movement, the head of the radio rolls and slides through the convexity of the humeral condyle. During active flexion, the radial head is pulled against the humeral condyle by

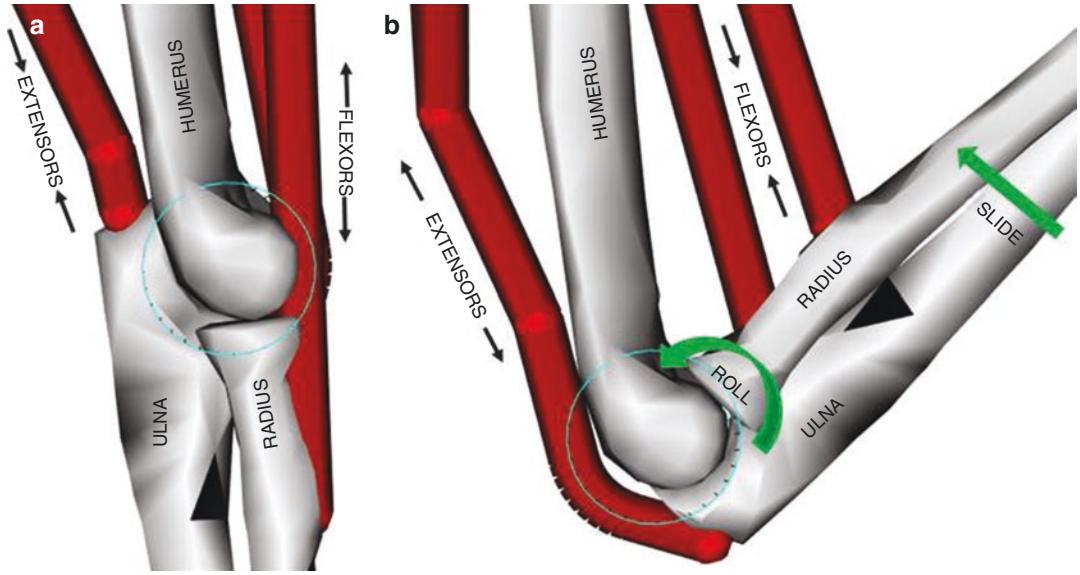

Fig. 4.2 The humero-ulnar joint (sagittal section). (**a**) Full extension. (**b**) Full flexion

muscle contraction. The humeral-radial articulation provides about 50% of the resistance against a valgus force [8].

4.1.6 The Interosseous Membrane

The interosseous membrane is stretched between the ulna and the radius. It is composed of numerous fibers, but the thickest and most resistant are the central bands that originate from the radius head and insert down and medially on the ulna. They represent the component with greatest biomechanical resistance among the interosseous membrane, being comparable, for what concerns the resistance, to the patellar tendon [9–11].

The interosseous membrane has many functions. First of all, it connects the ulna and the radio, while allowing a greater attack surface for several muscles of the hand. Secondly, it balances the forces transmitted proximally along the upper limb. The central bands of the interosseous membrane, thanks to the direction of their fibers, transfer part of the force transmitted proximally (resulting mostly from the radio-carpal joint) from the ulnar-carpal joint medially toward the humerus-ulnar articulation, so that in correspondence of the elbow, the forces can be distributed uniformly [12]. Finally, the interosseous membrane is able to lighten the compressive force from the radio toward the ulna, thereby protecting the humeral-radial articulation from excessive biomechanical stress.

The orientation of the central bands of the interosseous membrane, however, does not allow to resist to forces applied distally to the radius (Fig. 4.3). In this case, in fact, forces are applied almost exclusively through the radius, and other structures, such as the oblique rope and the annular ligament, contribute to joint stability. A further contribution can be provided by the brachioradialis muscle, which with its contraction acts as dynamic stabilizer, keeping the radio in relation with the humeral condyle [13].

4.2 Proximal and Distal Radio-Ulnar Joints

In addition to the previously described interosseous membrane, the proximal and the distal radio-ulnar joints contribute to the stability of the forearm. The latter not only keeps the ulna and the radio in contact but also allows them to rotate during pronation (palm down) and supination (palm up). Particularly, the pronation–supination

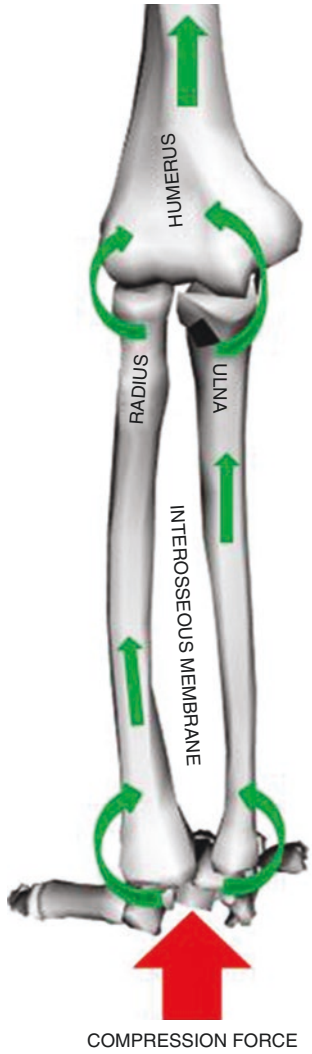

Fig. 4.3 Compression force through the hand. The force is transmitted primarily through the wrist at the radiocarpal joint and to the radius pulling the interosseous membrane taut, so the most part of the compression force is distributed to the ulna and across the elbow at the humeroulnar joint

movement is mostly performed by the rotation of radius and carpal bones. The axis of rotation is located between the radial head and the ulnar head and connects both the radio-ulnar joints. In the reference position (zero position) the forearm appears supine with ulna and radius in a parallel position. During pronation, the distal segment of the radius and the hand rotate above ulna, which remains fixed and permanently connected to the humerus.

4.2.1 Proximal Radio-Ulnar Joint

Radio-ulnar proximal ligament system is mainly composed of a fibro-osseous ring formed by the annular ligament. This is a thick, circular ligament that originates from the ulna and reinserts on it, after having surrounded the radial head in order to keep it adherent to the radial incision of the ulna, which represents the remaining component of joint stability. The fibers of the annular ligament in contact with the radio are coated with cartilage so as to minimize friction during prono-supination movements. The external fibers, instead, receive capsular insertions, fibers of the collateral radial ligament, and muscle bundles of the supinator muscle. Further down, a thin fibrous ligament, the quadrate ligament, connects the ulna to the neck of the radio with the purpose of joint support during pronation movements [14].

4.2.2 Distal Radio-Ulnar Joint

The distal radio-ulnar joint is composed by the distal ends of radius and ulna. The ulna is articulated with the ulnar incision of the radio which, however, only partially guarantees joint stability that is guaranteed by a complex connective tissue system. The "triangular fibrocartilage" is present between the two articular heads [15] and represents the main stabilizer of the distal radio-ulnar joint. It occupies the space between ulna and carpus and is composed, in addition to the articular disk, by the articular capsular ligaments and the ulnar collateral ligament. Moreover, the extensor carpi ulnaris muscle, the interosseous membrane, and the pronator quadratus muscle work as dynamic joint stabilizers [16].

4.2.3 Supination and Pronation

During supination, the radial head at the proximal radio-ulnar joint rotates inside the fibro-osseous ring, which, being extremely binding, does not allow the "roll-and-slide" movement. At the distal radio-ulnar joint, on the other hand, the radio, at

the ulnar incision, "roll-and-slides" in the same direction as the ulnar head does [17, 18].

The pronation movement is similar and contrary to the supination movement. The rotation of the palm of the hand downward gives tension to the posterior capsular level and going to relax the front fibers instead. During this movement, therefore, the ulnar head is more exposed to the front and can therefore be superficially palpable [18, 19].

Assuming that during supination and pronation the humeral-ulnar joint is conventionally considered as a fixed point, the movement of the radial head, during this movement, develops in the proximal radio-ulnar articulation but also at the humeral-radial level, with the rotation of the radial head against the humeral condyle. The main architect of this movement is the pronator muscle which, inserting itself on the radio, together with other muscular components, during pronation, imprints a compressive force on the humeral-radial articulation due to a proximal migration of the radio and also due to a state of resting of the interosseous membrane. This mechanism is known as the "screw home" movement of the elbow. Any movement that is performed at both the elbow and the forearm level affects the humeral-radial articulation. This certainly, in addition to a substantial complexity of the movement itself, justifies the greater tendency of the lateral compartment to undergo wear and degeneration compared to the medial compartment [20].

4.2.4 Pronation and Supination with the Radius and Handheld Fixed

When describing the movement of prono–supination, this always means a movement with extremity (hand) free. But, what happens if the distal end of the upper limb is blocked? In this case the blocked portion is represented by the hand and the radius, around which the humerus and the ulna rotate. In this case, then, the pronation of the forearm is expressed through an external rotation of the humerus which is transmitted to the ulna, which represents the true rotating portion. The supination movement, instead, includes an internal rotation of the humerus which likewise transmits to the ulna which rotates around the radio. At the proximal radio-ulnar joint, there is a rotation of the annular ligament and the radial incision of the ulna around the blocked radial head. At the distal radial-ulnar joint, instead, the ulna head rotates around the ulnar incision of the radio which remains blocked.

4.3 Biomechanics of Muscles Acting on the Elbow

The muscles that cross the elbow joint can be arbitrarily divided into four compartments: anterior, lateral, medial, and posterior. These muscles have different functions that include flexion, extension, pronation, and supination.

Biceps brachii, brachialis, and brachioradialis are flexor muscles; triceps brachii and anconeus are extensor muscles; biceps brachii and the supinator are supinator muscles; the pronator teres, the flexor carpi radialis, the palmaris longus, the flexor carpi ulnaris, and the flexor digitorum superficialis that form the common flexor tendon are flexor-pronator muscles; the extensor carpi radialis longus, the extensor carpi radialis brevis, the extensor digitorum longus, and the extensor carpi ulnaris that form the common extensor tendon are extensor-supinator muscles [21].

4.3.1 Biceps Brachii

It is a biarticular muscle, generally consisting of two heads, that crosses the shoulder and elbow and acts as a powerful flexor and supinator of the elbow.

The long head of the biceps originates from the superior glenoid labrum and supraglenoid tubercle, while the short head of the biceps originates from the coracoid process. The short head and the long head run parallel on the ulnar side and on the radial side of the arm, respectively. The tendon of the long head of the biceps passes under the coracohumeral ligament and through the rotator interval between the supraspinatus

and subscapularis tendons to enter the bicipital groove. Some fibers of the subscapularis tendon, of the supraspinatus tendon, and of the coracohumeral ligament form the transverse ligament, inserted between the lesser tuberosity and the greater tuberosity, that holds the tendon of the long head of the biceps in place. Near the deltoid tuberosity, the two biceps tendons converge to form a joint tendon. The short and long heads of the biceps muscle gradually merge, making it difficult to separate the myo-tendinous junction of each muscle belly.

The biceps tendon inserts distally into the ulnar margin of the bicipital tuberosity of the radius, forming the so-called footprint on the bone [22]. The anteromedial fibers of the distal tendon, formed by the short head, insert on the bicipital tuberosity distally, playing a greater role in flexion of the elbow. The more substantial posterolateral fibers from the long head insert more proximally and act as a powerful supinator. The distal biceps tendon is a flat extra-synovial structure coated with peritoneum, without tendon sheath.

Cadaver studies have shown a clear separation of the two muscle heads or a proximal interdigitation of the two muscular heads with two distal tendons separated at the level of the insertion on the radial tuberosity [23].

The short head has a greater supinating action when the forearm is in a neutral position or at about 60° of pronation; this is due to the insertion of the short head on the apex of the tuberosity which results to be farthest from the center of rotation of the elbow. At 60° of supination, the long head became the more relatively efficient supinator. If the elbow is at 90° of flexion and the forearm is supine (most common position during flexion), the short head develops greater flexor strength.

The bicipital aponeurosis (or lacertus fibrosus), that originates from the biceps tendon and blends with the fascia of the forearm, can prevent proximal retraction of the broken biceps tendon.

The bicipitoradial bursa, which is located between the tendon and the radial tuberosity, decreases friction between the tendon and the radial tuberosity during pronation and supination.

It is innervated by the musculocutaneous nerve [24–27].

4.3.2 Brachialis

Brachialis muscle is located deeply at the biceps and consists of superficial and deep heads.

The superficial head is the largest one and originates distally to the deltoid tuberosity, partially encircling the deltoid muscle insertion and continuing on the anterolateral aspect of the middle third of the humerus, from the lateral intermuscular septum.

The smaller, deep head originates from the distal third of the anterior aspect of the humerus and the medial intermuscular septum. Most fibers converged on to an aponeurosis which is inserted on the ulnar tuberosity.

The superficial head is inserted distally on the ulnar tuberosity and is a thick tendinous structure, while the deep head fits proximally and is a broad aponeurotic structure. Despite this, the two heads attach to the ulnar tuberosity as a single blended structure.

The brachialis muscle is an important flexor of the elbow joint regardless of whether the forearm is in pronation or supination.

With the elbow fully extended, the brachialis has its poorest mechanical advantage, and the flexion moment is smallest. The most biomechanically favorable position is reached when the elbow is flexed to 90° with the ulna perpendicular to the brachialis fibers. Given their respective position on the ulna, it is likely that the deep head is more important for the initiation of flexion from full extension and that the superficial head provides greater power once the elbow is flexed. It is innervated by the musculocutaneous nerve [24, 28, 29].

4.3.3 Triceps Brachii

This muscle consists of three heads: long, lateral, and medial head. The long head originates from the subglenoid tuberosity of the scapula; the lateral head originates from the posterior surface of the humerus, above the groove for the radial nerve, from the lateral border of the humerus, and from the lateral intermuscular septum; the medial head originates from the posterior surface of the

humerus, below the groove for the radial nerve. The medial head of the triceps has a tendon that lies deep to and is initially separate from the tendon shared by the long and lateral heads. The tendons of all three heads insert on the olecranon process of the ulna. The triceps brachii muscle is the major extensor muscle of the forearm and is the direct antagonist to the biceps brachii and brachialis muscles. It is innervated by the radial nerve [30, 31].

4.3.4 Anconeus

The anconeus is a small triangular muscle. It originates from the dorsal aspect of the lateral epicondyle, and it fits on the posterior aspect of the ulna, at the level of the proximal quarter. The anconeus contributes up to 15% of the extension moment, in synergy with the uni-articular heads of triceps brachii, and actively stabilizes the elbow during extension. It is innervated by the radial nerve [32].

4.3.5 Pronator Teres

It is composed of a humeral head and an ulnar head. The deep, smaller ulnar head originates from the medial border of the coronoid process and the medial side of the brachialis tendon. The larger, superficial humeral head originates from the proximal and anterior aspect of the medial epicondyle, the medial intermuscular septum of the arm, the medial common flexor tendons, the fascia between these tendons and the flexor carpi radialis tendon, and the antebrachial fascia. The two heads fuse distally to form a muscular body, which inserts through a short tendon on the lateral side of the middle third of the radius. It acts as a forearm pronator and, to a lesser degree, as an elbow flexor. Through its ulnar head, the pronator teres also contributes to the medial stability of the elbow during valgus stress.

It has been shown how its action can be enhanced by increased radius bowing, with a more proximal enthesis and with a larger medial epicondyle. It is innervated by the median nerve [33].

4.3.6 Palmaris Longus

The palmaris longus muscle originates from the medial epicondyle of the humerus and the antibrachial fascia and inserts with a long, thin tendon predominantly into central palmar surface of the aponeurosis. It is the most variable muscle of the human body: it may be agenetic, double, tendinous, split, incomplete, digastric, or exhibit anomalous insertions. Its main action is to stretch the palmar aponeurosis, but it also flexes the wrist and it can assist elbow flexion. It is innervated by the median nerve [34].

4.3.7 Flexor Carpi Radialis

The flexor carpi radialis muscle originates from the medial epicondyle of the humerus and the antibrachial fascia and inserts at the base of the second metacarpal bone. It can assist the forearm pronation and elbow flexion. It is innervated by the median nerve.

4.3.8 Flexor Carpi Ulnaris

This muscle consists of two heads: humeral head and ulnar head. The humeral head originates from the medial epicondyle of the humerus and the antibrachial fascia, while the ulnar head originates from medial margin of the olecranon and 2/3 proximal to the posterior margin of the ulna. It inserts with a long tendon to the pisiform bone and, through the ligaments, to the hooked bone and the fifth metacarpal bone. It can assist elbow flexion. It is innervated by the ulnar nerve.

4.3.9 Flexor Digitorum Superficialis

The flexor digitorum supericialis muscle consists of two heads: humeroulnar head and radial head. The humeroulnar head originates from the medial epicondyle of the humerus and the coronoid process of the ulna, while the radial head originates from the proximal portion of the front face of the radio. It inserts through four tendons

on the sides of the intermediate phalanx of II, III, IV, and V finger. It is innervated by the median nerve [35].

4.3.10 Brachioradialis

The brachioradialis muscle originates from the lateral supracondylar ridge, the lateral aspect of the diaphysis of the humerus, and the lateral intermuscular septum and inserts into the lateral aspect of the styloid process of the radius. It is a flexor of the elbow regardless of forearm position. However, electromyography studies have shown that the muscle is more active during pronation than supination. It is innervated by the radial nerve [36].

4.3.11 Extensor Carpi Radialis Longus

The extensor carpi radialis longus muscle originates from the distal third of the lateral supracondylar ridge of the humerus and lateral intermuscular septum and inserts on the radial side of the second metacarpal bone. It can assist elbow flexion. It is innervated by the radial nerve [37].

4.3.12 Extensor Carpi Radialis Brevis

The extensor carpi radialis brevis muscle originates from the lateral epicondyle of the humerus and the antibrachial fascia and inserts on base of the third metacarpal bone. It is innervated by the radial nerve [37].

4.3.13 Extensor Carpi Ulnaris

The extensor carpi ulnaris muscle originates from lateral epicondyle of the humerus, the posterior margin of the ulna, and the antibrachial fascia and inserts on the ulnar side of the base of the fifth metacarpal bone. It is innervated by the radial nerve.

4.3.14 Extensor Digitorum

The extensor digitorum muscle originates from the lateral epicondyle of the humerus and the antibrachial fascia and inserts with four tendons on the I, II, III, and IV finger through an average tendon bundle on the base of the middle phalanx and two lateral tendon bundles on the base of the distal phalanx. It is innervated by the radial nerve.

4.3.15 Supinator Muscle

The supinator muscle originates from the lateral epicondyle of the humerus, the collateral radial ligament, the ring ligament of the radio, and the ridge of the ulna supinator and inserts on the anterolateral surface of the upper third of the radio. This muscle supinates the forearm. It is innervated by the radial nerve.

4.4 Dynamic Stabilization

The bony structures, ligamentous complexes, joint capsule, and muscle groups contribute to the stability of the elbow. The elbow in extension is stabilized by the bones, while during flexion there is less bony contact, and the soft tissues become more critical in providing elbow stability [38, 39].

Muscles that cross the elbow joint provide dynamic stabilization to the joint and protect the static constraints. Muscle contraction compresses the elbow joint and adds stability. The triceps, biceps, and brachialis provide the greatest compressive force across the elbow, but do not provide much varus–valgus stability. The greatest compressive forces are present during isometric elbow flexion in a position near full extension and during isometric elbow extension in flexed position.

4.4.1 Valgus Stabilization

In the flexed arm position, the ulnar collateral ligament, in particular the anterior oblique ligament, is the primary static stabilizer to valgus

stress and contributes 54% of the resistance to valgus loading. However, the contribution of the elbow stabilizers and the elbow muscles are necessary to reduce the stress. The dynamic stabilization of the flexor–pronator muscles is greater with the supine forearm, because in this position the muscles have a higher passive tension because of their lengthening, and, presumably, this effect on elbow stability would be even greater with active muscle tensioning.

Because of their orientation and origin, the flexor–pronator muscles provide a dynamic support to valgus stress [40]. In particular, the flexor carpi ulnaris and portions of the flexor digitorum superficialis are located directly on the anterior bundle of the medial ulnar collateral ligament [41]. The flexor carpi ulnaris, because of its optimal position, and the flexor digitorum superficialis because of its relative bulk represent the most effective active stabilizers of the elbow to valgus stress. The pronator teres provides the least dynamic stability. The pronator teres muscle, flexor carpi radialis muscle, palmaris longus muscle, and flexor digitorum superficialis muscle converge and form a common tendon at their proximal origin (the anterior common tendon, ACT) that fits to the medial epicondyle and the joint capsule, just anteriorly and parallel to the anterior oblique ligament; the anterior oblique ligament and the anterior common tendon are very similar histologically. It is possible that the location and morphology of the anterior common tendon allow it to help the ulnar collateral ligament in the dynamic stabilization of the elbow.

The intermuscular fascia between the flexor digitorum superficialis and flexor carpi ulnaris muscle also form the posteriori common tendon, which is attached to the inferior end of the medial epicondyle and medial joint capsule, just posterior to the anterior oblique ligament [42, 43].

4.4.2 Varus Stabilization

The lateral side of the elbow joint is both statically and dynamically stabilized by the extensor–supinator group. The extensor digitorum communis, extensor carpi radialis brevis, extensor carpi radialis longus, anconeus, and extensor carpi ulnaris muscles produce a valgus moment, stabilizing the elbow in varus; in the studies of An et al. [44, 45], the stabilization results greatest in neutral rotation as compared with supination or pronation, but according to the studies of Kenneth et al. [46] the dynamic stabilization of the extensor–supinator muscles is greater with the pronated forearm, because in this position the muscles have a higher passive tension, and, presumably, this effect on elbow stability would be even greater with active muscle tensioning.

The lateral collateral ligament is the most important constraint to posterolateral rotational stability of the elbow. The anconeus muscle adheres tenaciously to the lateral humerus-ulnar capsule, and this makes it an active enhancer of the posterior bundle of the ulnar collateral ligament [47–49]. The anconeus muscle is active during both pronation and supination, and this serves to stabilize the elbow more than to generate torque. Furthermore, the anconeus is active during resisted finger and shoulder movements and during actions that require a limited torque of the elbow. The anconeus contributes to the centripetal force required to maintain joint integrity, and this is shown by the fact that muscle activity increases with increasing angular velocity. The anconeus may thus help to prevent posterolateral dislocation of the elbow [21, 46, 50, 51].

4.5 Forces Across the Elbow Joint

The evaluation of forces acting across the elbow can be done by means of two- or three-dimensional studies, in dynamic or static conditions, with or without considering muscles activities. All these conditions need a biomechanical model to be built so that a certain degree of approximation is always included in the analysis.

In two-dimensional studies, the elbow is considered as a hinge joint, in which moments and forces due to loads at the hand correspond to forces developed by muscles, tendons, and ligaments. The forearm and hand are considered

independently, and, as described by Morrey [52], equilibrium equations can be obtained to calculate forces acting on the elbow:

$$\sum |F_i| f_{xi} + R_x + P_x = 0$$

$$\sum |F_i| f_{yi} + R_y + P_y = 0$$

$$\sum |F_i| * r_i + P^* r_p = 0$$

in which $|F_i|$represents the magnitude of tension in I^{th} muscles; f_{xi}, f_{yi} represent the components in the x and y directions for the unit vector in the action's line of muscle; R_x, R_y represent the components in the x and y directions of the force of contact at the joint; P, P_x, P_y represent the magnitude of the forces applied on the forearm and x and y associated components; r_i, r_p represent the moment arm of the muscle's force and the force applied at the center of the joint.

In a sagittal plane, the muscles contributing the most to flexion–extension movements are represented by biceps, brachialis, brachioradialis, extensor carpi radialis longus, triceps, and anconeus, with relative contributions varying according to the elbow flexion angle, as reported above. Restricted contributions to elbow flexion–extension are given by other wrist and hand muscles.

In the two-dimensional model, the joint constraint force vector is considered to be perpendicular to the arc of the articular surface and to run across the center of curvature of the same arc. Indeed, even for a simple movement, several muscles are involved, thereby being difficult to calculate real forces across the elbow, also considering that if a change in muscle moment arm occurs, the resultant force at the elbow will change consequently.

The joint force and the magnitude of muscle force that have to oppose to an external force weaken with decrease of external force's moment arm. In this case the resultant segmental moment at the joint decreases when moment arm decreases. Contrarily, muscle's magnitude and joint force increase at the growth of external force's magnitudes.

When the direction of the force at the wrist modify from vertical to horizontal, the effect of this force change, so change the resultant segmental moment.

In the end magnitudes and orientations of forces at the elbow depend on the upper arm and forearm muscles, as loads applied externally at the joint alter the moment arm and the muscles line's orientation.

Three-dimensional models, on the other side, allow to calculate the add-on effect of several muscles as well as of different bones' position in the space. By using 3D models, for example, it can be easily argued that the action of any given muscle changes with variation of joint position as a function of the length, as well as of the line of action of muscular fibers (Fig. 4.4) [53].

4.5.1 Forces and Pathologies of the Elbow

The study of forces acting on the elbow structures during traumatic events is of interest. It has been demonstrated that posterior fracture–dislocations occur between 15° of extension and 30° of flexion, anterior or posterior fracture–dislocations at 60°, and exclusively anterior fracture–dislocations at 90°. Elbow's injuries are mostly concentrated in anterior or posterior structures. Stress concentration areas drift from the coronoid process to the olecranon along with position changed from extension to flexion. The very high frequency of concurrent fractures and dislocations of radial head or neck suggested that the radial head may also play a role as a stabilizer in the anterior support system [54].

4.6 Biomechanics in Elbow Prosthesis

New anatomic and biomechanical knowledges impact on the production of elbow prosthesis that are as similar as possible to the physiological model of the elbow joint. Elbow prosthesis can be broadly distinguished in hemiarthroplasty or total elbow prosthesis. The biomechanical characteristic of different kind of elbow arthroplasties will be discussed here.

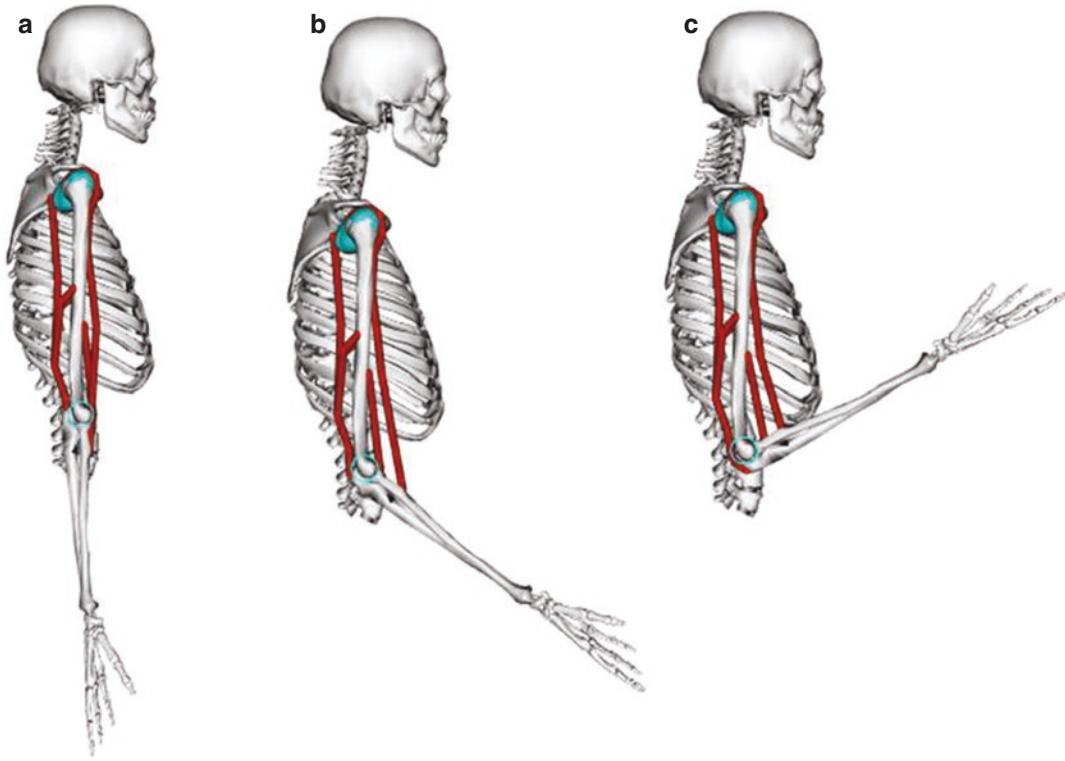

Fig. 4.4 Three-dimensional model of the arm with triceps brachii, biceps brachii, and brachialis muscles represented at 0° (**a**), 70° (**b**), and 110° (**c**) of elbow flexion. The different length of each muscle can be evidenced, as well as their different lines of action in the three positions

4.6.1 Radial Head Prosthesis

The radial head guarantee axial and valgus stability as well as adequate load transfer across the elbow. For these reasons its resection causes significant alterations on elbow biomechanics and increases laxity.

Clinical outcome studies of metallic radial head arthroplasty systems indicate that radial head replacement is a reasonable option to offer patients with comminuted radial head fractures and complex elbow trauma.

Radial head arthroplasty provides improved valgus stability. The exact length of the radius is important to maintain normal elbow kinematics, in fact both lengthening or shortening, as well as radiocapitellar gap may alter elbow kinematics [55].

The lengthening of the radial neck by 2.5 mm or more forces the ulna into a more varus and externally rotated position even with the application of valgus stress; shortening the radius by 2.5 mm or more has an opposite effect and causes the ulna to track in a valgus and internally rotated position; it also causes increased total laxity of the elbow. Both lengthening and shortening cause the ulna to track in a significantly different path of motion, when compared to the nominal length situation and altered elbow kinematics or maltracking of the ulnar-humeral joint due to altered radial neck length, could induce degenerative disease due to abnormally high stresses on the cartilage [56].

The capitellum has a role as a valgus and external rotational stabilizer of the ulnar-humeral joint. Capitellar hemiarthroplasty is a therapeutic option for isolated capitellar deficiency, but data about its effects on elbow biomechanics are limited.

Cadaveric studies have demonstrated that when the capitellum is excised, active flexion in

the valgus and vertical positions is associated with a measurable increase in ulnar external rotation (1.2–1.8° maximum increase), with the forearm in pronation but not in supination. Normal elbow kinematics can be restored with optimal placement of a capitellar hemiarthroplasty that is able to maintain normal varus–valgus laxity in both active and passive elbow flexion. The placement of a capitellar hemiarthroplasty mitigates the altered ulnar rotation observed in the capitellum-deficient elbow, creating a normal kinematic environment during active elbow flexion [57].

4.6.2 Hemiarthroplasty

Hemiarthroplasty represents a less invasive surgical approach, in alternative to total elbow arthroplasty, in those clinical situations in which only one portion of the elbow is affected, such as distal humeral fractures.

The distal humeral hemiarthroplasty implant size has an influence on joint kinematics and stability, in both the varus and valgus positions. In an in vitro study, with cadaveric specimens mounted on a motion simulator, undersized implants were consistently more lax than the oversized implants in both the valgus and varus positions [58]. Larger implants, therefore, potentially reduce postoperative instability and provide more favorable contact mechanic, thereby suggesting that, when uncertainty exists in choosing between sizes, the surgeon should choose the larger implant; however the effect that this may have on articular cartilage contact area, loading, and wear is still unknown.

As regards the coronoid process, it also has an important role to maintain elbow stability. In complex elbow injuries, the coronoid process may be fractured, with disruption of one or more of the collateral ligaments, with or without a fracture of the radial head. Coronoid replacement with an anatomically shaped prosthesis restores stability to the coronoid-deficient elbow; with repaired ligaments, no differences can be observed in rotational or varus–valgus kinematics in the coronoid prosthesis with either passive or active motions, regardless of the position of the elbow. Kinematic restoration has to be attributed to the morphology of the prosthesis, which recreated a congruous articulation between the humerus and the ulna. It is detailed that an anatomic coronoid implant restores the stability of the coronoid-deficient elbow when the collateral ligaments are repaired or reconstructed. With the collateral ligament insufficiency, an extended prosthesis prevents dislocation and reduces elbow laxity relative to the native coronoid and to the anatomic prosthesis but is not enough to restore full stability similar to that of the intact elbow; for this reason, the collateral ligament repair or reconstruction is still recommended even if the coronoid is replaced [59].

4.6.3 Total Elbow Arthroplasty

The currently used prosthetic models are two general types: (1) loose hinge (linked) and (2) resurfacing (unlinked). The main biomechanics characteristics of these implants in vivo are not yet fully recognized; however, it is a matter of fact that the main concern with them relies on instability, which is attributable to different factors including prosthesis design, ligament integrity, and position of the prosthesis.

The various prosthetic designs may differ significantly for the radius and arc of curvature of the components in the sagittal plane, the contour of the ulnar-humeral joint in the coronal plane. These are the important characteristics that define intrinsic stability and the amount of constraint imparted by the articulation. Joint constraint, in fact, is a function of the congruity of the articular geometry and the surrounding ligaments and muscles. In model analyses simulating axial distraction displacements, the stress transfers either into the soft tissues that resist to axial distraction or into the prosthesis-bone interface if the articular geometry is too highly constrained. This dynamic stabilization mechanism is important from the clinical point of view aimed at performance, and probably it could have an effect on the functional long-term survival of the prosthesis.

Prosthetic designs also vary considering the carrying angle and particularly the way in which

this angle is incorporated in the design through either the humeral or ulnar implant.

Moreover, some implants can use a radial head component, which is an important additional variable. When replacing the radial head, a reduction in valgus and varus laxity can be observed, which is important for stress distribution and for transfer of joint reactive force.

Precise orientation of the humeral and ulnar components and their sizes is essential, as the degree of motion and laxity of the elbow, wear, and loosening are affected significantly by positioning [60].

Linked and unlinked prosthesis brands do not significantly differ in the survival rates, the main cause identified for revision for both types being loosening [61]. Biomechanical studies observed the presence of abnormal bone stresses for the linked type, which has been associated with the risk of loosening [62].

In 2011, Completo et al. [63] demonstrated that the use of an unconstrained prosthesis also changes the biomechanical behavior of the humerus and ulna, with risk of bone fatigue failure by overload in metaphyseal regions, particularly at the ulna, and bone resorption by stress-shielding at epiphyseal regions, for elbow loads in the range of daily activities.

4.6.4 Proprioception in Prosthetic Elbow

Joint lesions negatively affect proprioception. Accurate orientation of the elbow is necessary for optimal positioning of the hand, because the accurately positioned joint then enables muscle contraction to produce the angular joint forces required to achieve power and precision tasks. This in turn partly depends on proprioceptive function, defined as a sense of articular position that is based on a complex system that relies on central integration of various afferent and efferent components. Peripheral proprioceptive information is transmitted from mechanoreceptors located in the skin, muscles, and joint via sensory nerves to the central nervous system. Muscle spindles provide feedback in response to centrally generated motor actions and trigger motor adjustments in reaction to unexpected loads or obstacles, being particularly important when the limb is actively controlled. For passive movements, other components of proprioception probably have a major contribution. Tendons are believed to provide the sense of tension.

Proprioceptive accuracy can be tested using a range of proprioception measurement approaches, such as force reproduction, threshold to detection of passive movement (TDPM), and joint position sense, depending on the modality that is judged most important.

Often, surgical procedures for total elbow replacement require fairly aggressive dissection, the release of many ligament and tendon attachments, and cause significant periarticular soft tissue damage. This can conversely cause the loosening of structures deputed to proprioception in healthy joints. When elbow proprioception has been tested on patients, 48 and 72 months after total elbow arthroplasty, they showed differences on the TDPM, with high movement perception latency at the prosthetic elbow joint compared with the contralateral side [64]. The reasons for the proprioceptive deficit in TDPM are possibly explained by the TEA removing or damaging the tissues, such as the capsule and ligaments, that are the main sources of proprioceptive information. Pacinian corpuscles in the ligaments and Ruffini-like organs in the joint have been well documented to play a strong role in joint proprioception. Therefore, the compromised afferent input might adversely influence the postoperative proprioception performance on the TDPM test. Furthermore, the modification of soft tissue tensioning patterns throughout the joint caused by fibrosis and mechanical load absorption by the semi-constrained hinge of the prosthesis may also compromise the physiological activation of the remaining receptors. To determine TDPM as a functional outcome measure after surgery and subsequent rehabilitation, it is, therefore, worthwhile for clinicians to consider [65].

4.7 In Vivo Kinematics of Total Elbow Arthroplasty

To analyze how people perform activities of daily life in vivo after elbow surgery can be done using motion analysis systems.

Using a stereophotogrammetric system [ELITE, BTS, Milan, Italy], we analyzed 8 subjects (8 males; mean age 62, 8 years [range 47–84]; mean time from surgery 24, 6 months [range 11–57]) with total elbow arthroplasty in a movement analysis laboratory (Fig. 4.5).

Subjects have been analyzed during the following tasks: browse a book; drink from a glass; eat with a fork; pour water from a carafe; comb; use the cell phone.

The elbow flexion–extension range of motion was quite similar in our sample, between affected (i.e., with total elbow arthroplasty) and unaffected side in all the analyzed tasks, confirming how a great joint excursion is needed for some contemporary tasks, like the use of cellular phone (Fig. 4.6).

Interestingly, total elbow arthroplasty account for greater pronation–supination range of motion in almost all the analyzed tasks (Fig. 4.7). This can be probably related to the intrinsic characteristics of the prosthetic implant, as well as to the need for the patient to compensate altered movements in different planes of motion.

Far from being exhaustive, these data demonstrate that an in vivo analysis is possible in people

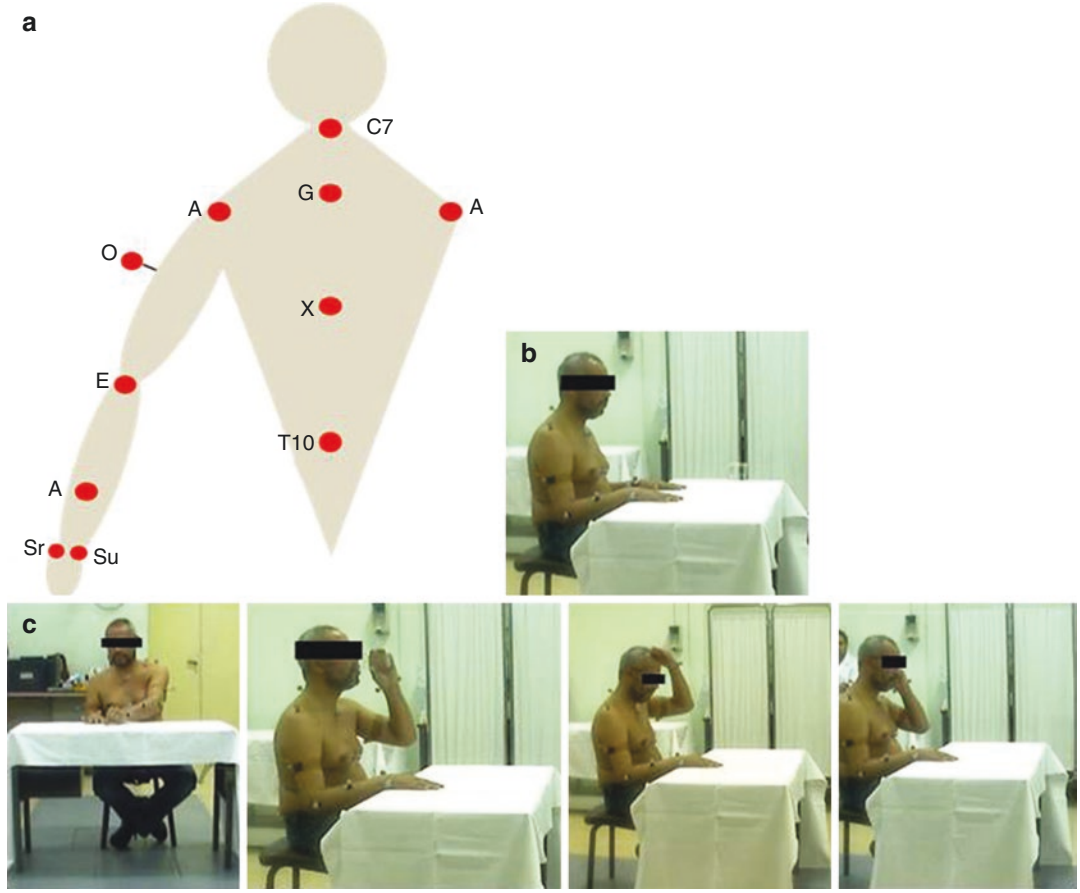

Fig. 4.5 Biomechanical model (**a**), starting position (**b**), and performance of functional tasks (**c**) in the laboratory setting for in vivo kinematic analysis of total elbow arthroplasty patients

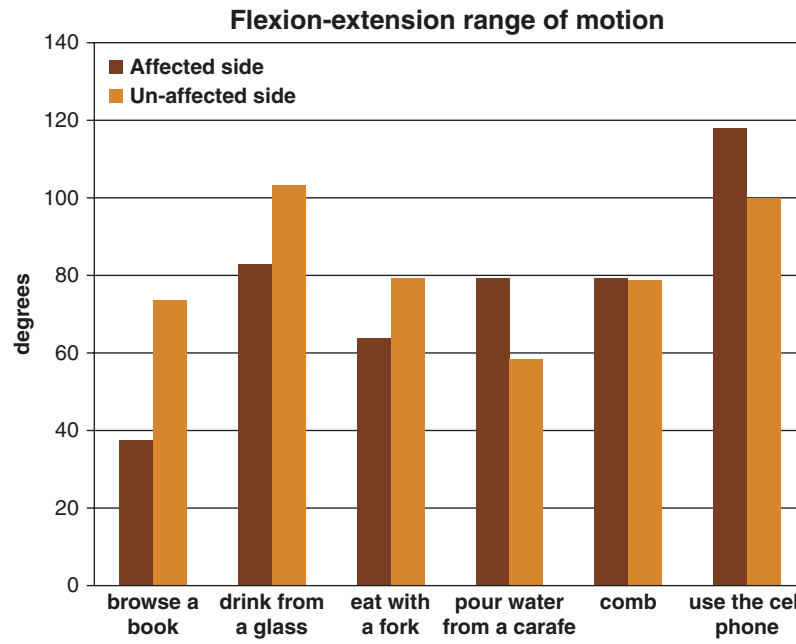

Fig. 4.6 Flexion-extension range of motion of the elbow in subjects with total elbow arthroplasty during the functional tasks analyzed

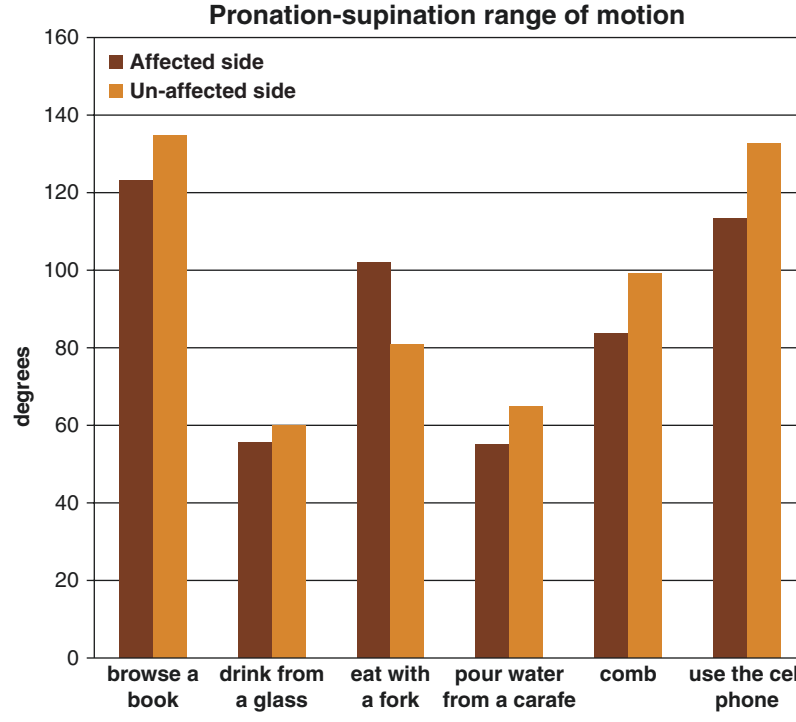

Fig. 4.7 Pronation-supination range of motion of the elbow in subjects with total elbow arthroplasty during the functional tasks analyzed

with total elbow arthroplasty. A movement analysis for selected patients could be useful not only in experimental but even in clinical setting, in order to define if specific rehabilitation programs can be suited for that patient.

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5 Surgical Approaches for Elbow Replacements

Enrico Guerra, Roberta Zaccaro, Alessandro Marinelli, Marco Cavallo, Graziano Betttelli, and Roberto Rotini

5.1 Introduction

Elbow arthroplasty presents some unique characteristics; in fact, compared to the hip and knee joints, the elbow is relatively small, and its stability depends largely on ligamentous integrity.

Inflammatory arthropathies such as rheumatoid arthritis represent the classic indication for elbow arthroplasty, but indications have been expanded to include post-traumatic osteoarthritis, acute distal humerus fractures, distal humerus nonunions, and reconstruction after tumor resection. Elbow arthroplasty is very successful in terms of pain relief, motion, and function. However, its complication rate remains higher than arthroplasty of other joints. The most common complications following elbow arthroplasty include infection, loosening, wear, triceps weakness, and ulnar neuropathy. If surgery needs to be revisited, bone augmentation techniques provide a reasonable outcome [1].

Total elbow arthroplasty (TEA) for an acute distal humeral fracture does not have to be performed as an emergency procedure. The skin must be in reasonable condition, and if dermal abrasions or bruises are present, it is preferable to wait several days before surgery is undertaken.

5.1.1 Indications for TEA for Acute Fracture

- Non-construable distal humeral fracture.
- Reconstruction failure.
- Osteoporotic bone stock.
- Rheumatoid arthritis or inflammatory disease.
- Elderly patients aged >70 years.

5.1.2 Contraindications for TEA for Acute Fracture

- Infection.
- Massive contamination.
- Neurological deficit [2].

A separate chapter in this book addresses the replacement of the humeral side only of the elbow joint: hemi-elbow arthroplasty.

This technique is a relative new approach that is struggling to be accepted into surgical

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practice because of the level of difficulty involved and because of as yet uncertain results. The most common indications include irrecoverable fractures of the humeral trochlea in young patients and less frequently primary or secondary arthritic degeneration where the articular cartilage of the large sigmoid incision is partially conserved. One of the greatest surgical difficulties in hemiarthroplasty lies in surgical access; this topic is discussed at the end of this chapter.

5.2 Surgical Approach for Total Elbow Arthroplasty

Every surgical approach used for implantation of an elbow arthroplasty requires mobilization of the elbow extensor mechanism and management of the ulnar nerve transposition [1].

The many surgical procedures available and their potential complications make it essential for the surgeon who treats elbow injuries and performs elective elbow surgery to have a sound knowledge of the local anatomy.

The question of which is the best surgical approach for total elbow arthroplasty is of broad and intense current interest. Correct identification of the injury and evaluation of the potential surgical difficulties may alter the initial procedure.

5.2.1 Patient Position

An elbow prosthesis can be performed both with the patient in the supine position and with the patient in a lateral or prone decubitus.

The supine position allows working on the ulna more easily, the one step in the intervention that is technically more difficult, especially in cases of arthritis in degenerative or post-traumatic arthropathy when the anatomy of the proximal ulna can be distorted.

The supine decubitus position, with the arm brought across the chest, has the disadvantage of requiring an assistant to support the limb throughout the operation, positioned on the opposite side of the patient's chest. This assistant will not be able to easily follow all the surgical steps. Alternatively, a pneumatic positioner can be used that allows easy release and that can be hung onto the arm when necessary, without affecting the sterility of the surgical field.

The lateral or prone position allows the humerus to be constantly resting on the arm support below the sterile field. In this situation, operating on the ulnar side is slightly more difficult. However, this position is advisable with irreparable fractures or in cases in which the synthesis is particularly difficult (for the fracture comminution) but is still judged "possible" in surgical planning. The decubitus position does not in any way prevent a change of approach during the operation if a fracture with a non-reparable humeral trochlea is found.

Finally, the prone position maintains the limb to a similar extent to the supine decubitus position, but compared with the other positions makes it more difficult to provide anesthesiologic assistance to the patient.

5.2.2 Skin Incision

In order to implant a prosthesis it is necessary to achieve a large working area, for which a "universal" incision with mobilization of a thick lateral and medial fasciocutaneous flaps is particularly useful.

The "front door of the elbow" is usually considered "the back." A posterior incision with a posterior exposure can be used for the majority of surgical interventions on the elbow. With the patient in a supine position with the arm brought across the chest, a classical posterior skin incision is made 7 cm proximal and 7 cm distal to the tip of the olecranon (Fig. 5.1).

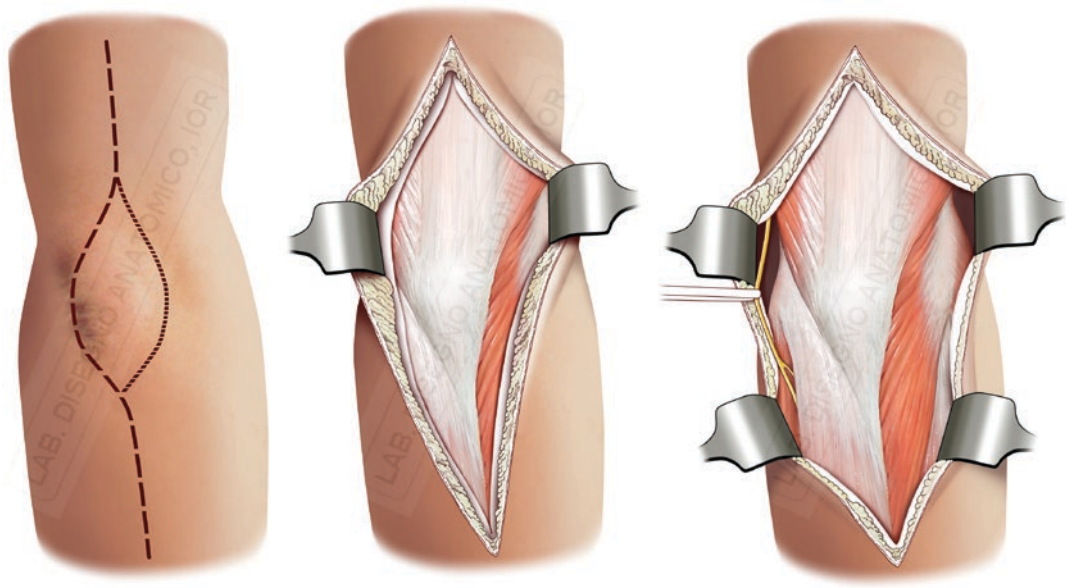


Fig. 5.1 Posterior skin incision, avoiding the olecranon and ulnar nerve dissection (Reproduced from surgical fields by the Anatomic Design School of University of Bologna)

5.2.3 Management of the Extensor Mechanism

Orthopedic surgeons recognize the management of the extensor mechanism as a key element for the success of the procedure. Problems associated with triceps insufficiency after total elbow arthroplasty are a well known phenomenon, despite the many potentials solutions proposed [1, 3, 4]. As the awareness of triceps insufficiency has grown, surgeons have turned to alternative procedures.

The techniques involved in total elbow arthroplasty may be divided into ways to manage the triceps and how to attain an adequate exposition to implant the prostheses: triceps splitting, reflecting the triceps mechanism, or preserving the triceps approach. The first option is to split of the triceps in the midline, The second is to reflect the triceps in continuity with soft tissues, with or without a portion of the osseous attachment. The third is to leave the triceps tendon attached to the olecranon by for example stripping the distal humerus.

Booker and Chris [5] discussed in their review the different approaches "triceps on" and "triceps-off" in an attempt to discover which approach is better in terms of lower complications. Olecranon osteotomy was excluded probably because of the very few indications involving this procedure (however, we did include it in the triceps-on group) (Table 5.1).

Table 5.1 Booker and Smith's classification of the different approaches to performing elbow arthroplasty

Triceps off		Triceps on	
Splitting	1. Splitting 2. Shahane-Stanley 3. Triceps split and snip 4. Anconeus triceps lateral flap	Single	1. Medial 2. Lateral
Turn down (tongue)		Dual	1. Alonso-Llames 2. Modified bilatero-tricipital anconeus 3. Paraolecranon 4. Olecranon osteotomy
Elevating	1. Brian-Morrey 2. Modified Kocher approach		

Below we analyze the surgical approaches individually.

5.3 Triceps Off

In all these approaches, the triceps is detached from its position on the olecranon tip and reattached at the end of the procedure.

1. *Splitting.*
   In all the different versions of this technique, the ulnar nerve is identified and protected and not necessarily released, but great care must be taken to avoid injury at the time of retraction [4].
   - *Splitting* (Fig. 5.2) [6, 7].
     - A longitudinal incision is made from the proximal triceps muscle to the distal triceps tendon across its attachment at the proximal olecranon.
     - The triceps is split down the midline.
     - The triceps attachment is elevated from the posterior aspect of the olecranon both medially and laterally.
     - The detachment from the olecranon can be performed subperiosteally or with a thin osteotomy (wafer technique).
     - The dissection continues subperiosteally both medially and laterally at the proximal ulna.
     - The lateral and medial collateral ligaments (MCL) are detached together with the muscle attachments of the medial and lateral epicondyles, respectively.
     - The joint is easily dislocated.
     - The repair requires transosseous sutures through the olecranon.
   - Splitting: *Shahane-Stanley* [8].
     - In this modification of the splitting technique, the triceps is split 75% laterally and 25% medially.
     - The lateral part is detached subperiosteally together with the anconeus and the lateral muscles.
     - The medial part remains attached to the olecranon.
     - The MCL has to be cut beneath the ulnar nerve.
     - The ulnar nerve has to be isolated but remains in its groove.
     - The dislocation of the joint is performed through the spit quite easily.
     - The repair requires transosseous sutures through the olecranon.
   - Splitting: *Triceps split and snip* (Fig. 5.3) [9].
     - Splitting the entire triceps down the midline is described.
     - The lateral part of the tendon is left attached to the olecranon.

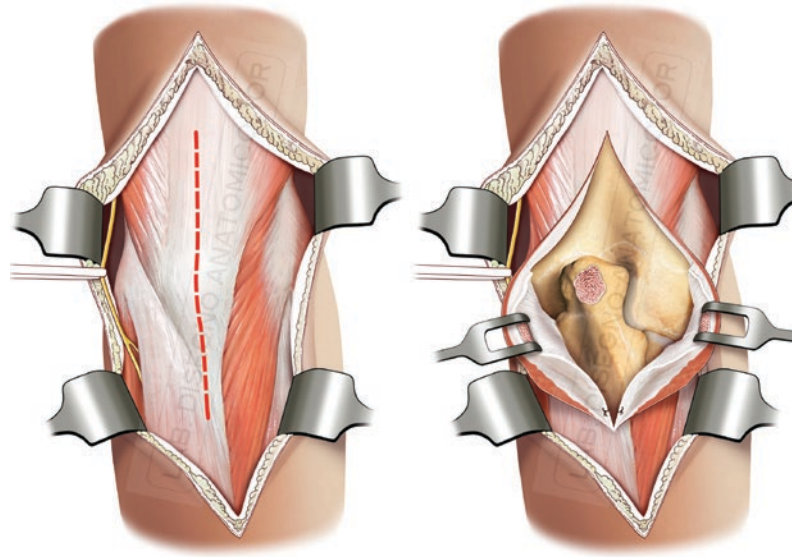


Fig. 5.2 Posterior triceps incision and splitting (wafer technique) (Reproduced from surgical fields by the Anatomic Design School of University of Bologna)

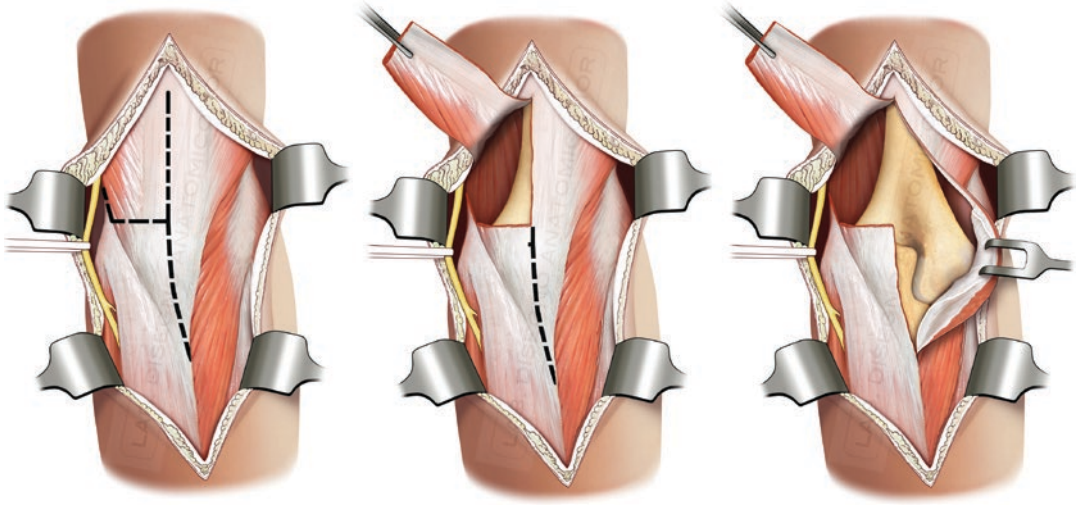


Fig. 5.3 Triceps split and snip (Reproduced from surgical fields by the Anatomic Design School of University of Bologna)

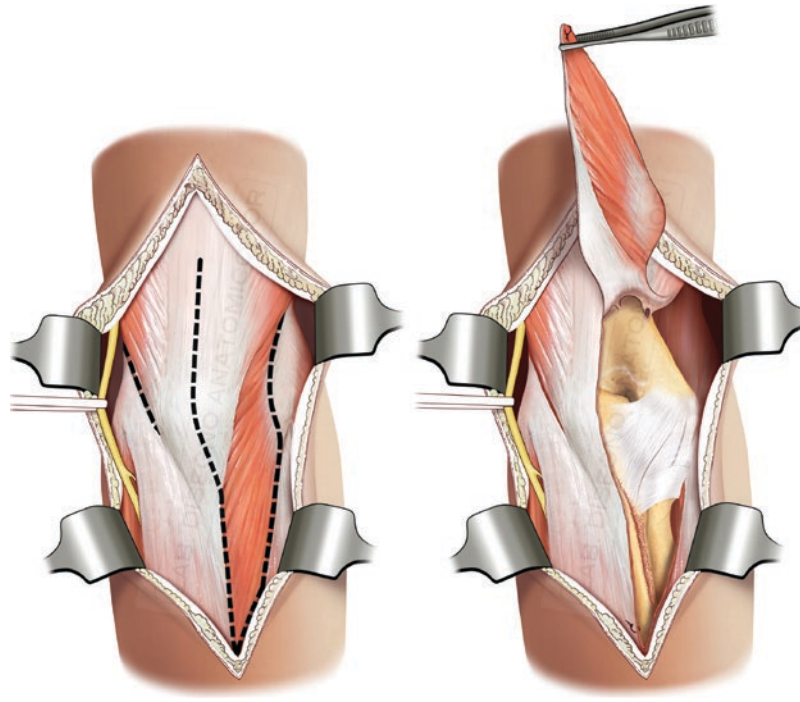


Fig. 5.4 Triceps splitting: anconeus triceps lateral flap (Reproduced from surgical fields by the Anatomic Design School of University of Bologna)

- The medial part is snipped 1 cm from the insertion (approximately).
- The technique is the same as that for the splitting technique.
- The repair will be end to end, with a side-to-side tendon closure.

- Splitting: *Anconeus triceps lateral flap* (Fig. 5.4) [10, 11].
  - The Kocher interval is used: between the anconeus and extensor carpi ulnaris.

- A plane between the lateral triceps expansion and the true tendinous part of the triceps is developed (triceps decussation).
- This triangular flap is elevated proximally off the ulna.

- The medial tendinous part of the triceps remains on the ulna.

2. *Turn down (tongue)* (Fig. 5.5).
   - The triceps insertion is left undisturbed, but the tendon is turned down completely, and the integrity between the tendon and the muscle is disrupted. For this reason, this procedure has been included in the triceps-off group.
   - The ulnar nerve is identified and secured.
   - A V-shaped tongue is carved through the triceps aponeurosis.
   - The underlying muscle is split down the midline.
   - The lateral and MCL are detached together with the muscular flap (triceps-flexor/pronator medially and triceps-extensor/supinator laterally).
   - The joint is dislocated to allow the implant.
   - *(Historically, a variation was osteotomy of the medial and/or lateral epicondyle.)*
3. *Elevating.*
   - Brian-Morrey.
     - The ulnar nerve has to be well isolated in all positions along the elbow.
     - The cubital tunnel retinaculum is released.
     - The triceps is detached.
     - The entire muscle is exposed, from medial to lateral.
     - Its continuity with the anconeus (elevated from its bed) and the forearm fascia is maintained.
     - The MCL is detached.
     - The posterior and anterior capsule is removed.
     - The joint is dislocated medially *(paying attention not to pull the ulnar nerve excessively).*
     - The collateral ligaments released from their humeral origins allow the ulna to separate from the humerus, providing excellent visualization [4].
     - It is necessary to securely reattach the insertion site to the olecranon, at the end of the procedure, with a crisscross type of suture [4, 6, 9, 10].
     - Use a heavy nonabsorbable suture that is placed through cruciate drill holes in

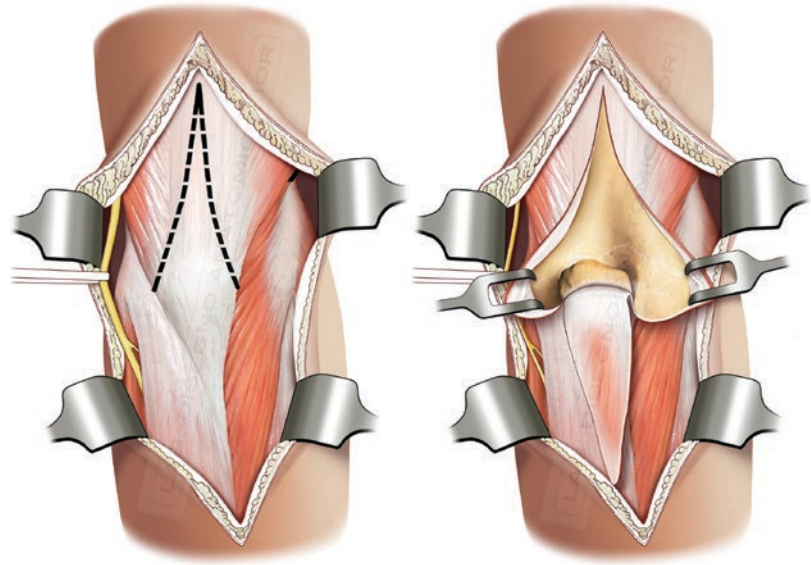


Fig. 5.5 Triceps turn down: tongue (Reproduced from surgical fields by the Anatomic Design School of University of Bologna)

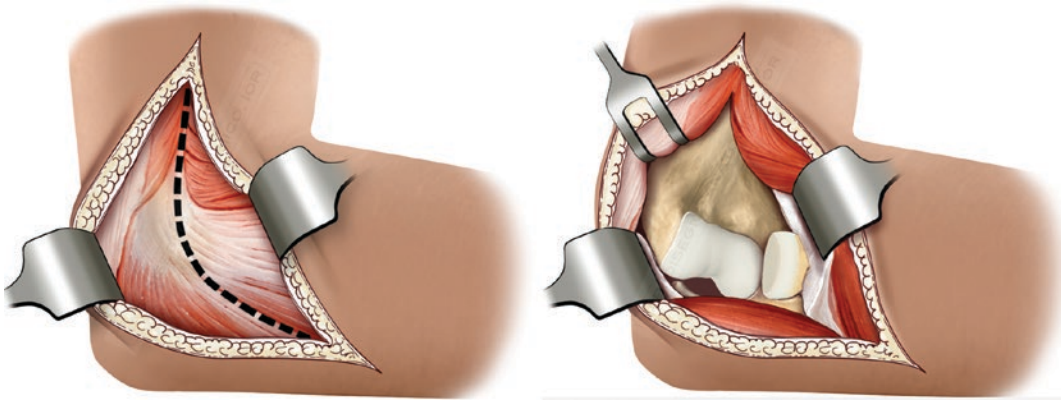


Fig. 5.6 Triceps elevating: Kocher modified (Reproduced from surgical fields by the Anatomic Design School of University of Bologna)

the ulna it is firmly locked into place by stitches in the triceps tendon and aponeurosis.

- Modified KOCHER approach (Fig. 5.6).
  - The ulnar nerve is identified and secured.
  - The triceps is detached.
  - All the muscles are exposed from lateral to medial (the extensor carpi ulnaris and common extensor muscle mass from the lateral epicondyle).
  - The extensor longus and distal fibers of the brachioradialis must be elevated from the humerus.
  - The lateral collateral ligament (LCL) is detached.
  - The posterior and anterior capsule is removed.
  - The triceps may be elevated from the posterior aspect of the humerus, and the anconeus is lifted from its insertion (preferably from medial to lateral) [1].
  - The joint is dislocated laterally by a varus supinatory stress.
  - Often the MCL (and common flexor muscles) can be left intact and will act as a hinge to dislocate the elbow.

5.4 Triceps On

In these approaches, the surgeon tries to leave the attachment of the triceps intact.

1. *Single.*
   (a) Medial.
   - The ulnar nerve is released from proximal to distal and retracted.
   - The MCL is detached together with flexor-pronator muscles.
   - The flexor-pronator muscles are elevated from the distal humerus and proximal ulna.
   - The capsule is removed.
   - The dislocation occurs on the medial side, near the ulnar nerve, using a strong pronation.
   - The LCL can act as a hinge, but it has to be detached when the elbow is very tight.

   (b) Lateral.
   - A posterior incision is suggested.
   - The ulnar nerve is identified.
   - The Kocher interval is identified.
   - The LCL exided.
   - All the epicondyle muscles are elevated.

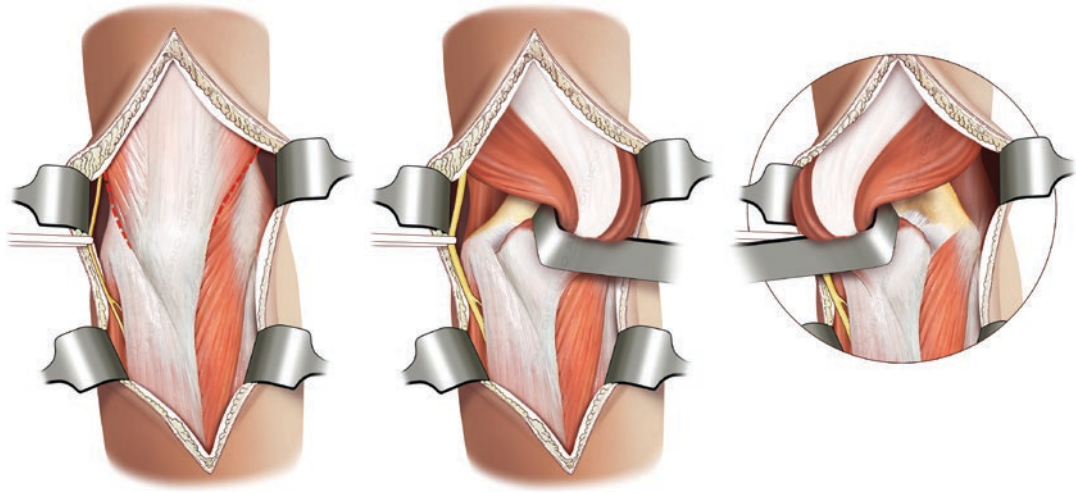


Fig. 5.7 Triceps on: Alonso-Llames triceps insertion preserving (Reproduced from surgical fields by the Anatomic Design School of University of Bologna)

- The capsule is removed.
- The joint is dislocated by means of a strong supination maneuver.
- The MCL is usually the hinge for the dislocation, but it has to be detached when the elbow is very tight.

2. *Dual.*
   (a) Alonso-Llames (Fig. 5.7) [12].
   - The ulnar nerve is released from proximal to distal and retracted.
   - The triceps is lifted off the intermuscular septum lateral and medially.
   - The posterior capsule is removed.
   - To dislocate the joint medially or laterally, both medial and lateral ligaments have to be detached.
   - The muscles have to be lifted off the medial and lateral epicondyle (together with the collateral ligament).

   (b) Modified bilatero-tricipital anconeus.
   - The anconeus is isolated and remains attached to the ulna.
   - The dislocation occurs laterally (between the anconeus and extensor carpi ulnaris).
   - Hyper-pronation allows the surgery to be performed on the proximalulna.

   (c) Paraolecranon (Fig. 5.8) [13]
   - After ulnar nerve transposition, the medial intramuscular septum must be excised, and the dissection is continued between the brachialis and the medial head of the triceps.
   - The triceps muscle is elevated from the posterior humerus, while its tendon, which is attached to the olecranon tip, remains in place.
   - The anconeus is lifted from the ulna to expose the lateral aspect of the greater sigmoid notch and the posterior radiocapitellar joint.
   - The triceps is split in line with the lateral side of the proximal ulna.
   - All the tendons remain intact on the olecranon.
   - The lateral side of the triceps is elevated laterally together with the anconeus, lateral epicondyle muscles, and insertion of the LCL.
   - The MCL and the common flexor–pronator origin are released from the medial epicondyle to allow dislocation of the elbow.
   - The entire triceps and ulna are dislocated medially by hypersupination of the forearm.
   - After implantation of the prosthesis, the medial and lateral arthrotomies are closed, as well as the split between the lateral aspect of the triceps tendon and the lateral cubital retinaculum using

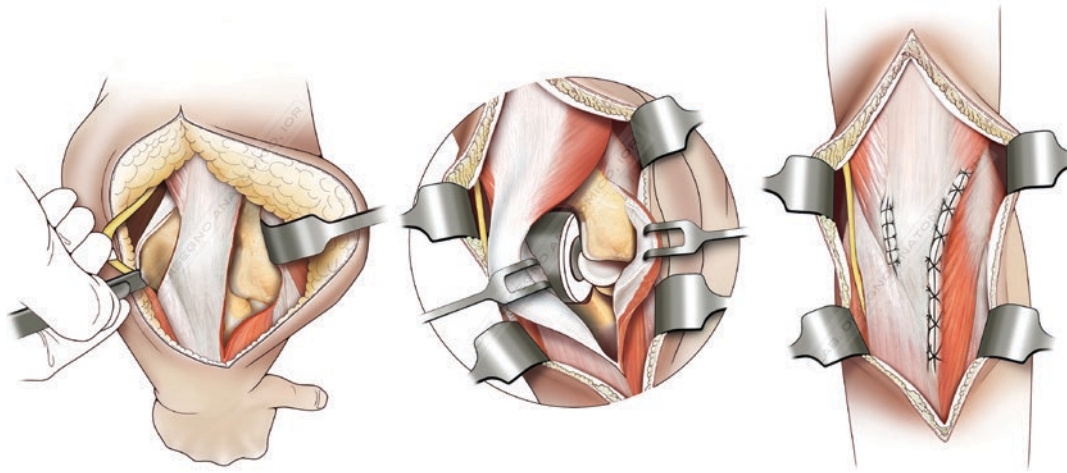


Fig. 5.8 Triceps on: Paraolecranon approach (Reproduced from surgical fields by the Anatomic Design School of University of Bologna)

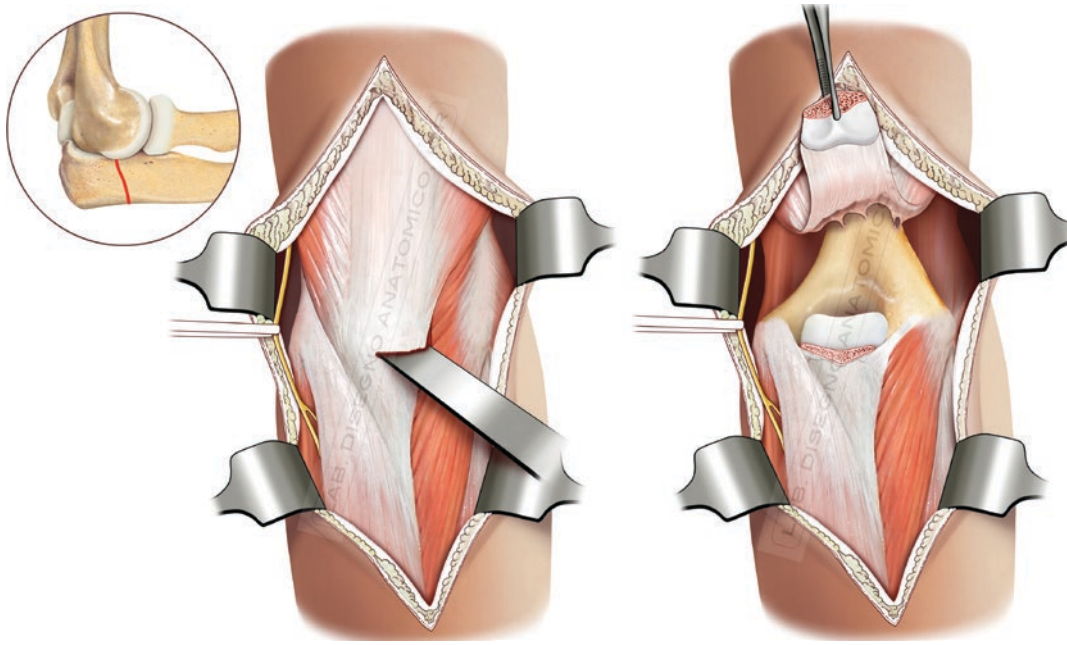


Fig. 5.9 Triceps olecranon preserving insertion by a Chevron osteotomy of the olecranon (Reproduced from surgical fields by the Anatomic Design School of University of Bologna)

buried nonabsorbable sutures. The flexor–pronator origin is repaired onto the medial triceps and medial epicondyle if present to cover and protect the prosthesis.

(d) Olecranon osteotomy (Fig. 5.9) [14].
This is not considered a viable option for joint replacement arthroplasty, except in selected cases treated with humeral hemiarthroplasty, or unexpected intraoperative conversion of fixation to arthroplasty in the treatment of distal humeral fractures.

- Posterior midline incision (passing medial or lateral to the olecranon).
- The medial and lateral sides of the olecranon are subperiosteally exposed.

- The ulnar nerve is identified and released.
- The posterolateral and medial capsule is incised.
- Olecranon Chevron osteotomy is performed using a saw and completed with an osteotome.
- The triceps is released at its lateral and medial sides from the intermuscular septum.
- MCL and LCL remain safely under the common flexor tendon unit and anconeus muscle, respectively.
- The triceps, which is fully attached to the olecranon, is now elevated. Removing the posterior capsule, the joint is exposed. By flexing the elbow, it is now possible to completely visualize the anterior trochlea and humeral capitellum.
- LCL, MCL, or both may now be released from the epicondyle or epitrochlea to dislocate the joint.
- To close the approach, the olecranon has to be fixed by a cancellous screw and/or wire cerclage or a precontoured plate.

5.5 The Authors' Preferred Method

Over the years, we have used each of the different approaches described. We started with removal of the triceps according to Brian-Morrey, the "godfather" of elbow surgery, moving gradually to the triceps-on techniques to preserve the triceps attachment on the olecranon and to reduce the risk of weakness of the extensor apparatus (at follow-up). The reattachment of the triceps by transosseous stitches is often not easy, especially resulting from weakness of the residual olecranon after preparation to insert the ulnar component of the prosthesis.

Unfortunately, the Alonso-Llames approach presented great difficulties during the ulnar period of prosthetic surgery. For one thing, the surgical view is reduced, and in order to find the medullary canal of the ulna and prepare the correct housing of the ulnar component, we would need to perform repetitively dangerous torsional manoeuvers.

This has led, today, to the suggestion that, for one of the most used prosthetic implants, the approach should be based on a combination of the triceps-on approach and the medial splitting of its tendon immediately above the olecranon apex; this combination yields a good exposure for working longitudinally with rasps and stalks in the ulna. However, in our surgical experience, at the end of this technique, the triceps tendon remained severely damaged.

We therefore moved on to the triceps-off approach, choosing median splitting, with the separation of the triceps from the olecranon with two bone bracts. This wafer technique is particularly useful for restoring the correct length to the triceps.

With this procedure, the surgical "sight" is very wide. As described above, the triceps is divided into two parts; both medial and lateral flaps remain in place in with the respective capsuloligamentous compartments and the epicondylar tendons. At the end of this procedure, the triceps reconstruction is good and functional, but the problem of possible weakness of the extensor mechanism still remains.

The last phase of our experience involved further changes thanks to the new procedure described by King, the paraolecranon access, which in our opinion is the best compromise in that it allows working along the longitudinal axis of ulnar diaphyseal canal, preserving the triceps insertion at the olecranon.

In conclusion. We can state that triceps-on procedures are more demanding while triceps-off procedures are more risky in terms of weakness of the extension [5].

In reality, there is no procedure that has demonstrated a significant difference in clinical results at follow-up. Surgeons must make a choice based on their experience and their preparation; if less than five implants a year are performed, our advice is to choose a triceps-off procedure because this offers a wider surgical visualization and doesn't add difficulties to an already complex intervention such as the implan-

tation of a total elbow prosthesis. The more expert surgeons can select different options case by case, depending on the type of arthritis/fracture/anatomy of the patient.

The debate regarding the management of the ulnar nerve is still continuing. A 3% incidence of significant ulnar nerve complications after TEA compares favorably with systematic reviews [15]. The nerve must always be identified and prudently isolated. The most commonly held view is not to leave the nerve in contact with the implant, as frequently occurs in implants for serious comminuted fractures of elderly patients, where the columns are not or cannot be synthesized.

In elective cases, when the surgical procedure allows reduced isolation and the epitrochlear tissue envelope appears to be preserved, there is no general agreement on the need for anteposition. In our experience this eventuality is extremely rare; we prefer to isolate the nerve extensively to avoid excessive or accidental tractions during surgery, and at the end of the procedure, we prefer to routinely perform subcutaneous anteposition.

5.6 Surgical Approach for Hemi-Elbow Arthroplasty

Hemi-elbow arthroplasty involves leaving the great sigmoid notch intact and pairing it to a prosthetic distal humerus trochlea. Stability is essential for reducing cartilage wear and consequently for the survival of the implant.

The correct approach in these difficult surgical procedures makes a great difference.

Distal humerus fractures are increasingly frequent in patients older than 60 years.

Open reduction and internal fixation are always the first treatment options, but there must be sufficient stability to allow an early range of motion [16].

Total elbow arthroplasty (TEA) is a well accepted indication in elderly patients with comminuted intra-articular fractures, but complications mostly in the ulnar component of the implant are not uncommon (loosening, periprosthetic fracture, etc.). For these reasons, it is commonly accepted that a patient with TEA has important permanent restrictions: repetitive lifting greater than 1 kg is not recommended, and single-event lifting over 5 kg is strongly discouraged.

Distal humeral hemiarthroplasty (DHH) is a new treatment option devised to reduce restrictions and possible complications in adult patients. The existing follow-up is currently too short to confirm real advantages compared to TEA, but preliminary results are encouraging [17].

Distal humeral hemiarthroplasty is indicated in:

- Non-reparable intra-articular fracture.
- Fracture mal−/non-union.
- ORIF failure.
- *(Arthritis changings in younger patients.)*

We started performing DHH 11 years ago, choosing very careful indications and surgical approach.

In our experience, the decision regarding the best surgical procedure is a really difficult one and strongly related to the particular case under examination.

In every elbow replacement, a valid surgical approach should offer wide visualization in addition to effective management of collateral ligaments and triceps insertions [18]. Moreover, in DHH, the surgeon might have to deal with fractured columns, non-/mal-union of distal humeral fractures, previous ORIF failure, etc.

Elbow stability is essential for a painless and functional joint as well as for the longevity of the prosthesis. Therefore the humeroulnar and radiocapitellar anatomy has to be rebuilt:

- The right prosthesis at the correct height and orientation has to perfectly match the greater trochlear notch and radial head.
- Both medial and lateral columns have to be preserved or repaired if fractured.
- The integrity of the anterior band of medial collateral ligrament (aMCL) and the ulnar head of the lateral ligament (LUCL) has to be preserved or reconstructed.

Many elbow approaches are described in the literature. They differ substantially on the way to manage the triceps mechanism, with good results reported in TER.

For DHH it is different, with only a few cases described and a short follow-up. Olecranon osteotomy seems to be more effective with regard to ligament preservation [17], while sparing or reflecting triceps techniques make the choice of prosthesis and positioning easier [16]. Olecranon osteotomy and triceps-reflecting anconeus pedicle are better when attempting an ORIF treatment [19, 20], while a midline triceps split is useful when DHH will definitely be perfomed [21, 22]. On the other hand, an olecranon osteotomy or triceps-preserving [12, 23] approach is the best method for avoiding triceps rupture or impairment, despite their disadvantages [18].

We carefully studied the following four approaches:

- Olecranon osteotomy.
- Triceps-reflecting anconeus pedicle (TRAP).
- Midline triceps splitting.
- Triceps preserving technique (triceps on).

5.6.1 Olecranon Osteotomy

For surgical technique: see earlier in this chapter.

Advantages

- Wide view over the posterior and anterior side of the humerus [24].
- Triceps insertion is not violated at all.
- The collateral ligaments can be completely saved if left attached to the displaced fragments of the epicondyle.
- Column fractures can be fixed with long precontoured plates.

Disadvantages

- Ulnar nerve needs to be well isolated.
- Olecranon osteotomy may not heal or induce arthritic changes.
- Less landmarks to choose DHH, intraoperative tracking is the only way to judge.
- A good osteotomy plane and a precise and strong olecranon ORIF are mandatory.
- The hardware at the olecranon may have to be removed.

…in our opinion

- Lateral decubitus: useful for olecranon synthesis.
- Makes the choice of the correct length and orientation of DHH more difficult.
- It is the best approach when we have an articular fracture probably amenable to fixation, the patient is young, and the fracture completely involves the anterior trochlea, as ORIF is always the gold standard treatment… and so intraoperative conversion to arthroplasty is possible but in reality rare.
- Passing through the fractured column, lateral and MCL remain intact to the bone.
- Column fractures can also be fixed by long precontoured plates, if necessary.
- When the olecranon osteotomy and the fracture are fixed around DHH, elbow stability will quickly recover intraoperatively.

5.6.2 Triceps-Reflecting Anconeus Pedicle (TRAP)

Surgical technique

- It is a triceps turn-off technique.
- Posterior midline incision (passing medial or lateral to the olecranon).
- The interval between anconeus and extensor carpi ulnaris is developed.
- The ulnar nerve is identified and released.
- The triceps is released at its lateral and medial sides from intermuscular septum.
- The anconeus is detached from the ulna, posterolateral capsule, and LCL complex.
- The triceps is separated from the olecranon (subperiosteally or by a very thin osteotomy called wafer technique) and elevated together with the anconeus tongue.
- Removal of the posterior capsule exposes the joint.

- By hyperflexion, it is possible to visualize almost completely the anterior trochlea and humeral capitellum.
- LCL, MCL, or both may now be released from the epicondyle or epitrochlea to dislocate the joint.
- To close the approach the triceps has to be sutured to the bone (transosseous sutures) and anconeus to soft tissue around.

Advantages

- Wide view over the posterior side of the humerus.
- Anconeus tongue is a vascular olecranon supply.
- The pedicle is a landmark for reconstruction (together with a wafer technique) and a soft tissue coverage of the prosthesis and LCL and seems to provide posterolateral stability.
- The intact olecranon together with the coronoid is a precise mold for rebuilding the anatomy before fixation of the comminuted intra-articular fractures or to choose the right dimension and orientation of the prosthesis.

Disadvantages

- Ulnar nerve needs to be widely released.
- A wider distal incision to achieve a complete anconeus detachment is needed.
- Elbow hyperflexion allows a sufficient view of the anterior side of the joint, but the dislocation is necessary for DHH.
- Transosseous and precise reconstruction of the triceps is mandatory.

… in our opinion.

- Supine position: a third assistant is needed but makes DHH easier.
- Landmark stitches around anconeus: the muscle may change its shape a little during surgery; these stitches are really useful to find the right position while choosing the height of the humeral stem as well as a closure.
- Bony detachment by an osteotome (wafer technique) of the triceps: it works as a landmark during surgery and as augmentation for the tendon to heal.
- We use the fracture to dislocate the joint: Collateral ligaments could be left attached to the fractured columns; this is the preferred way to achieve a good elbow stability at the end of the surgery.
- When we have a fixable articular fracture, the patient will be old. In these patients, the gold standard remains the ORIF, but the osteotomy of the olecranon has shown a higher rate of non-union. The TRAP approach gives a good view of articular surfaces only a little lower than the olecranon osteotomy and allows the reduction/fixation of the fracture as well as the intraoperative conversion to DHH.

Passing through the fractured columns, lateral and MCL remain attached to the bone. When the medial and lateral epicondyle are fixed around DHH, elbow stability will be quickly recovered intraoperatively.

5.6.3 Midline Triceps Splitting

Surgical technique (as described above):

- Posterior midline incision (passing medial or lateral to the olecranon).
- Ulnar nerve is identified and released. The triceps is incised full thickness in the middle, and the tendon is subperiosteally dissected to either side from the olecranon. Anconeus and flexor carpi ulnaris are divided from the olecranon.
- Removing the posterior capsule, the joint is exposed.
- MCL and LCL have to be released from the epicondyle and epitrochlea to dislocate the joint and perform DHH; even if detached from the humerus, ligaments are left attached to the triceps and flexor (medially) or triceps and extensor (laterally) common tendon unit; in this way a soft tissue envelope is created, which is well vascularized and easy to close.
- At the end, both medial and lateral complexes and the two parts of the triceps have to be strongly sutured by transosseous stitches.

Advantages

- Quick to carry out.
- Wide view over the posterior side of the humerus.
- The two sides of soft tissue envelope seem reliable for transosseous reconstruction of lateral and medial collateral mechanism.
- The intact olecranon and columns are precise landmarks for performing DHH.

Disadvantages

- Not useful to fix column fractures.
- If expanded proximally could lead to triceps weakening.

… in our opinion

- Supine position: A third assistant is needed but makes DHH easier.
- Bony detachment by an osteotome (wafer technique) of the triceps: It works as a landmark but above all as augmentation for the tendon to heal.
- The effective intraoperative recovery of elbow stability after only transosseous sutures is related to the single midline cut with all the soft tissue together (lateral and medial). This envelope is particularly useful when the acute fracture (or sequelae) do not involve the columns but only the trochlea.

Thus, we prefer triceps splitting when we have decided to perform a DHH and there are no fractures of the column. In these cases, it is mandatory to release the medial and LCL to dislocate the elbow.

We leave the ligament intact with the triceps and epicondyle muscles, as two functional units.

At the end of surgery, we suture the ligaments to the bone and close the two sides of this soft tissue "envelope" using side-to-side stiches. The triceps will be reattached to the olecranon as strongly as possible.

This reconstruction is really effective for recovering elbow stability after surgery.

5.6.4 Triceps Preserving Technique (Triceps on)

Surgical technique (as described above):

- Posterior midline incision (passing medial or lateral to the olecranon).
- Ulnar nerve is identified and released.
- The triceps is released at its lateral and medial sides from the intermuscular septum and subperiosteally from the humerus and posterior capsule, allowing a retractor to pass under the muscle.
- Removing the posterior capsule, the joint is exposed, moving the triceps from side to side.
- MCL and LCL have to be released from epicondyle and epitrochlea to dislocate the joint and perform DHH, and they have to be strongly secured by transosseous sutures at the end of the procedure.
- If the columns are fractured, collateral ligaments remain attached to the bone. The dislocation will be performed through these fractures, which will be fixed around DHH to recover the elbow stability.

Advantages

- Completely safe with regard to olecranon and triceps insertion.
- The length of the triceps together with intact olecranon helps to choose the right position of DHH.
- Allows ORIF of small column fractures.
- Might be converted in olecranon osteotomy, if needed.
- Closure is quick.

Disadvantages

- If the columns are not fractured, this approach interrupts continuity between triceps and liga-

ments constructs as well as ligament insertion at the epicondyle/epitrochlea.
- Without ligament release the view is limited.
- Moving the triceps continuously from one side to the other is uncomfortable.
- If joint dislocation is performed medially, a wide ulnar nerve release is needed.

… in our opinion

- Supine position: a third assistant is needed but makes DHH easier.
- Really useful when the trochlea has to be removed completely.
- Good landmarks are the triceps and olecranon integrity.
- Faster to close at the end of the procedure.
- Less pain and immediately complete triceps strength after surgery.
- If they aren't fractures of the columns, this approach interrupts continuity between triceps and ligaments constructs as well as ligament insertion at epicondyle/epitrochlea (without ligament release, the dislocation could be difficult or impossible)… and the stability of the implant could be compromised.

We choose to preserve the triceps when we have decided to perform a DHH and there is a small fracture of one or both columns. Using this approach small epicondyle or epitrochlear fractures can be fixed with screws, *K* wires, or bony sutures. Extensive fractures need a wider approach to be effectively stabilized by long precontoured plates.

Passing through the fractured column, lateral and MCL remain attached to the bone. When the fractures are fixed around DHH, elbow stability will be quickly recovered intraoperatively.

5.7 Conclusions

In our experience there is no one surgical approach that is better than the others in every case. Each approach has many advantages or disadvantages, and each allows the surgeon to perform DHH.

We strongly believe that an experienced elbow surgeon has to be confident with all the described approaches, in fact DHH is a surgery restricted to dedicated elbow surgery units because of the inherent difficulties.

The reason for switching between these different techniques lies in the collateral ligament anatomy. To perform an elbow prosthesis, we need to dislocate the joint. If the linked TEA solves the problem with prosthesis design, DHH (as well as unlinked TEA) needs complete recovery of the stability.

Therefore:

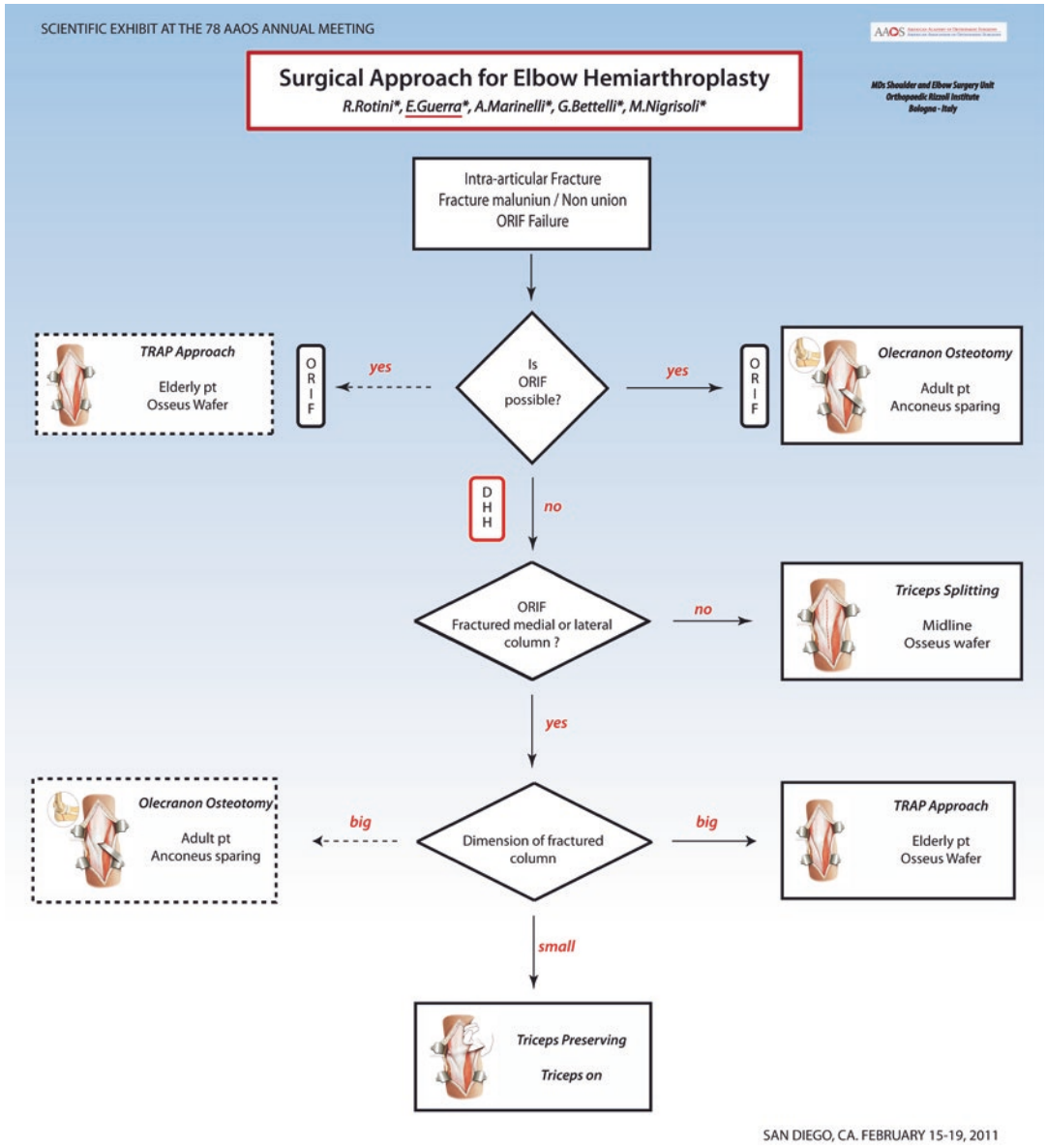
- The implant components have to be correctly chosen and orientated.
- The collateral ligaments as well as the triceps tendon have to be preserved or strongly reconstructed.

On the basis of all these considerations, we propose an algorithm to solve this difficult decision-making involved in choosing a surgical approach, which was accepted as a scientific exhibit at the 78 AAOS annual meeting (Table 5.2).

We suggest choosing:

- Olecranon osteotomy.
- When we have an articular fracture probably amenable to fixation, the patient is young, and the fracture completely involves the anterior trochlea, with ORIF always being the gold standard treatment.
- Triceps-reflecting anconeus pedicle (TRAP).
- When we have a probably fixable articular fracture, the patient is old, and the osteotomy is more hazardous.
- Midline triceps splitting.
- When we have decided to perform a DHH, there are no column fractures, so we have to release and reattach the collateral ligament.
- Triceps preserving technique (triceps-on).
- When we have decided to perform a DHH, and there is a small fracture of one or both columns.

Table 5.2 The algorithm we use for the decision-making in choosing the surgical approach for DHH, which was accepted as a scientific exhibit at the 78 AAOS annual meeting



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Part II

Total Elbow Arthroplasty

6 Indications and Surgical Technique of Primary Elbow Linked Arthroplasty

M. Scacchi and G. Giannicola

6.1 Introduction

Since the introduction of total elbow arthroplasty (TEA), the continual evolution of biomaterials and increasing knowledge of the anatomy of the elbow has raised awareness among orthopedic surgeons of the potential of TEA and has extended the indications for this kind of surgery. Although the use of TEA has almost doubled during the last two decades in the United States, it is still a relatively uncommon orthopedic procedure [1, 2]. It is performed more often in women than in men and is also now used in relatively young patients [2–4]. The number of TEAs performed annually is 1.4 per 100,000 persons, which is considerably less than the 70 to 99 per 100,000 persons for total hip replacement [2, 5, 6]. The aim of this chapter is to analyze the leading indications for TEA and to describe the main steps of the surgical technique for this kind of surgery.

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6.2 Indications for Linked Total Elbow Arthroplasty

Historically the main indications for linked total elbow arthroplasty have been chronic inflammatory arthropathies in an advanced stage (Stage III–V, Mayo Clinic classification), particularly rheumatoid arthritis within a setting of severe joint destruction after failed medical therapy [7] (Fig. 6.1). Since the introduction of disease-modifying antirheumatic in the 1980s, the incidence of TEA performed in rheumatoid patients is reported to have declined from 48% to 19% [3, 8].

The indications for TEA are widely recognized as being prevalently the presence of disabling pain, stiffness, and/or instability preventing normal activities of daily living [9, 10]. Patients with inflammatory diseases are the best candidates for TEA because it relieves pain and improves elbow function markedly and rapidly and because the systemic nature of such diseases is associated with a low level of physical activity and functional demand, which in turn leads to a lower rate of wear and aseptic mobilization [11, 12].

In recent decades, the indications for TEA have been extended to non-reconstructible intra-articular distal humerus fractures (Fig. 6.2) [13]. It has been estimated that distal humeral fractures account for 2% of all fractures, an incidence that is projected to triple by 2030 [14–16]. The gold standard for the operative treatment of intra-articular distal humeral fractures includes open reduction-internal fixation (ORIF) with bicolumnar plate

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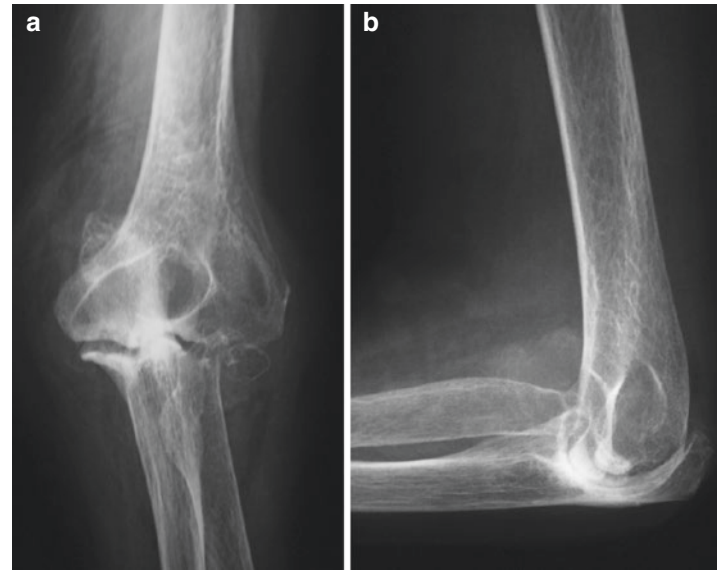

Fig. 6.1 Elbow rheumatoid arthritis. (**a**) Anteroposterior view, (**b**) lateral view

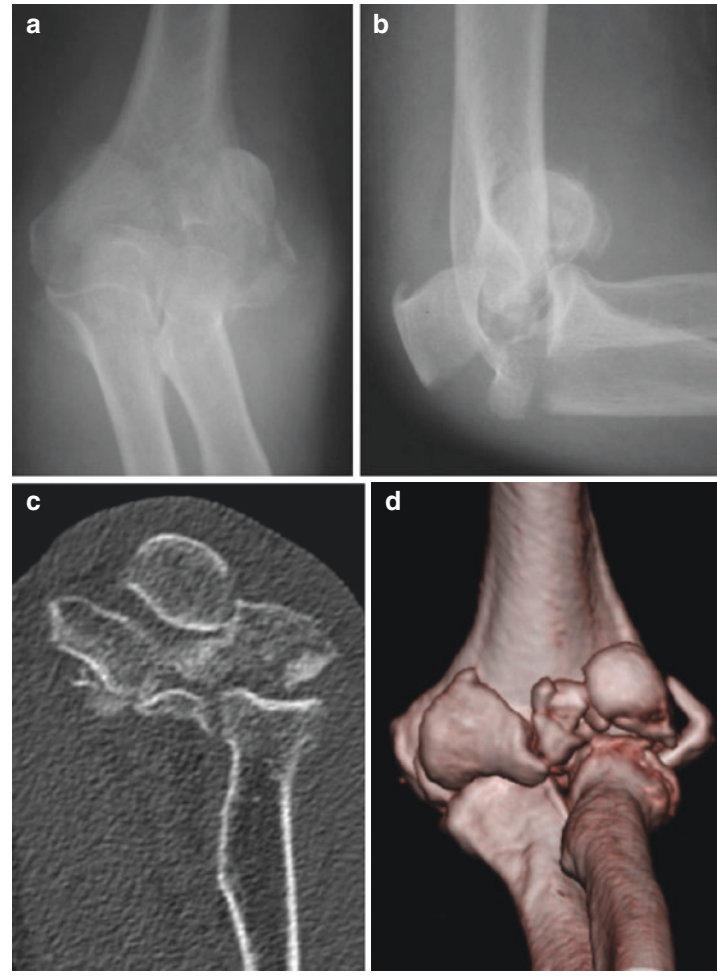

Fig. 6.2 Intra-articular plurifragmentary distal humerus fracture with associated olecranon fracture in an 80-year-old woman. (**a**) Anteroposterior view, (**b**) lateral view, (**c**) CT scan axial view, (**d**) 3D reconstruction of the fractured elbow

osteosynthesis [17]. However, a relatively high rate of poor results and fixation failures has been reported in elderly patients because of osteoporotic bone, metaphyseal comminution, and low tolerance for immobilization. This has led to TEA being used in this population prevalently as primary acute treatment for displaced, intra-articular distal humeral fractures [17]. Rajaee et al. reported a significant increase in the use of primary TEA for humeral fractures from 2002 to 2012. They reported that TEA was performed in 13% of surgically treated distal humeral fractures in 2012 compared with only 5.1% in 2002 [18].

Post-traumatic sequelae of the elbow leading to severe joint degeneration also represent an indication for TEA in cases of severe pain, stiffness, or instability (Fig. 6.3). In particular, intra-articular distal humerus fractures and proximal radius and ulna fracture-dislocations (i.e., complex elbow instability) may evolve into disabling conditions such as malunions, nonunions, and chronic instability, which in turn lead to progressive joint destruction and a disabling loss of elbow function. When reconstructible procedures are not feasible in such cases, joint replacement represents a viable option that provides pain

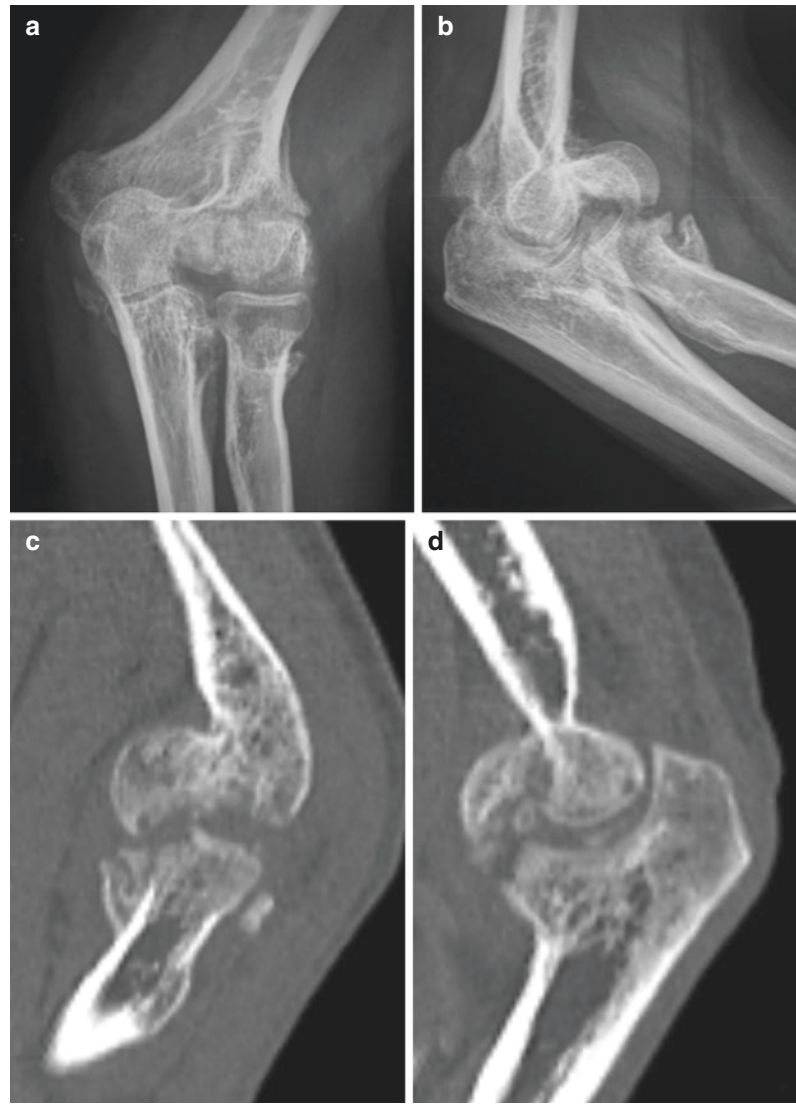

Fig. 6.3 Severe post-traumatic osteoarthritis following a shear fracture of the distal humerus. (**a**) Anteroposterior view, (**b**) lateral view, (**c**, **d**) CT scan sagittal view

relief, a functional improvement, and patient satisfaction [19–21]. According to the Mitsunaga classification of distal humerus nonunions, transcondylar and intercondylar nonunions represent the most frequent indications for TEA, especially in the elderly [22–27]. The types of implants currently available include linked devices, which are generally used in post-traumatic sequelae because these conditions are frequently associated with joint deformity, joint instability, and severe stiffness, for which unlinked prostheses are contraindicated. A careful selection of patients and detailed information regarding the restrictions related to TEA is essential in such cases because the long-term clinical results are closely associated with the patient's compliance and level of activity [11, 12, 28]. When Celli and Morrey studied a series of patients aged 40 years or less who had undergone TEA for inflammatory arthritis or post-traumatic arthritis, they reported better results in the inflammatory arthritis group than in the post-traumatic arthritis, with a higher rate of complications and loosening being observed in the latter group. These results may be explained by the fact that patients affected by juvenile arthritis or rheumatoid arthritis have lower daily functional demands and thus subject the prosthesis to a lower degree of overload [11].

Primary osteoarthritis may also represent a rare indication for TEA (Fig. 6.4). It is a relatively common condition often associated with overuse of the joint over an extended period of time. It is considerably more common in men, with most patients being involved in manual labor or repetitive weight lifting [29, 30]. Symptoms in the early stages usually consist of loss of motion and impingement pain at the extremes of the arc of motion. There is often little

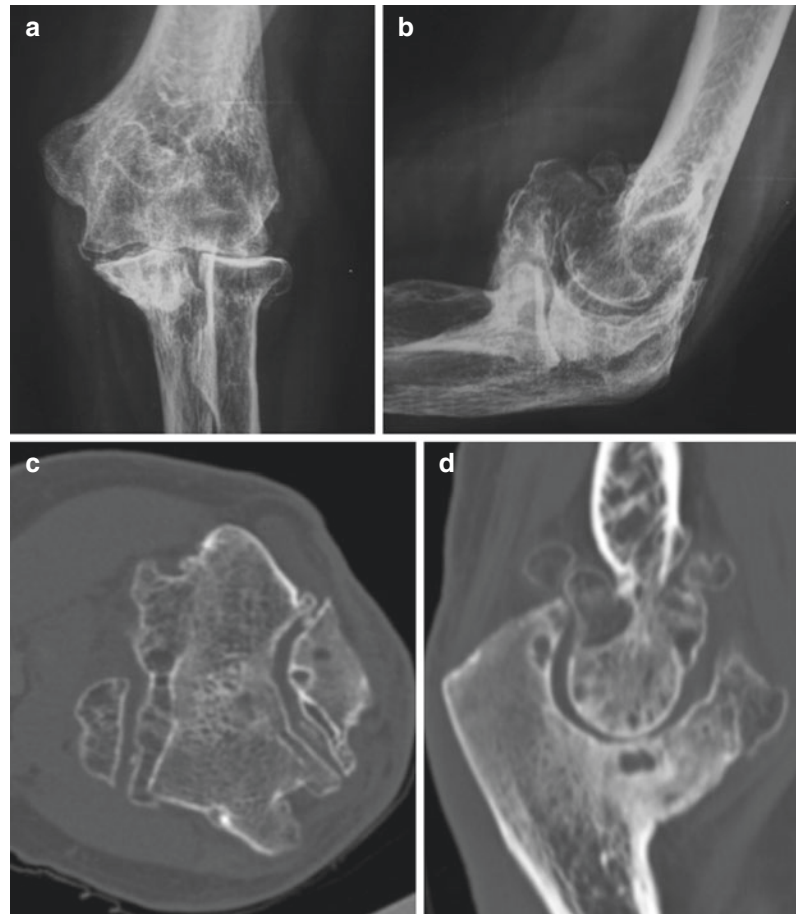

Fig. 6.4 Primary osteoarthritis of the elbow in an 82-year-old woman. (**a**) Anteroposterior view, (**b**) lateral view, (**c**, **d**) CT scan axial and sagittal view

or no pain in the mid arc of flexion, which is in contrast to what happens in inflammatory arthritis. Primary osteoarthritis of the elbow can be treated successfully in this phase by means of osteophyte removal and capsulectomy [30–32]. Arthritic changes in the subsequent stage, which involve the lateral compartment of the elbow, induce lateral pain during motion; the later stages are associated with a progressive involvement of the ulno-humeral joint. In this last phase of grade III osteoarthritis, when the patient develops pain through the mid arc of motion that may not respond well to conservative surgery, TEA may represent a valid option. However, since the baseline activity level is often higher in patients with primary osteoarthritis than in those with inflammatory arthritis, which is a systemic disease, the former must be made aware of and accept the limitations of TEA in order to avoid early implant failure. This precaution is particularly relevant to younger patients, in whom good long-term results are of paramount importance. Since primary elbow osteoarthritis affects less than 5% of the general population and TEA is performed in a very small proportion of the cases with this diagnosis [3, 13, 33], very little information is available on the outcomes of TEA in primary osteoarthritis. Such information would be extremely useful when counseling patients being considered for elbow arthroplasty.

Linked total elbow replacement is indicated for hemophilic arthropathy (Fig. 6.5) [34, 35]. In

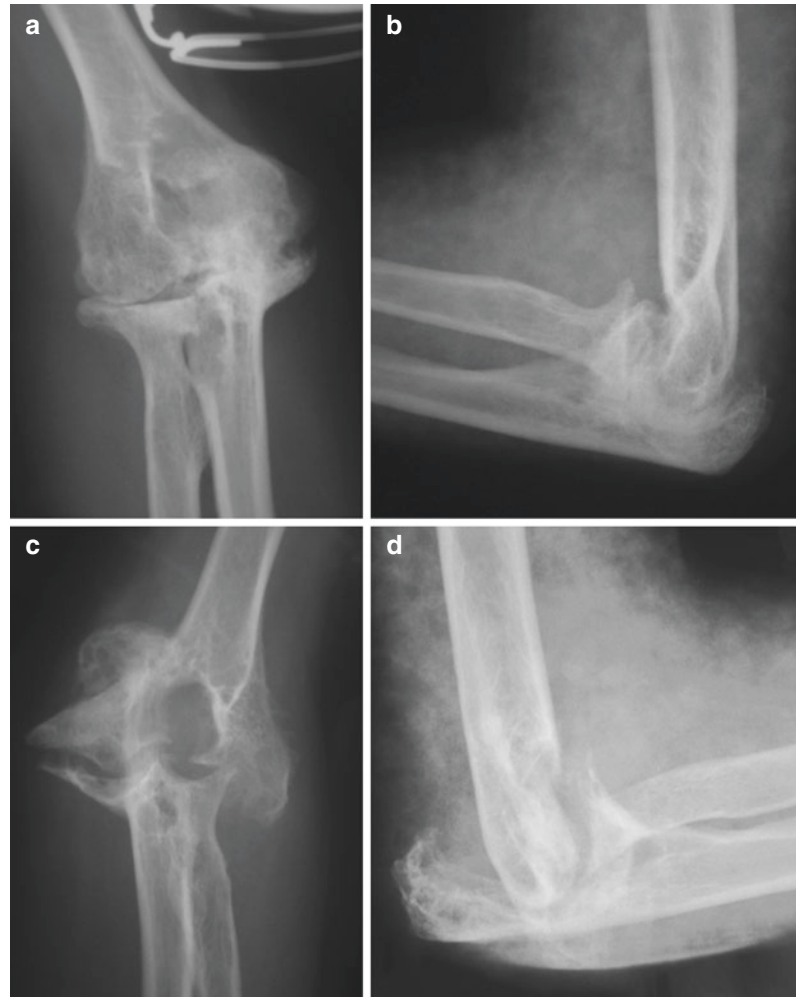

Fig. 6.5 Severe joint destruction of both elbows in a patient affected by hemophilic arthropathy. (**a**) Anteroposterior view and (**b**) lateral view of the left elbow. (**c**) Anteroposterior view and (**d**) lateral view of the right elbow

patients affected by this disease, spontaneous bleeding in the joints is responsible for synovitis and cartilage damage, which cause progressive joint damage and lead to advanced joint destruction associated with elbow stiffness and pain [36, 37].

Although primary bone and soft tissue tumors and metastases involving the elbow are rare (<1%), TEA may be a viable option in selected cases [38]. Limb-salvage surgery has become the most common approach in carefully selected patients following an improvement in functional results and the fact that it is more easily accepted on an emotional level than amputation, which was once the most frequent curative treatment. Allograft-prosthesis composite reconstruction is preferred in young patients with primary benign tumors, primary malignant tumors that can be treated by means of a short resection, and metastatic lesions that do not require muscle sacrifice. When previous treatments involving the proximal half of the humerus have failed or primary malignant tumors require very large humeral resections, partial or total humerus replacement is performed using modular devices (megaprosthesis) [38].

Spontaneous fusion of the elbow following infection, trauma, or rheumatic disease also represents an indication for TEA [39], which provides reliable and predictable results in such cases. Linked implants represent the only viable choice in these kinds of patients because extensive soft tissue release is required to mobilize the ankylosed joint. However, the surgical technique used is highly demanding and represents a real challenge even for an expert elbow surgeon. The distortion of the anatomy and loss of architecture markedly affect the ability to correctly position the implant; moreover, the reported complication rate, which mainly consists of postoperative wound breakdown, stiffness, and infection, is relatively high (26%) [39]. The technical difficulties involved and the high complication rate highlight the need to carefully weigh up the risks and benefits of this operation and accurately select patients that may undergo TEA.

Regardless of the diagnosis that leads to surgery, there are some general considerations that need to be borne in mind when selecting patients for TEA. The best candidates for TEA tend to be elderly patients over 65–70 years of age, patients who are sedentary or have low demands, and patients with a shorter life expectancy, owing to the lower activity demands of such patients. However, indications have recently been extended to include low-demand young patients with elbow arthritis or patients who are expected to comply with limited use following the elbow arthroplasty [11, 12, 21]. Nevertheless, surgeons tend not to perform arthroplasty in young patients with elbow arthritis because of the high risk of implant loosening and need for revision surgery [11, 12, 19, 28]. Alternatives strategies, such as arthrodesis, interposition arthroplasty, or no further treatment, are often proposed first; however, elbow fusion is not an appealing option nowadays as it results in a considerable loss of function that is not always accepted by young or active patients, who often prefer to face the risks associated with possible revision surgery rather than resign themselves to living without a functional elbow. Similar considerations apply to interposition arthroplasty, which represents the other therapeutic option in severe arthritis in young patients who refuse to accept the limitations that may be imposed by TEA [40–43]. Although a satisfactory outcome, as assessed by means of the MEPS, is achieved in only 30% of patients who undergo interposition arthroplasty, pain and stiffness relief is achieved in up to 75% of these patients [40]. These results tend to deteriorate over time, though Larson et al. believe that even if this procedure does not fully restore pain and function, it is appropriate for some patients insofar as it generally provides a higher level of function than either arthrodesis or resection arthroplasty, and patient satisfaction is high in spite of the low functional ratings [42]. However, the unpredictability of the outcomes reported in other studies combined with a high failure rate is such that this option rarely appeals to patients. The numerous complications that have been reported include bone resorption, heterotopic ossifications, triceps ruptures, seroma formation in the fascial graft donor site and, most frequently, high rates of infection and instability, especially in patients with pre-existing elbow instability [40–43].

6.2.1 Contraindications for Linked Total Elbow Arthroplasty

The relative contraindications related to a linked TEA implant are basically distant foci of infection (e.g., dental procedures, genitourinary, pulmonary, chronic skin lesions or ulcerations, or other infected sites) which should be treated before TEA is performed. The importance of these sites of infection is highlighted by the fact that they represent the main cause of late infection of replaced joints. Severe elbow joint destruction after a postoperative joint infection, such as one associated with primary TEA or ORIF, was once considered a strong contraindication for implantation or reimplantation of an elbow prosthesis. Following improvements in antibiotic therapy and infection management, TEA is now considered in cases in which treatment has adequately eradicated such infections. The authors of this chapter personally believe that a minimum period of 6 months should be observed following the interruption of antibiotic therapy and that the patient should be warned of the risk of reinfection after treatment [44] (Fig. 6.6).

TEA is also relatively contraindicated in patients who are non-compliant (patients affected by psychiatric diseases, alcoholic patients, patients with cognitive impairment) or poorly motivated and patients who require an elbow that can cope with fairly high functional demands. Moreover, TEA may be contraindicated in patients with deambulatory issues or who use a wheelchair or crutches. Obesity, which is not per se considered as a contraindication, should also be taken into account by the surgeon. Baghdadi et al. recently showed that primary total elbow arthroplasty carries a substantially higher risk of failure and revision rate in obese than in non-obese patients. Patients with a high BMI being considered for elbow replacement surgery should thus be counseled accordingly [45].

The absolute contraindication for TEA is a joint with an active infection. Other contraindications include an elbow with inadequate soft tissue coverage, as may be observed in patients with AR or other immunologic or hematologic diseases that require the long-term use of corticosteroids, an elbow that lacks adequate muscle or motor power to flex (biceps function), and skeletally

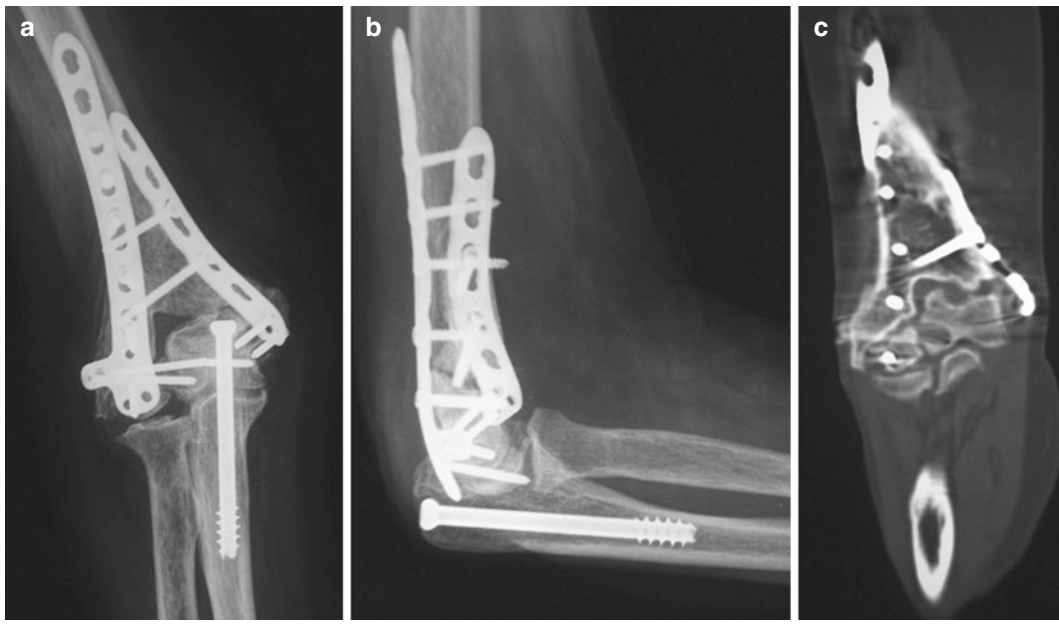

Fig. 6.6 Distal humerus nonunion following a distal humerus fracture treated with perpendicular plates in a 79-year-old woman. (**a**) Anteroposterior view, (**b**) lateral view, (**c**) CT scan coronal view

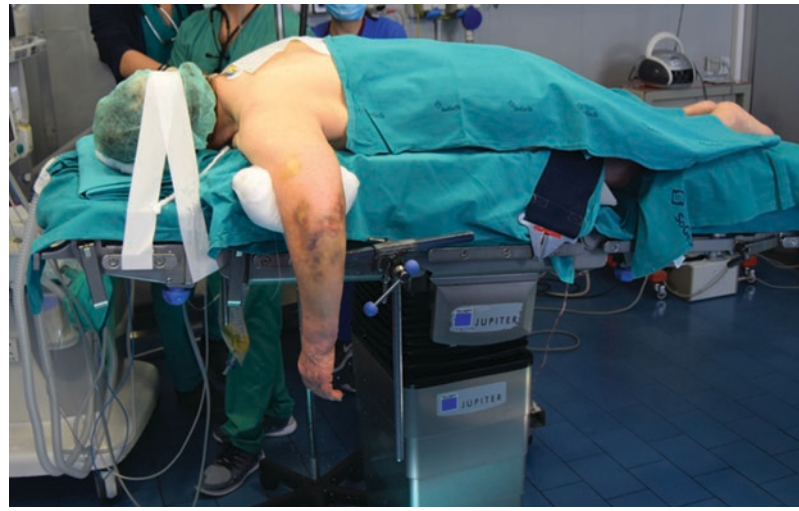

Fig. 6.7 The patient in prone position on the surgical table

immature or very young patients and a neuropathic (Charcot) elbow joint. The authors of this chapter believe that an additional absolute contraindication is a nonfunctional hand and wrist, which often occurs in post-traumatic sequelae of upper-limb traumas, advanced inflammatory arthritis, and peripheral neurological disorders.

6.3 Surgical Technique

Numerous implants are available for total elbow replacement. According to the current literature, the most commonly used implants are the Coonrad-Morrey and Nexel device (Zimmer, Warsaw, IN), the Discovery Elbow System (DonJoy Orthopedics, San Diego, CA), and Latitude (Tornier, Edina, MN) implants. Although each prosthesis can only be positioned correctly by following specific technical instructions provided with the instrumentation, there are some common key steps that need to be followed regardless of the type of implant used. The aim of this chapter is to illustrate the principles shared by all of these prostheses without going into the specific technical steps that are peculiar to each one.

The main steps consist of (1) ulnar nerve management, (2) the choice of a surgical approach that allows adequate joint exposure, debridement, and soft tissue balancing to be achieved, (3) preparation of the distal humerus and proximal ulna and radius, (5) positioning and evaluation of the trial implant, (6) implantation of the final components, and (7) reconstruction and closure of the soft tissues.

Patient positioning represents a crucial aspect of surgery. Several positions may be used, each of which has its advantages and drawbacks. The supine position with the arm across the chest is the most widely used position [10]. Whenever possible, the authors of this chapter prefer to position the patient prone or in a lateral decubitus position, with the arm involved placed over a padded support under the proximal third of the humerus (Fig. 6.7). The authors believe that this position affords greater stability of the arm and forearm during surgery, thereby reducing the risk of intraoperative fractures and implant malpositioning [20]. A sterile tourniquet inflated to 250 mm Hg can be used during the operative procedure, though the authors prefer to use a silicone ring, whose reduced size allows the surgical incision to be extended proximally if required (Fig. 6.8).

A posterior longitudinal incision is usually used. This can be curved slightly either laterally or medially around the tip of the olecranon process. A lateral and medial subcutaneous flap can be developed in order to obtain a working posterior window that includes both the medial and lateral compartments of the elbow (Fig. 6.9). Before exposing the joint, it is mandatory to visualize and mobilize the ulnar nerve and to trans-

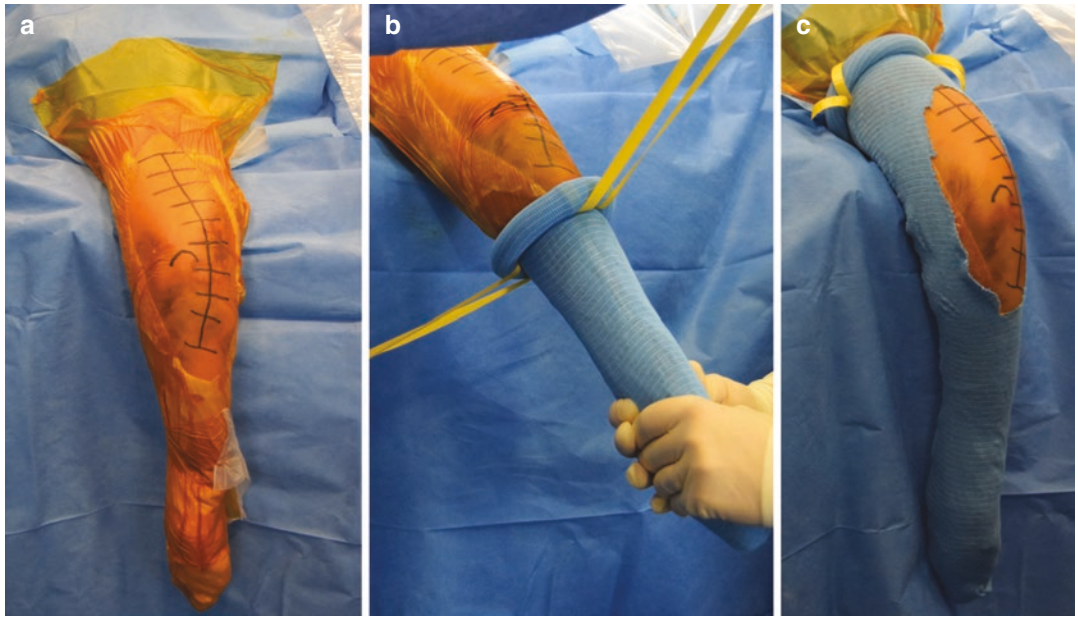

Fig. 6.8 (**a**) Posterior view of the elbow, (**b**) silicone ring positioning, (**c**) silicone ring positioned

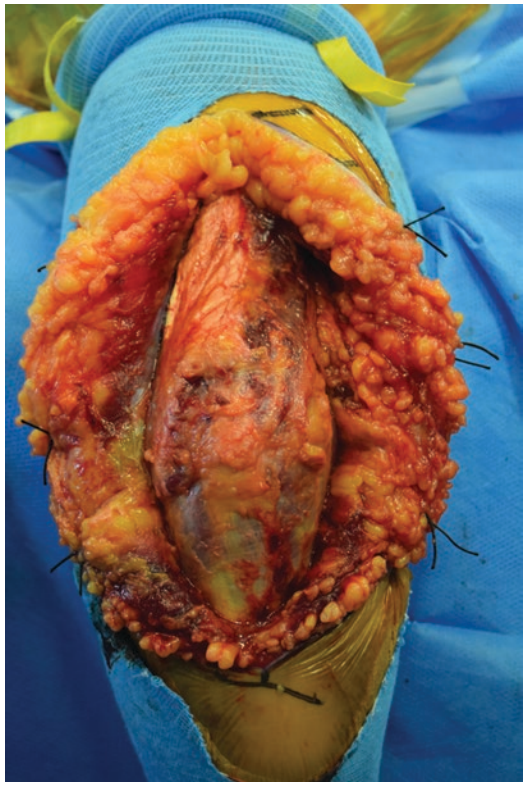

Fig. 6.9 Medial and lateral subcutaneous flaps developed

pose it anteriorly and subcutaneously both during and at the end of surgery (Fig. 6.10). Several deep approaches have been proposed for TEA. These approaches can be divided in three main categories, triceps reflecting, triceps preserving, and triceps splitting, with the choice depending on the management of the triceps tendon, as described in Chap. 5. The authors of this chapter believe that deep approaches which preserve the triceps insertion, are advisable in the majority of cases. The detachment of the triceps tendon may, however, still be necessary in a very few cases with severe elbow stiffness. In patients with intra-articular, plurifragmentary distal humerus fractures, the surgeon should decide preoperatively which of these approaches to adopt on the basis of the 2D–3D CT scans and the patient's characteristics, to avoid having to convert an ORIF into TEA intraoperatively, i.e., after the olecranon osteotomy has been performed. In the authors' experience, very few cases are likely to give rise to doubts; however, if doubts should arise, it is advisable to first develop a "triceps-on" approach so as to expose the joint and then decide how to proceed. When we first started performing total elbow replacements in our institution, we

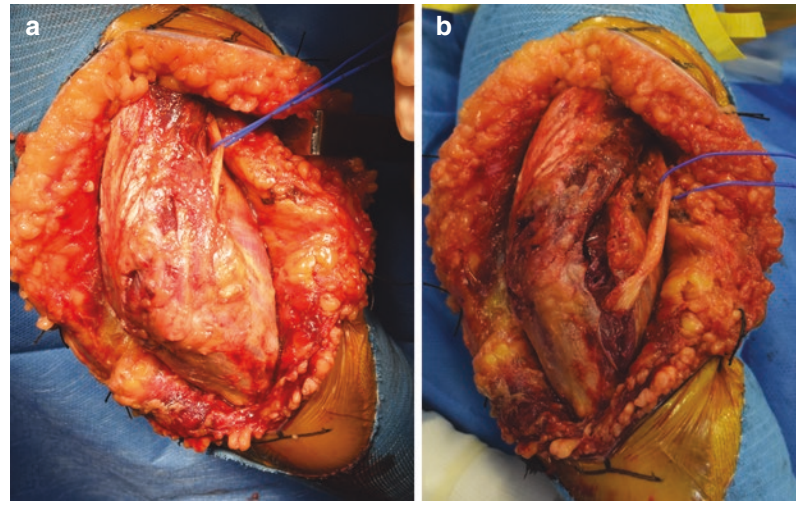

Fig. 6.10 (**a**) The ulnar nerve is identified and (**b**) mobilized for anterior subcutaneous transposition

used different posterior approaches, whereas now we perform a "triceps-on" approach in the vast majority of our patients. The integrity of the triceps tendon is, in our opinion, essential to achieve early mobilization and avoid triceps complications and pain.

When the joint is reached, an anterior and posterior capsulectomy is performed, and the collateral ligaments and epicondyle muscles are released, thereby allowing the mobilization of the forearm to expose the joint adequately (Fig. 6.11). In post-traumatic and inflammatory arthritis diseases, this step is achieved only after extensive articular debridement with osteophytes, intra-articular fibrosis removal, and soft tissue balancing.

A key point in TEA is the identification of the flexion–extension axis of the elbow. This axis can be identified by drawing a virtual line from the ligamentous insertion of the LCL on the lateral epicondyle to the point of the MCL insertion, which is located just anterior and inferior to the medial epicondyle (Fig. 6.12). According to Brownhill et al., identifying the F–E axis intraoperatively is a somewhat challenging task because the ligamentous footprint is so wide as to lead to errors in the range of several millimeters [46, 47]. Brownhill et al. therefore advocated the use of a computer-navigated system to correctly identify the F–E axis; however, the authors themselves concluded by saying that computer-navigated surgery is not always feasible in clinical practice and that the efficacy of this system has yet to be demonstrated [46]. Furthermore, in some cases, such as acute fractures and post-traumatic deformities in which the epicondyles are either not available

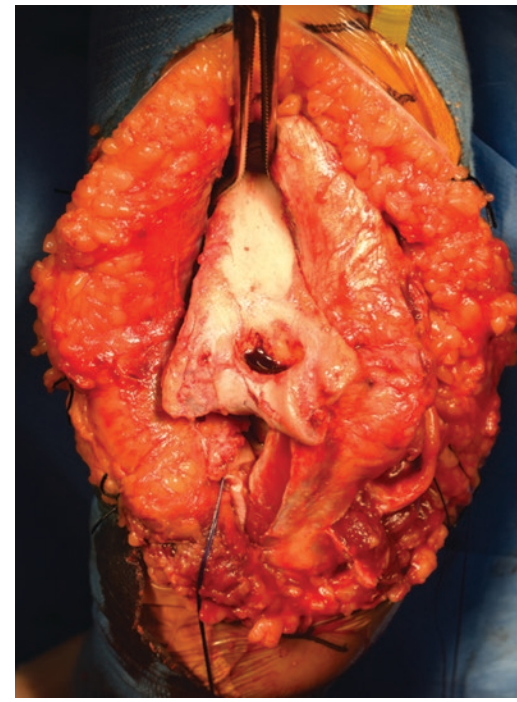

Fig. 6.11 After soft tissue release, the triceps, the ulna, and the radius are mobilized medially, and the distal humerus is finally exposed for preparation

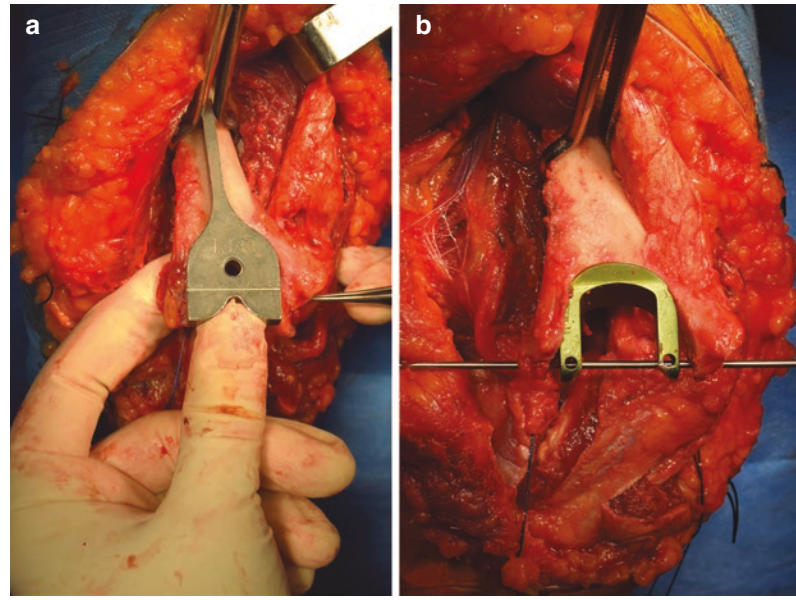

Fig. 6.12 (**a**) Visualization of the epicondyles allows the flexion–extension axis to be identified. (**b**) Trial implant positioning is verified by considering the height of the F–E axis

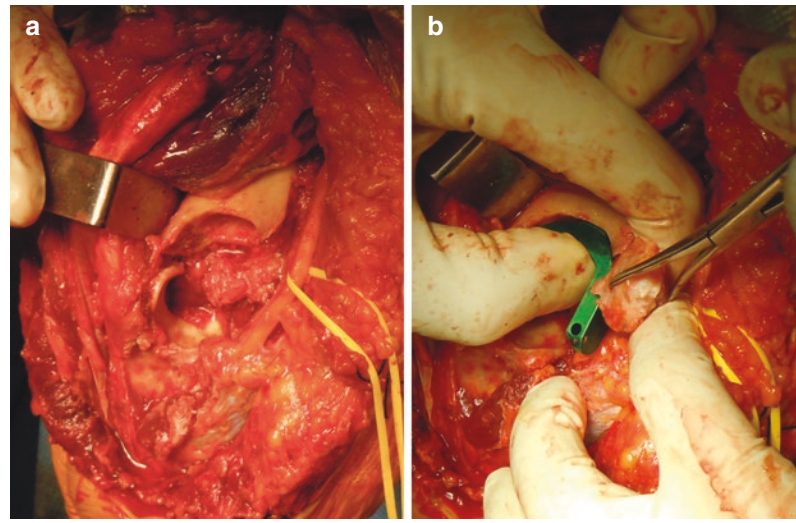

Fig. 6.13 (**a**) The distal humerus has been prepared for trial humeral component seating. The medial and lateral columns are fractured and are thus removed. (**b**) The fragments are manually recomposed in order to identify the F–E axis and properly position the implant

or not usable, the correct identification of the F–E axis is even more challenging. In distal humeral fractures, the surgeon may instead be able to use the fracture fragments to manually recompose the lateral and medial column and thereby more accurately identify the height and the orientation of the F–E axis (Fig. 6.13). When anatomic landmarks are not available, it is important to bear in mind that the placement of the components in a lengthened or proud position relative to the normal elbow axis of rotation leads to flexion contracture and limits elbow extension [48]. For this reason, it is better position the implant in a slightly shortened position. It should, however, also be borne in mind that placement of the components in an excessively shortened position (i.e., by more than 2–3 cm) may lead to weakening of the elbow flexors and extensors, hyperextension of the elbow joint, and early loosening of the components [47]. In difficult cases, once the fragment and the distal humerus have been resected, the ulna is brought back over the resected distal humerus as a first

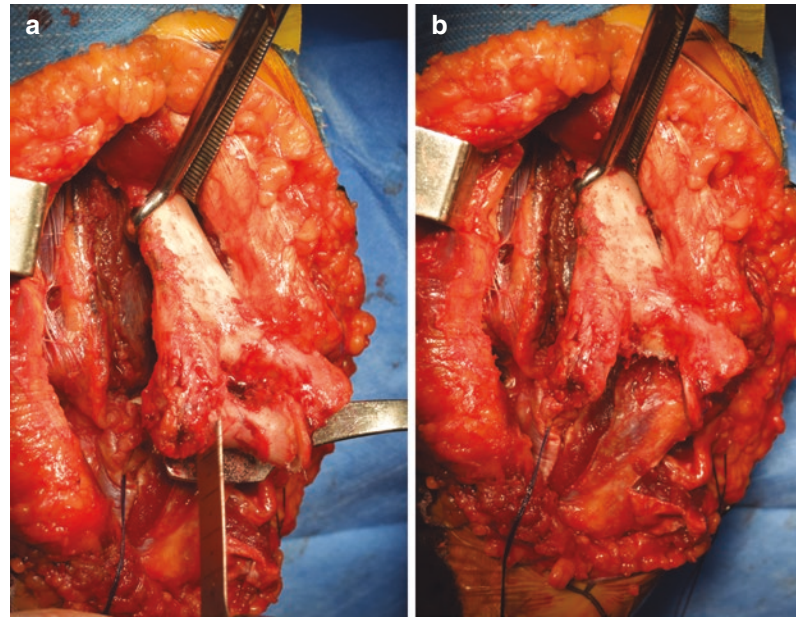

Fig. 6.14 Humeral cuts are performed either freehand or using the guide provided by the manufacturer. (**a**) An oscillating saw is used to cut between the lateral and medial ridge of the trochlea. (**b**) The cut is performed and the central portion of the distal humerus is removed

estimate of correct tension and balancing [49]. When the distal humerus is well preserved and the rotation axis is identifiable, the surgeon can accurately perform the humeral cuts (Fig. 6.14) and correctly place the prosthesis by means of the devices that are provided with each of the implants currently available on the market.

The preparation of the distal humerus starts with the identification of the medullary canal; this can be easily identified by using a high-speed burr to perforate the posterior cortex that limits the superior part of the olecranon fossa. The preparation continues with the widening of the canal by means of dedicated broaches, bearing in mind that the narrowest part of the endomedullary canal is located in the distal portion, just below the olecranon fossa (Fig. 6.15). During the broaching, attention must be paid in osteoporotic patients and in some patients with post-traumatic or congenital deformities (as well as in anatomical variations) to avoid intraoperative fractures or cortical perforation, especially when straight and long broaches, which do not take into account the anatomical humeral bow, are used [50]. A similar degree of attention is required to avoid implant malpositioning in varus-valgus angulation on the frontal plane or flexion–extension angulation on the sagittal plane. Adequate preoperative planning with CT scans is mandatory in cases with distal humerus deformities.

Once the humeral canal has been prepared, the trial humeral component can be positioned to verify the correct orientation and size of the implant. Some implants are provided with their own intrarotation of the articular hinge in relation to the stem, which is designed to reproduce the physiologic intrarotation of the flexion–extension axis. The rotation in other implants instead needs to be reproduced by the surgeon by intrarotating the humeral component. The rotation of the implant can be accomplished by taking into account the ligamentous insertions, when available, which correspond to the center of a circle that resembles the lateral and medial border of the articular surface. In the presence of a bone defect involving one or both distal columns, the plane of the posterior cortex of the humerus just proximal to the olecranon fossa may prove particularly useful for this purpose. It is important to bear in mind that the posterior cortex is externally rotated by 14.0° ± 4.2° in relation to the F–E axis, though this rotation is slightly smaller in males than in females (males, 12.6° ± 3.6°; females, 16.4° ± 5.2°) [51] (Fig. 6.16). The surgeon must consequently be aware of the need for an internal rotation correction factor and consider the effect

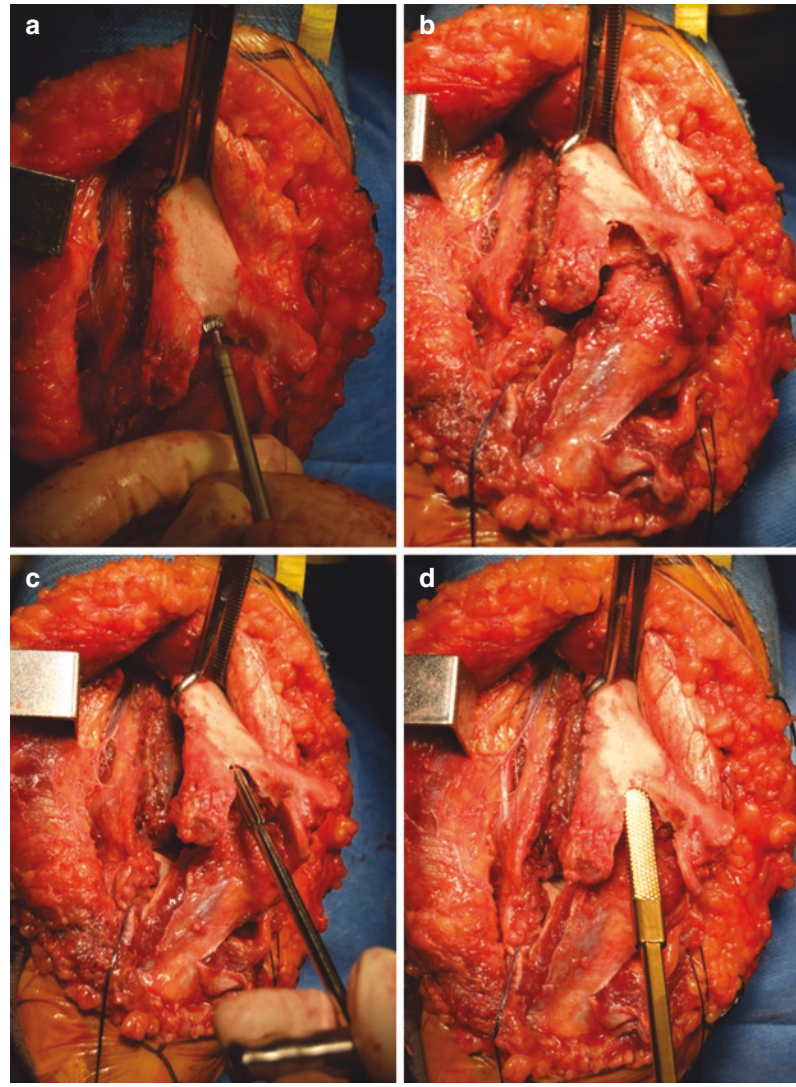

Fig. 6.15 Identification of the medullary canal starts with (**a**) perforation of the posterior cortex over the olecranon fossa by means of a high-speed burr after which (**b**) the access to the medullary canal is enlarged. (**c**) The canal is identified and (**d**) progressively widened with dedicated broaches

of the patient's sex on this correction when using the posterior humeral cortex as a landmark to obtain a correct humeral component orientation. In practice, the implant is positioned with its posterior aspect in line with the posterior cortex of the humerus and then gently rotated internally by about 15°. It is advisable that this calculation be performed during the positioning of the trial component, after which the surgeon must bear this step in mind when definitively positioning the implant after cementation. The transepicondylar axis may also be used as a landmark for implant positioning. This is usually determined by drawing a line between the most prominent points on the epicondyles; this line then usually needs to be externally rotated by a mean of 2.8° ± 3.5° in relation to the F–E axis (males, 2.7° ± 3.4°; females, 2.6° ± 3.7°) [51]. However, the identification of the transepicondylar axis is highly challenging, particularly in patients with post-traumatic sequelae or acute trauma. In selected cases, such as proximal nonunions of the distal humerus or when the anatomy is severely distorted, some authors recommend that the plane of the intermuscular septa be used as a landmark for the orientation of the humeral component [52].

Once the humerus has been positioned, the ulna is prepared. The olecranon tip and osteo-

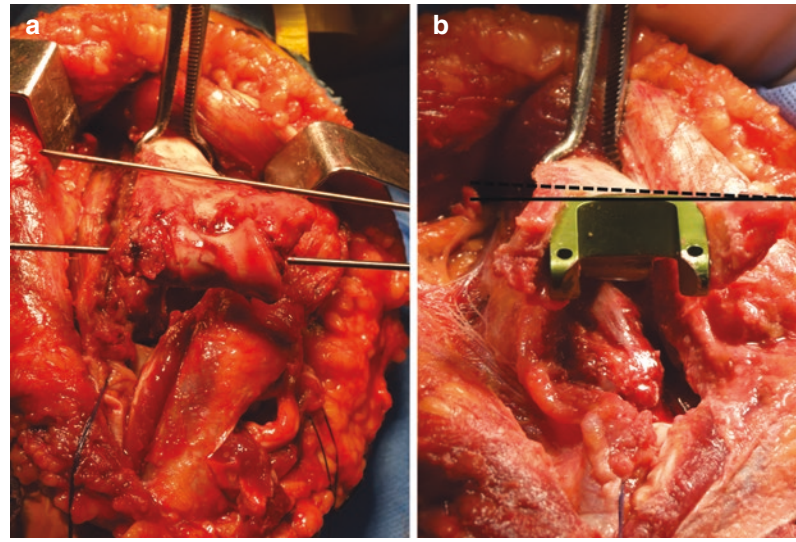

Fig. 6.16 (**a**) The F–E axis internally rotated by about 10°. (**b**) The trial humeral component is positioned with a slight internal rotation (solid line, the plane of the trial component; dotted line, the plane of the posterior cortex of the distal humerus)

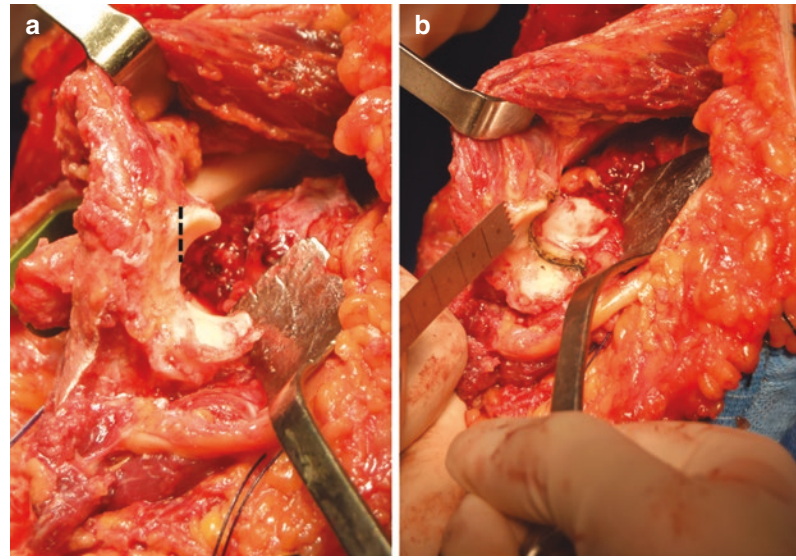

Fig. 6.17 (**a**) Sagittal view of the proximal ulna (the dotted line shows the level of the olecranon osteotomy). (**b**) The olecranon tip is excised using an oscillating saw

phytes are removed to allow the correct alignment of the broach; the tip can be excised using an oscillating saw along a line tangent to the most posterior portion (i.e., the deepest) of the olecranon articular surface (Fig. 6.17). The ulnar canal is usually found using a high-speed burr or a drill guide and then enlarged with a combination of the burr, ulnar rasps, or broaches so as to accommodate the stem of the ulnar component. Alternatively, a reamer can be used to prepare a channel through the olecranon to gain direct access to the ulnar canal, as is recommended for the Nexel total elbow prosthesis (Fig. 6.18). A rasp can then be positioned into the ulnar canal and pushed back and forth while keeping the rasp in a posterior position. Such instruments usually have a landmark that indicates the axis of rotation of the implant. The goal is to place the ulnar component in a position that reproduces the natural center of rotation of the greater sigmoid notch. To accomplish this goal, the surgeon must carefully consider three aspects related to the correct posi-

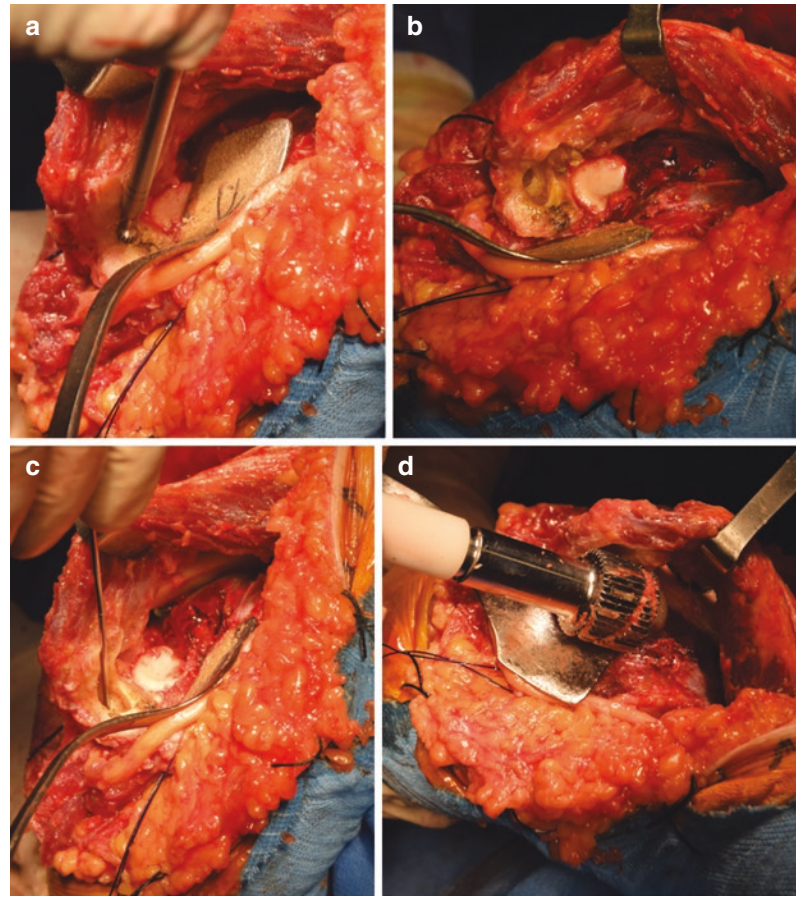

Fig. 6.18 (**a**, **b**) The ulnar medullary canal is found with an high-speed burr and widened. (**c**) The ulnar canal is enlarged with a reamer. (**d**) The sigmoid notch is prepared with a dedicated cylindrical burr

tion of the center of rotation of the ulnar component: (1) the height in the coronal plane, (2) the rotation in the axial plane, and (3) the anterior-posterior offset in the sagittal plane.

1. The center of the rasp is usually concentric, with the projected center of the sigmoid notch in the sagittal plane; alternatively, the axis of rotation should lie approximately equidistant between the tip of the olecranon and the tip of the coronoid [53] (Fig. 6.19).
2. Some useful landmarks for the correct positioning in the axial plane are the ulnar crest of the sigmoid notch, which may orientate the component along the longitudinal plane, and the so-called flat zone, which is the flat posterior portion of the olecranon; the articular portion of the ulnar implant must run perpendicular to these two landmarks (Fig. 6.20).
3. To obtain an adequate anterior-posterior offset, the surgeon can refer to the virtual center of a circle inscribed into the greater sigmoid notch (Fig. 6.19a). The most frequent mistake is to position the implant with an excessive anterior offset. Should this happen, a high-speed burr may be used to carefully enlarge the trough in the bed of the sigmoid notch and proximal ulna to position the implant more posteriorly.

The development of modular implants and navigation systems may help to optimize implant position in the future. The coronoid tip osteophytosis needs to be removed before the ulnar component is implanted to avoid the so-called

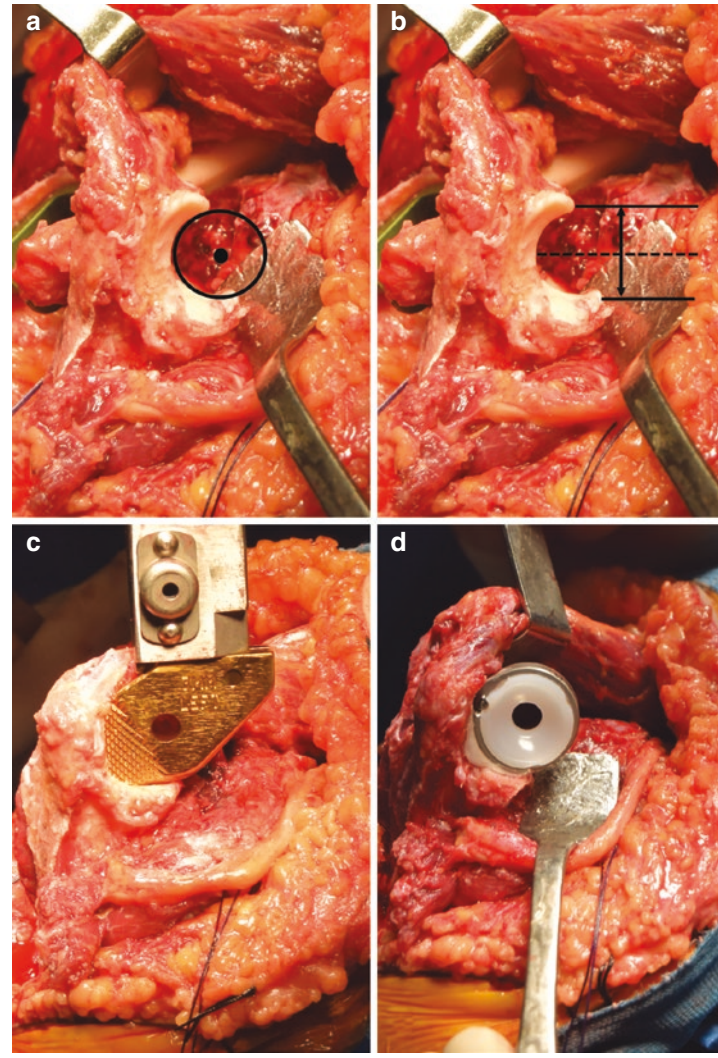

Fig. 6.19 (**a**) The projected center of a circle inscribed into the sigmoid notch allows the correct positioning of the axis of rotation of the ulnar component for both the anterior–posterior and proximal-distal offset. (**b**) The proximal-distal offset can also lie equidistant between the tip of the olecranon and coronoid. (**c**) The red dot (center of rotation) over the ulnar broach confirms the correct position into the ulna. (**d**) The definitive ulnar component correctly positioned

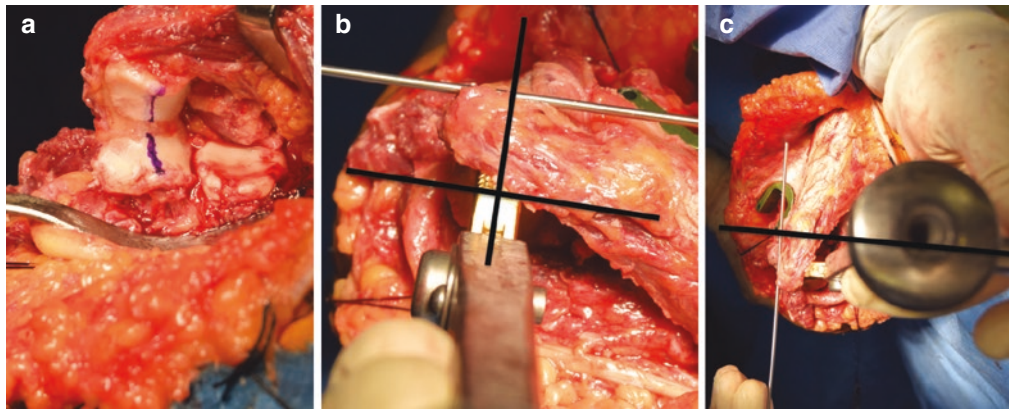

Fig. 6.20 (**a**) The ulnar crest (drawn line) is the anatomical landmark that allows the axial plane to be oriented. (**b**) The flat zone of the olecranon (*K*-wire) is the anatomical landmark used to correctly incline the axial plane of the implant. The horizontal portion of the broach or the ulnar trial should lie parallel to the flat zone of the olecranon. (**c**) The handle of the broach is perpendicular to the flat zone

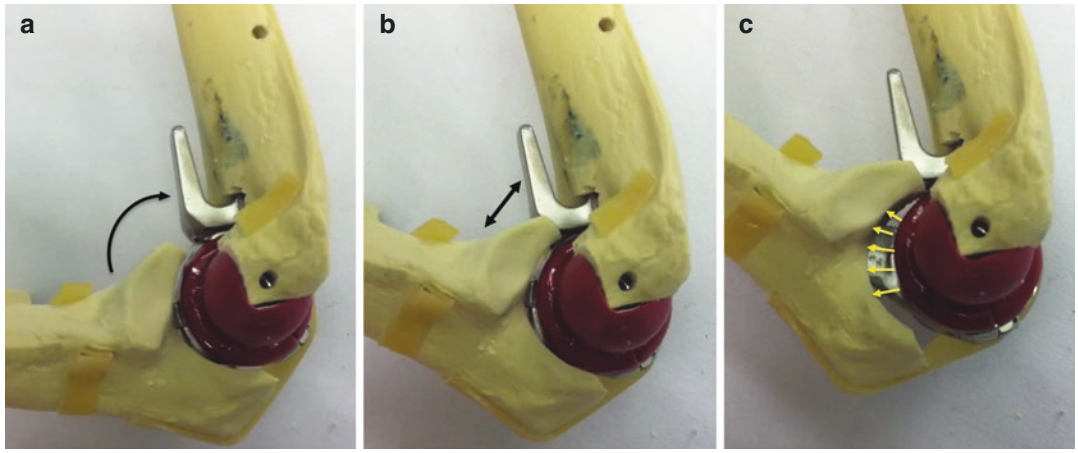

Fig. 6.21 From (**a**) to (**b**)—during the progressive flexion of the elbow, the coronoid impacts the anterior flange of the humeral component. (**c**) Applying additional force to flexion, the ulnar component is progressively pulled out from its seating

pistoning effect against the humerus during the maximum flexion (Fig. 6.21) [54, 55].

With linked implants, the radial head can be left as it is, excised, or replaced. An oscillating saw is used to resect the radial head at the level of the radial neck, after release of the annular ligament and protection of the posterior interosseous nerve. The forearm can be rotated so as to expose different portions of the radial neck during the radial neck cut. The cut is performed perpendicular to the long axis of the radial neck. For implants that require the replacement of the radial head, the cut is made either freehand or with the use of a radial head-cutting guide. In the authors' opinion, every effort should be made to spare the radial head, particularly in implants where radial head replacement is not mandatory, because the native radial head may serve as a graft for revision surgery, if required. Moreover, since it prevents the translation of the radius in relation to the ulna following the resection, it helps to maintain better pronation–supination over time. If the radial head must be resected, this operation should be performed at the end of surgery because the head allows a better evaluation of the implant positioning during surgery by allowing the relationship with the capitulum humeri to be assessed.

At this point the ulnar trial implant is positioned and assembled with the humeral trial component. The intraoperative evaluation with fluoroscopy is, in our opinion, mandatory to ensure that the implants have been seated correctly and that their dimensions are appropriate. A second evaluation of the balancing and tension of the triceps can be performed at this stage by direct visualization, and if bone loss at the level of the metaphysis and/or the epicondyles is observed, the so-called Shuck test may be performed: the forearm, flexed at 90° in relation to the arm, is pulled off the humerus as much as is allowed by the soft tissues (Fig. 6.22) [52].

Cementation is then performed in retrograde fashion using a pistol that is pressurized and restricted by either a synthetic or bone plug in the canal. An adequate cementation technique is fundamental for the survivorship of the implant, which is why a chapter (Chap. 7) is dedicated to cementation in this book. The author's preferred method is a double stage cementation technique starting from the humeral side. Some TEA devices allow for separate implantation of the ulnar and humeral components, thereby providing better control over the alignment and obviating the need to reflect the triceps. Two-staged cementation may help to avoid some intraoperative early complications such as fractures and malpositioning [20]. Whenever a space remains between the anterior humeral cortex and the inner

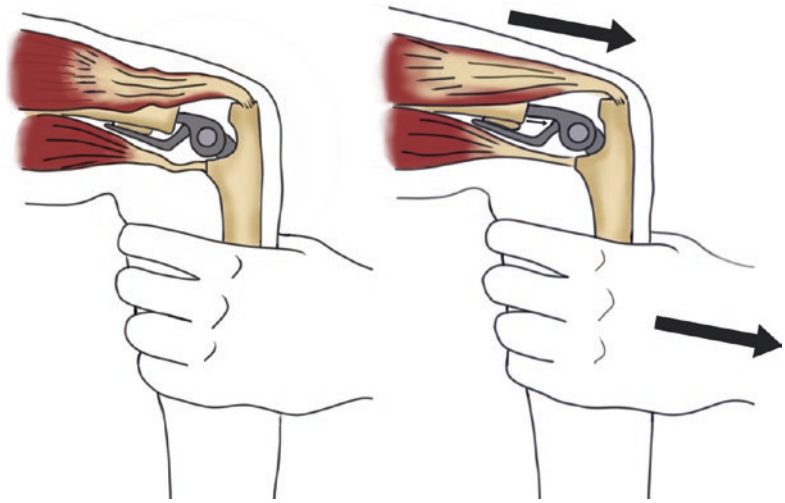

Fig. 6.22 The "Shuck test." With the elbow flexed at 90°, the flexor and extensor muscles of the arm are tensioned by applying a backward force on the forearm

side of the anterior flange of the implant, it should be filled with a cancellous bone graft prepared from the excised trochlea or from the radial head. The graft should measure about 1.5 cm in length and 1 cm in width and should be positioned in concomitance with the introduction of the humeral stem to enhance compression of the graft. Before its positioning, the anterior cortex should be prepared to allow the graft integration. Once the cement hardens, the implant can be assembled definitively by connecting the two components at the hinge.

If linked implants are used, the surgeon may choose to either repair or not repair the collateral ligaments. Nonabsorbable no. 2 sutures are placed in the lateral and medial collateral ligaments and common extensor and flexor origins. The sutures are inserted through transosseous suture holes made in the lateral and medial epicondyles at the level of the central axis of rotation. Most elbow surgeons do not repair the collateral ligaments to avoid excessive tension and consequent maltracking. When the epicondyles are not available or the transosseous suture is not possible because of excessive soft tissue tension, the flexor-pronator mass origin and the common extensor origin are sutured to the medial and lateral side of the triceps aponeurosis, respectively [53]. In cases in which the triceps sparing or splitting approaches are used, a careful triceps transosseous reinsertion should be performed. This provides a running locked suture of the tendon and cruciate crisscross bone tunnels starting from the triceps olecranon footprint to the proximal ulna [10].

The anterior subcutaneous transposition of the ulnar nerve is performed by carefully bringing it into a subcutaneous pocket and securing it, using absorbable sutures placed in the subcutaneous tissue, to the medial epicondylar region. Suction drains are positioned to avoid subcutaneous hematoma. The wound is closed in layers, and a bulky dressing is applied. Alternatively, the elbow is protected in an anterior long-arm splint with the elbow in extension or in a posterior long-arm splint with the elbow in partial or 90° of flexion [48]. Drains are removed after 48–36 h. Cryotherapy is applied in the first 2 weeks. In our institution indomethacin (100 mg daily) is administered for 4 weeks to prevent heterotopic ossifications (HO) and to control swelling and pain. All the patients are usually discharged 2–3 days after surgery.

Conflict of Interests The authors declare no commercial associations (e.g., consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) that might pose a conflict of interest in connection with the submitted manuscript.

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7 Cementing Technique in Total Elbow Arthroplasty

Jason R. Kang and Shawn W. O'Driscoll

Key Points

- Optimal cementing technique achieves implant fixation and facilitates future removal.
- It is of the senior author's impression that press-fitting components with minimal cement mantle is sufficient to achieve stable fixation in elbow arthroplasty.
- The ideal cement mantle has minimal to no cement past the tip of the prosthesis.
- Bone graft should be used as cement restrictor for the humeral and ulnar medullary canals.
- Measures to facilitate future procedures such as the addition of methylene blue to cement should be taken.

7.1 Introduction

Cement is the most commonly used method of achieving fixation of total elbow arthroplasty components. The goal of cementing is to achieve immediate and definitive component fixation. Cementing technique has the potential to impact the short- and long-term outcomes of patients undergoing total elbow arthroplasty. This chapter will review the key technical considerations in cemented total elbow arthroplasty.

7.2 Cement Mantle

The ideal thickness of the cement mantle for orthopedic implants has been debated extensively in the hip arthroplasty literature [1]. For femoral components, cement mantles between 2 and 5 mm have been associated with improved outcomes [2]. This has been challenged by the excellent long-term results of French surgeons who use press-fit components supplemented with cement, thus leaving only a very thin or minimal cement mantle [1, 3]. This technique has become known as the "French paradox." This is analogous to how methyl methacrylate is routinely used for dental crowns, which are known for their durability and longevity. The use of a press-fit technique with a minimal cement mantle around femoral components in hip arthroplasty has been shown to be just as good as, if not better than, a stem with a complete, thick cement mantle [1].

The role and necessity of the cement mantle in total elbow arthroplasty are unclear. Thick cement mantles and those extending past the tip of an elbow prosthesis are extremely difficult to remove. Complications during removal, such as fractures and retained cement, are common. Therefore, a thin cement mantle that does not extend past the tip of an elbow prosthesis would

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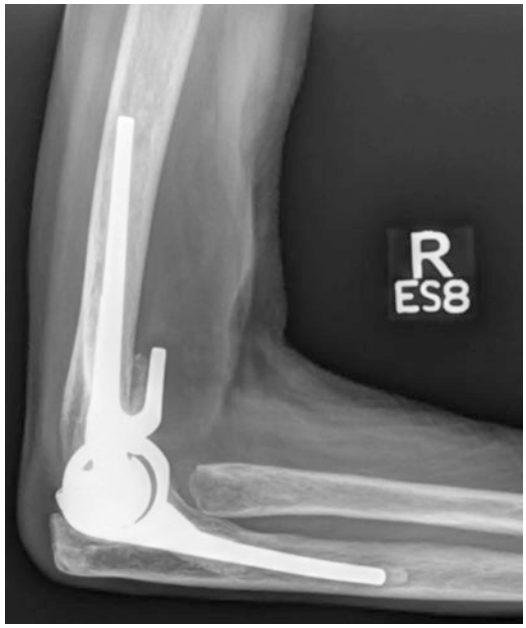

Fig. 7.1 Using our recommended technique, a cemented total elbow fits tightly within the canal, with minimal cement mantle and minimal or no cement past the tip of the prosthesis. By permission of Mayo Foundation for Medical Education and Research. All rights reserved

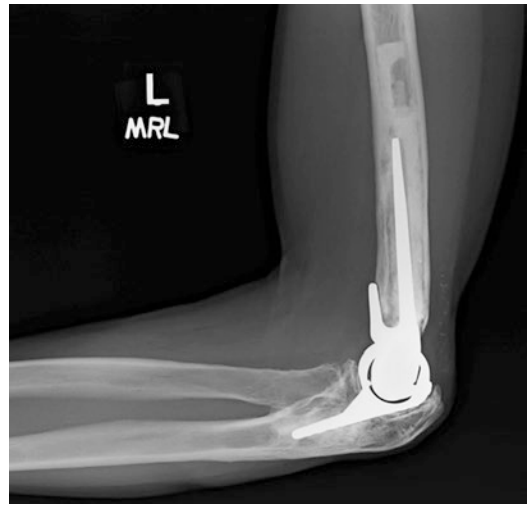

Fig. 7.2 Example of a wide cement mantle (which we do not recommend) around the stems of the ulnar and humeral components, in this case with lucencies around the humeral stem. A commercially available plastic cement restrictor was placed in the humeral canal and failed to restrict cement extrusion proximally. This rendered the humeral revision more complicated. By permission of Mayo Foundation for Medical Education and Research. All rights reserved

reduce complications during revision surgery or removal for infection. It would also make revision operations faster. It is of the senior author's impression that press-fitting components with minimal cement mantle is sufficient to achieve stable fixation in elbow arthroplasty (Fig. 7.1).

Early experiences in cemented total elbow arthroplasty suggested that cementing past the tip of the prosthesis was desirable and decreased rates of component loosening [4]. However, a recently proposed method of quantifying the length of the cement mantle relative to the length of the prosthesis failed to show correlation between the cementation index and elbow arthroplasty implant failure [5].

7.3 Cement Restrictors

The use of cement restrictors is an advanced cementing technique that permits pressurization and improves fixation strength of prosthetic implants [6]. There are several methods described for restricting cement in total elbow arthroplasty [7, 8]. Commercially available cement restrictors are suboptimal for numerous reasons. Anatomically, the isthmus of the humerus is located at the junction of the middle and distal thirds of the diaphysis and enlarges in a constant manner, which is unlike the femur and tibia [9]. As such, commercial cement restrictors are typically placed proximal to the isthmus of the humerus and lead to restrictor migration or cement leakage (Fig. 7.2) [7]. In some cases, cement extrudes deep into the canal, especially if no restrictors are used (Fig. 7.3). Most restrictors are manufactured in sizes for lower extremity arthroplasty and are too large to be used in the elbow. Commercial cement restrictors are largely unreliable and are an additional source of foreign material that can be a challenge to remove during revision surgery.

These challenges make it not only difficult to control the extrusion of cement into the canals beyond the desired distances but also impair one's effort to obtain adequate pressurization of the cement mantle, which most surgeons believe yields superior results in terms of component longevity before loosening.

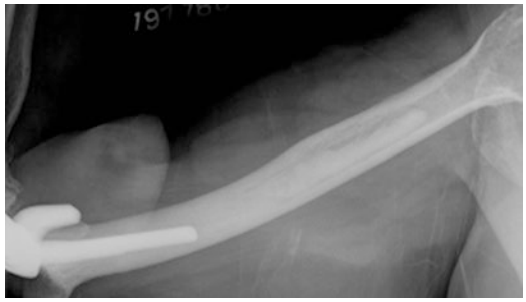

Fig. 7.3 Example of excessive cement extrusion up the humeral canal. This degree of excess cement greatly increases the complexity and risk of complications during humeral revision (Courtesy of Dr. John Sperling, Mayo Clinic. By permission of Mayo Foundation for Medical Education and Research. All rights reserved).

Skinner et al. compared 10-year survivorship of femoral stems implanted using two cementing techniques clinically and in cadaveric femora [1]. The first technique (group 1) used broaches oversized by 2 mm and a centralizing plug to permit an even 2 mm cement mantle around the stem. The second technique (group 2) prepared the canals "line to line" with broaches with the same shape and size as the components to be inserted, such that a tight press-fit was accomplished. Survivorship at 10 years was 97% in group 1 and 99% in group 2. Vertical migration at 5 years was 1.8 mm in group 1 and 1 mm in group 2. Lytic lesions were significantly more common in group 1.

They also performed a cadaveric study in which they compared the traditional cementing technique (over-reaming to provide a 2 mm cement mantle) with a tight press fit before cementing. Cement penetration into the endosteal bone was greater in group 2 because pressurization forced the cement into the interstices of the trabecular bone. The authors concluded that there were no apparent disadvantages with the lack of a cement mantle.

If a tight press-fit stem is inserted into the canal that has been broached line to line with the same size broach as implant, the cement will be pressurized during component insertion. Song et al. showed that intramedullary pressures rise to the highest level, while the component stem is being inserted into the canal, suggesting that prior pressurization may not be necessary to achieve adequate pressurization [10].

The senior author has used a similar technique in elbow arthroplasty for a couple decades. Our preferred technique is to use bone as a cement restrictor [11]. Autograft bone from the resected portion of the distal humerus is the fashioned into cancellous pellets to fit within the medullary canals of the humerus and ulna. In revision cases, or when insufficient distal humerus is available, allograft bone can be used. Pieces of autograft or allograft bone are placed into the medullary canal and impacted into place with a broach or trial implant. By using the trial components to impact the bone graft into place, this ensures that the bone graft is advanced far enough to accommodate the final prosthesis and achieves a secure fit at the tip of the prosthesis. Cancellous bone graft is forgiving enough to impact the final prosthesis into the bone graft during final placement of the components.

7.4 Cement Technique Considering Possible Future Revision or Removal

Several considerations should be made during the cementing of primary total elbow arthroplasty to facilitate subsequent revision procedures. Addition of methylene blue to cement during the primary procedure greatly enhances cement removal [12]. Effective cement restriction reduces the need for humeral windows or invasive osteotomies during cement removal and component explantation. Minimal to no cement plug formation at tip of the prosthesis facilitates revision procedures such as cementing into an existing cement mantle [13]. The ideal cementing technique balances initial implant fixation and stability without apparently compromising future revision procedures.

7.5 Preferred Cement Technique for Total Elbow Arthroplasty

7.5.1 Materials

- Polymethyl methacrylate cement (40 g, with or without antibiotic).
- Cement gun.

- Cement mixer with vacuum pressurization.
- Narrow cement gun nozzle.
- 1% methylene blue (1 mL).
- Pulsatile lavage with canal irrigator.
- Bone graft (autograft or allograft).
- Rongeurs.
- Broaches and trial implants.

7.5.2 Cementing Technique

The humerus and ulna are cut and prepared with broaches for the total elbow implant of choice. Our preferred cement restrictor is the use of bone graft (Fig. 7.4). Autograft can be obtained from the bone resected from the distal humerus during primary arthroplasty procedures, and allograft can be used for revision procedures. Bone graft is prepared into appropriately sized "pellets" using a large or medium size rongeur for the humeral canal and a small size rongeur for the ulnar canal. Bone graft is placed into the canal with forceps and impacted into place with a broach or trial component. This is repeated with several pieces of bone graft until the surgeon feels confident that the canal is sufficiently occluded. Taking care to avoid dislodging the bone graft, the medullary canals are irrigated with pulsatile lavage using a modified canal irrigator (Fig. 7.5) and then meticulously dried with sponges.

Methylene blue (just enough to change the cement color) is added to 40 g of polymethyl methacrylate. The liquid polymer is added, and the cement is mixed under vacuum pressurization. The cement is loaded into a cement gun to which a narrow nozzle is attached (Fig. 7.6). The nozzle is cut obliquely to match the length of the humeral prosthesis and glides within the medullary canal without resistance. The cement is injected into the ulnar and humeral canals in a retrograde fashion with the cement gun on the "pressurized" setting. Additional cement is placed onto all bony surfaces that will contact the prosthesis. The final prosthesis is inserted by hand and impacted into its final position. Excess cement, which is easily visible due to its blue color (Fig. 7.7), is removed with cement removal instruments of choice. Additionally, the blue color greatly facilitates the distinction of cement from endosteal bone during

Fig. 7.4 Large rongeur used to fashion bone graft pellets to be used as cement restrictor for the humeral canal. Several pellets are impacted into the canal until they obstruct the canal at the tip of the trial prosthesis (or broach). By permission of Mayo Foundation for Medical Education and Research. All rights reserved

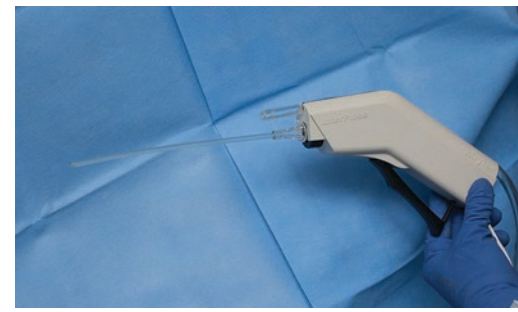

Fig. 7.5 Pulsatile lavage with modified canal irrigator for preparing and cleaning of the canal prior to cementing. By permission of Mayo Foundation for Medical Education and Research. All rights reserved

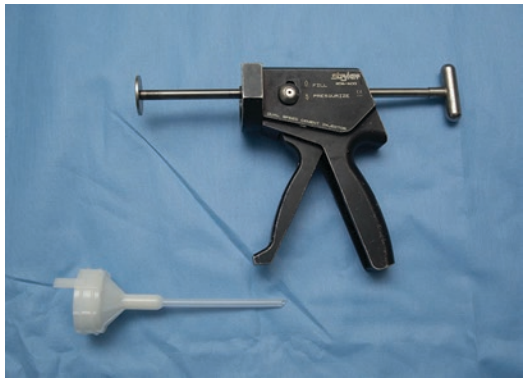

Fig. 7.6 Cement gun set on "pressurize." Narrow nozzle cut obliquely to the length of the prosthesis. By permission of Mayo Foundation for Medical Education and Research. All rights reserved

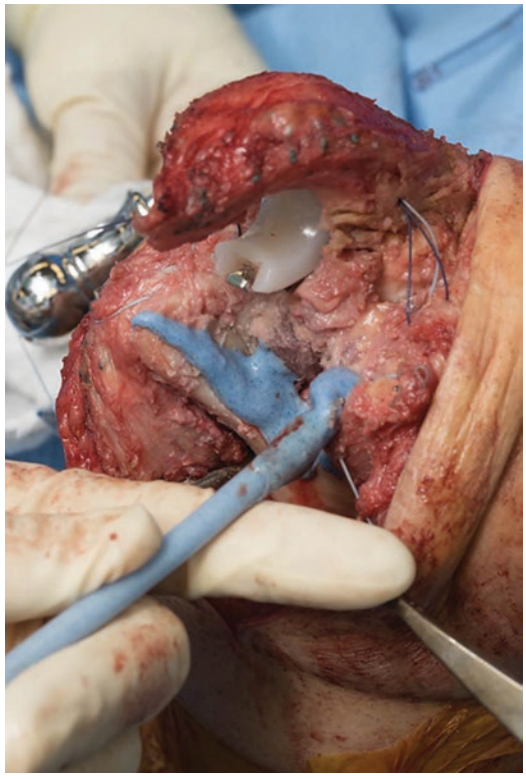

Fig. 7.7 Cement with methylene blue is placed into the canal in a retrograde fashion and on all bony surfaces contacting the prosthesis. By permission of Mayo Foundation for Medical Education and Research. All rights reserved

revision procedures (Fig. 7.8). Post-op radiographs are taken to confirm minimal cement plug past the tip of the prosthesis and no extrusion of cement outside the canal.

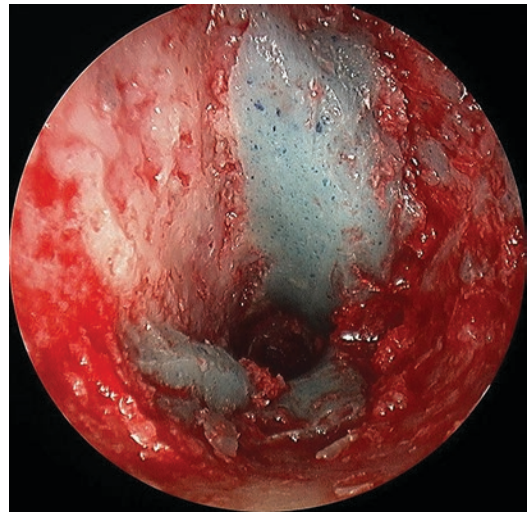

Fig. 7.8 The presence of methylene blue in the cement makes it much easier to distinguish methyl methacrylate from endosteal bone during cement removal. These views were taken with an arthroscope, which is useful during cement removal. By permission of Mayo Foundation for Medical Education and Research. All rights reserved

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8 Total Elbow Linked Arthroplasty in Distal Humeral Fractures and Distal Humeral Nonunion: Peculiarities of Surgical Technique and Expected Results

Raffaele Russo, Antonio Guastafierro, and Giuseppe Della Rotonda

8.1 Introduction

Elbow arthroplasty is a procedure progressively wide spreading and receiving increasing attention from the medical community. This surgical procedure was initially introduced in cases of inflammatory arthritis, then, thanks to the good clinical outcomes, its indication was extended to other pathological conditions. According to Fevang et al. [1] the surgical results are challenged by high failure rates especially in high demanding cases.

The elbow arthroplasty is indicated in selected cases, but several considerations are needed.

In the following chapter, we are going to evaluate the role of total elbow arthroplasty (TEA) in distal humeral fractures and distal humeral nonunion.

In these cases, the therapeutic strategy is still debated in the scientific community and represents a demanding topic.

We are going to analyze the types of implant, indications, surgical approaches, technical tips, and outcomes of TEA in acute distal humeral fracture and distal humeral nonunion.

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8.2 Types of Implants

Several types of implants are available and are mainly categorized in three subgroups: linked, unlinked, and linkable.

The joint stability and the bone stock guide the choice within the different implants, especially between unlinked (unconstrained) and linked (semi- or totally constrained) [2].

The most popular unlinked implants are Souter-Strathclyde and the Kudo prosthesis. In this type of implant, the resurfacing components are placed systematically on distal humerus and proximal ulna with or without radial head component. The humeral and ulnar components in the unconstrained implants are not mechanically linked. In these cases, the implant congruency is determined by the adequate position of the components, ligament integrity, and the stabilizing effect of the muscles. This type of implant is susceptible of instability that can compromise its clinical result.

The linked implants based their main characteristic on the physical link between the humeral and ulnar components that allow to reduce the risk of subluxation and dislocation. The first implants introduced were associated with high implant failure rate for the high stress forces applied on the artificial joint. The implementation of these prosthesis is provided to develop the new semi-constrained implants. With the

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Fig. 8.1 Coonrad-Morrey total elbow arthroplasty (Reproduced with permission from Zimmer, Warsav, IN, Inc.)

introduction of Coonrad-Morrey prosthesis (Fig. 8.1), the linking mechanism works as sloppy hinge and consequently provides less stress to the bone-implant interface. This kind of arthroplasty is the most commonly used for its better surgical outcomes and more reliable long-term fixation [3].

Thanks to their capability to ensure joint stability, the constrained and semi-constrained implants represent the preferred treatment in cases of severe bone defect or ligamentous insufficiency. Given that, the linked implants represent a valuable choice in acute elbow fractures and nonunion cases.

In a recent systematic review on elbow arthroplasty, Little et al. [4] founded comparable revision rate between linked and unlinked implants. In particular, radiographic loosening seems to be higher with unlinked implants and better functional outcomes in linked implants. In 2005, Levy et al. [5] reported a higher revision rate in unlinked when compared to linked implants.

Radial head is not systematically replaced. In case of arthritic disease or radial head resection, this procedure is able to increase the stability if correctly performed; otherwise an improper alignment is the main source of wear, osteolysis, and loosening.

The recent implementation of this technology is provided to preserve some fundamental features and improve other aspects:

- The bearing surface design for a thicker polyethylene subjected to less contact pressure.
- Dedicated instrumentation to ameliorate the setting of center of rotation.
- The possibility to link the components after a complete check of range of motion.

One of the best example of this implemented technologies is represented by Latitude™ EV (Tornier, Inc., USA) (Fig. 8.2). This modular system is linkable on the basis of intraoperative assessment of elbow stability. During the surgery, it is necessary to reduce the trial humeral, ulnar, and radial components, and then the elbow should articulate through a full range of motion (ROM) to test the stability, articular tracking, axis of rotation, and ROM and to evaluate the need to connect or not the humeral component to ulnar component. Furthermore, this system allows to convert a distal humeral hemiarthroplasty into a total elbow arthroplasty without revising the humeral stem.

8.3 Indications

Management of acute fractures and nonunions of the distal humerus by joint replacement has been an option of treatment for several decades [6, 7]. In particular, in elderly patients with comminuted distal humeral fractures, TEA is able to reach good clinical results. Generally, prosthetic replacement is indicated to relieve severe pain or significant disability following the effects of primary or secondary osteoarthritis, in rheumatoid arthritis, in correction of functional deformities, in revision procedures, and in fractures unmanageable with reduction and fixation.

Cobb and Morrey in their study [6] underlined the successful results of this procedure in distal humeral fractures even if 48% of their population were patients with rheumatoid arthritis.

Recently, other publications [8–10] have noted similar results, although a part of this studies have included patients with rheumatoid arthritis.

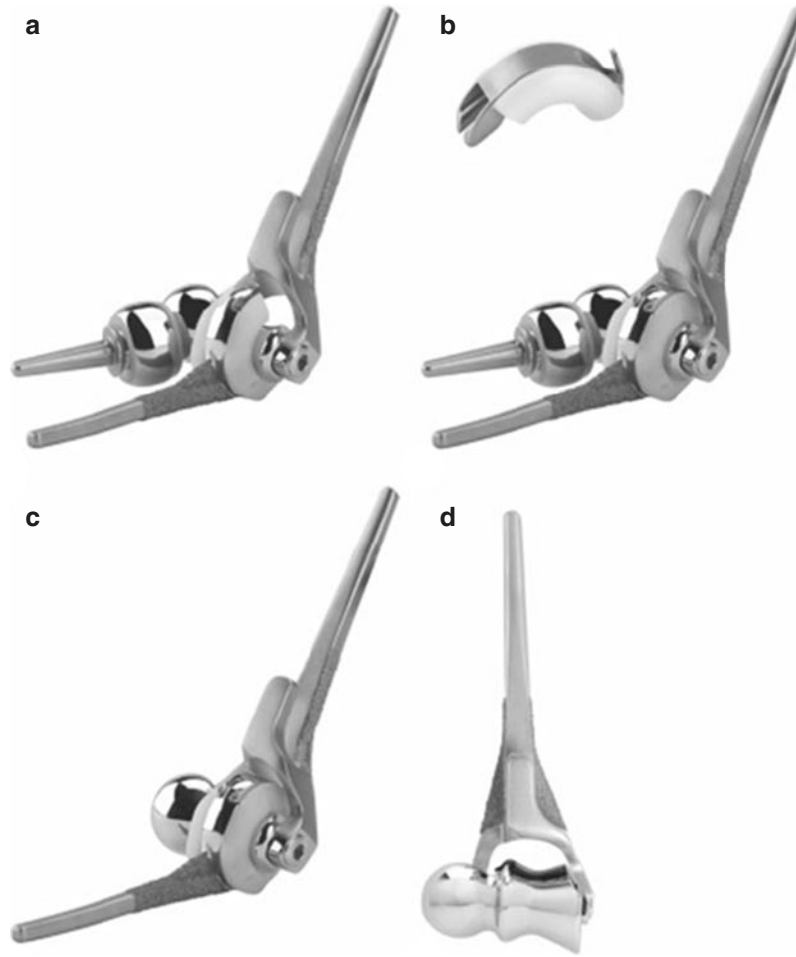

Fig. 8.2 Latitude EV system. (**a**) Unlinked latitude TEA with bipolar radial head arthroplasty. (**b**) Linked latitude TEA with locking cap. (**c**) Linked latitude TEA without radial head arthroplasty. (**d**) Anatomic latitude hemiarthroplasty (Reproduced with permission from Tornier, Edina, MN, Inc.)

Stanley et al. reported satisfactory results in a nonrheumatoid population at 3-year follow-up [11] and at 5-year follow-up [12].

Elbow arthroplasty is emerged as attractive solution for distal complex humeral fractures especially in case of severe osteoarticular injuries that challenged the traditional surgical treatment (ORIF). Several studies have reported good outcomes after the use of elbow arthroplasty for the treatment of acute distal humeral fractures [13, 14].

Despite this, the internal fixation remains the treatment of choice in most patients.

Limited bone stock, damage to the articular cartilage, joint contracture, and compromised bone viability may prevent union, pain relief, and restoration of function when internal fixation is attempted for repair of the distal humeral nonunion [15].

For these considerations, also in distal humeral nonunion, one of the most challenging elbow condition, the TEA represents an attractive solution.

Linked semi-constrained total elbow arthroplasty offers several advantages in these cases: the extensor mechanism can be left undisturbed, no postoperative protection is required, stability is reliably restored, a functional range of motion is predictable, and pain and limited motion secondary to persistent nonunion, malunion, or posttraumatic osteoarthritis are avoided.

The main disadvantages are the risk of implant-related complications and the need to limit use of the upper extremity postoperatively to minimize the risk of loosening and wear.

The key element is to give the right indication of TEA, for this reason, several authors proposed guideline to lead the therapeutic strategy.

In 2010 a Delphi-based consensus paper was performed [12]. According to elbow surgeon across the word was defined a list of indication in acute distal humeral fracture:

- Nonrheumatoid patients over the age of 75 years.
- Patients with rheumatoid elbow disease any age.
- Patients with reduced life expectancy any age.
- Patients with pathological bone any age.
- Patients with degenerative elbow disease over the age of 60 years.

According to Sanchez-Sotelo and Morrey study [13], total elbow arthroplasty was considered in case of distal humeral nonunion in the following circumstances:

- Elderly patient with low anticipated physical demands.
- A distal nonunion associated with severely compromised distal bone stock.
- Previous associated inflammatory or degenerative articular changes.

TEA was also considered contraindicated in case of infection and severe neurological deficiency.

In our clinical practice, a total elbow arthroplasty is indicated in:

- Acute comminuted distal humeral fractures in elderly patients (over 65 year), if stable internal fixation is impossible to obtain.
- Nonunion in elderly patients (over 65 year) in whom osteosynthesis is not an option due to inadequacy of the articular surface or articular osseous support or severe osteoporosis or deformity.
- Failure of osteosynthesis.
- Rheumatoid arthritis in case of severe inflammatory condition and pain.

In younger patients with unfixable comminuted distal humeral fractures, instead, the right choice is very demanding considering the encouraging results of osteoarticular allografts in our clinical practice.

8.4 Technique and Tips

8.4.1 Preoperative Assessment and Planning

It is necessary, preoperatively, to clinically analyze the neurovascular status of the affected limb and general conditions of the patient. Radiographically, in addition to traditional X-rays, computed tomography with the new implementation of 3D reconstruction has greatly improved both diagnosis and preoperative planning. The 3D reconstruction allows a better comprehension of the fracture (Fig. 8.3) and approximation of the implant sizes needed.

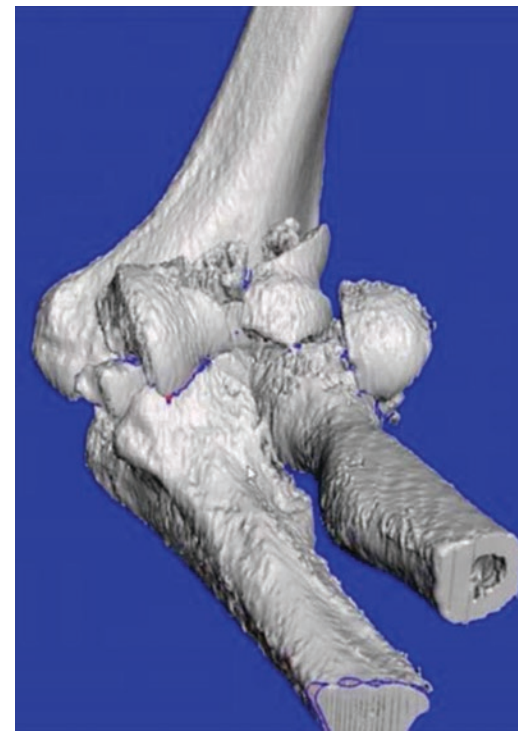

Fig. 8.3 The image shows an example of 3D reconstruction of a complex distal humeral fracture

In case of acute complex fractures, the key element is to exactly identify the site of injury. Fractures proximal to the olecranon fossa are usually managed with a long-flanged implant.

In nonunion cases, attention must be paid to the degree of deformity and location of previous skin incisions. The elbow deformity has to be correctly evaluated because it may require longer stems to avoid loosening. It is, therefore, important to have multiple prosthetic options available for these patients. Finally, the possibility of infection must be always considered as a possible cause of the nonunion.

It is also important to document the ulnar nerve status. If asymptomatic, the nerve simply needs to be identified at the time of surgery. If the patient is symptomatic, the decompression and possibly anterior transposition of the nerve have to be carried out.

8.4.2 Patient Positioning

The patients are placed on the table in a supine position or lateral decubitus according to the surgeon preferences. In supine position (author's preference), the arm is placed across the chest allowing the full mobility. The skin incision is variable on basis of surgical approach. In case of revision, a straight skin usually incorporate the old one. For those cases, if there is gross deformity, we employ the landmarks of the subcutaneous border of the ulna distally and the midportion of the humerus proximally in order to ensure that the final incision is straight once the deformity is corrected.

8.4.3 Surgical Approaches

In our clinical practice, for elbow replacement, we use, indifferently, three surgical approaches:

1. Extensile Kocher posterolateral approach with triceps attachment maintained.
2. Triceps aponeurosis tongue approach (O'Driscoll).
3. Posterior approaches.

8.4.3.1 Extensile Kocher Posterolateral Approach with Triceps Attachment Maintained

To access the elbow joint, in the Kocher approach, use the interval between the anconeus and extensor carpi ulnaris. Compared with distal Kocher approach, the skin incision is extended 6–7 cm proximal to the lateral epicondyle.

After entering Kocher interval, the extensor carpi ulnaris and common extensor tendon are reflected anteriorly to expose the capsule.

The triceps is easily elevated from posterior humerus; it remains attached to the ulna, but if the exposure is not enough, the Mayo modification of the Kocher approach consists of reflection and release of a portion (25–50%) of the triceps attachment from the tip of the olecranon. If more than 50% of the attachment is released, the triceps must be securely reattached to the bone. It is necessary to evaluate that the ulnar nerve is not compressed. In case of compression, it is released from cubital tunnel.

This approach has the advantage of keeping attached triceps without injuring the extensor mechanism; in some cases, joint exposure is more difficult than a posterior approach.

8.4.3.2 Triceps Aponeurosis Tongue Approach (O'Driscoll)

This is a posterior approach to elbow joint; the ulnar nerve is identified; if it is not compressed, it is not necessary to carry it anteriorly.

The triceps fascial tongue is marked with a marker pen. The triceps tongue is a distally based flap of the triceps tendon that is approximately 5–6 cm long and 2–3 cm wide and proximally may be rectangular or come to a point to form a V. It is essential that a portion of the tendon remain on all sides of the triceps tongue to help with a secure at tendon-to-tendon repair at the conclusion of the case [16]. The fascial tongue is elevated off the deep muscle but remains attached distally on the olecranon (Fig. 8.4). In this approach, it is not necessary to transpose the ulnar nerve; the exposure of elbow joint is optimal, and extensor mechanism is minimally insulted.

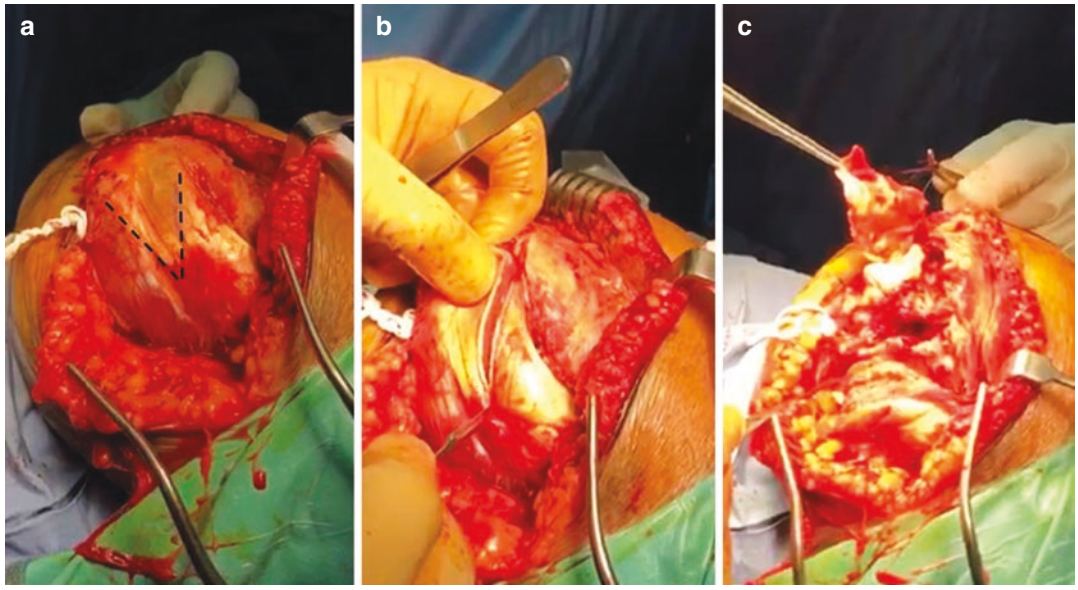

Fig. 8.4 Tongue approach to the elbow. (**a**) Drawing of the sides of the "tongue"; (**b**) "tongue" incision; (**c**) flap elevation

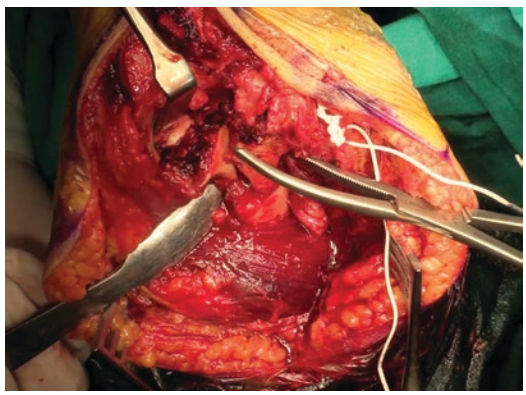

Fig. 8.5 The picture illustrates the "triceps-on" approach where the triceps is not detached but laterally positioned (left side of the picture)

8.4.3.3 Posterior Approaches

A posterior skin incision that passes just to the lateral side of the tip of the olecranon is made. The ulnar nerve is identified and superficially decompressed. In our clinical practice, we prefer to transpose anteriorly the ulnar nerve. The posterior access to the elbow can contemplate the section or the release of the triceps tendon. When allowed, it is possible to simply transfer the triceps laterally, preserving its integrity (triceps on approach, Fig. 8.5). In this way, the joint is widely exposed with easy access to distal humerus, ulna, and radial head.

8.4.4 Total Elbow Prosthesis: Setting and Implant

The correct placement of the humeral and ulnar components is necessary to achieve the normal elbow joint axis of rotation. The respect of the axis of rotation is essential to the correct function of the prosthetic implant.

The components in a lengthened position can lead to a deficit in the elbow extension and flexion contracture; the components in a shortened position can lead to excessive hyperextension of the elbow with the weakness of the flexor and extensor muscles.

In distal humeral fractures, the bone reference points for a good setting of the prosthetic implant are often altered. Although linked implants don't require the humeral condyles and the ulnar notch for component fixation, the humeral capitellum is fundamental for the evaluation of the elbow rotation and the prosthetic setting (Fig. 8.6). However, the presence of the collateral ligaments or the humeral condyles is not as crucial for the linked implant as it is for the unlinked implant, although the placement of the hinged portion of the implant at the proper axis of rotation is important. Definitively, the linked implants allow a major

toleration than the unlinked implant for their inherent stability. For these considerations, in our clinical practice, we use linked and linkable implants in distal humeral fractures and nonunion (Figs. 8.7 and 8.8), although we perform an accurate reconstruction of the fracture fragments.

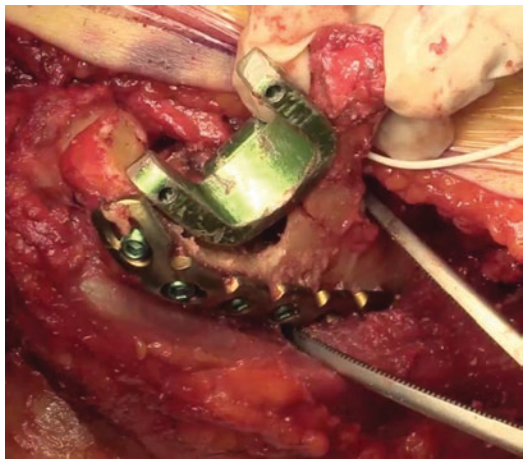

Fig. 8.6 The picture illustrates the condyle reconstruction for humeral component setting

8.4.4.1 Bone Preparation

In distal humeral fractures, the first step is to identify the fracture fragments. We try to reconstruct the anatomy of the humeral condyles as much as possible to help the prosthetic setting. The proximal part of the olecranon fossa is an important landmark for linked arthroplasties with an anterior flange. In fact, the flexion-extension axis should be reconstructed exactly if the anterior flange is positioned at that level. The presence of the fracture makes the humeral cutting guides useless. Once the humeral canal is identified, the humeral bone preparation is done using the humeral rasps. A trial implant is positioned to verify the correct fit and the proper height. In this way, the axis of rotation of the implant is aligned with the normal elbow axis. To provide adequate joint stability, we insert the shortest length but most extensive diameter implants performing the Coonrad-Morrey prosthesis (the mostly used implant in the distal humeral fractures).

Preparation of the proximal ulna is carried out with cutting guides that resect a portion of the greater sigmoid notch; in the next phase, the intramedullary canal is opened with a high-speed burr or a drill guide and prepared with ulnar

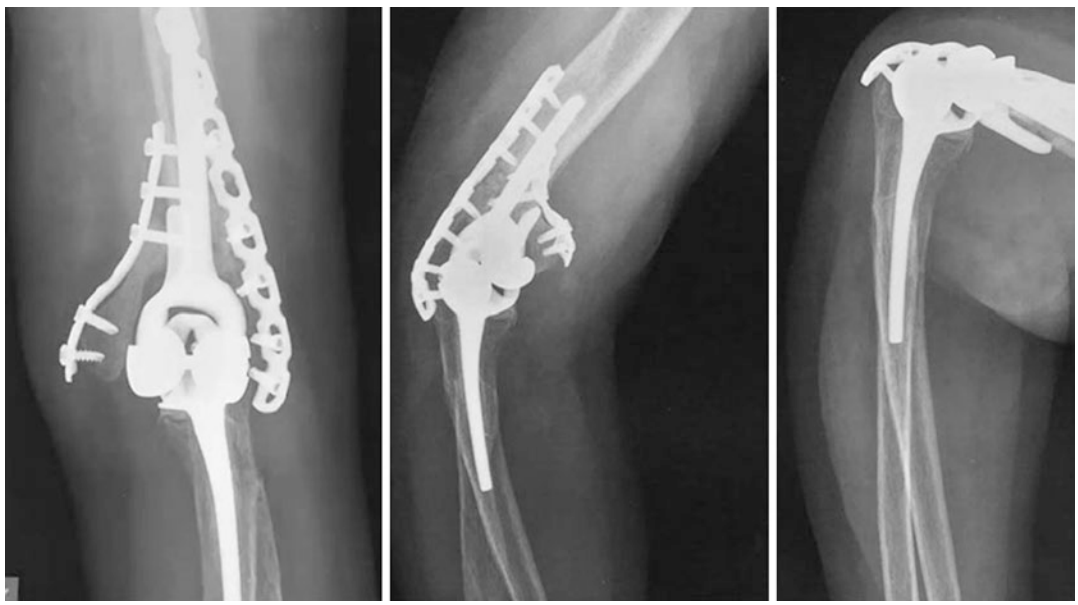

Fig. 8.7 Postoperative X-ray at 4 months' follow-up. Coonrad-Morrey prosthesis with accurate reconstruction of medial and lateral columns

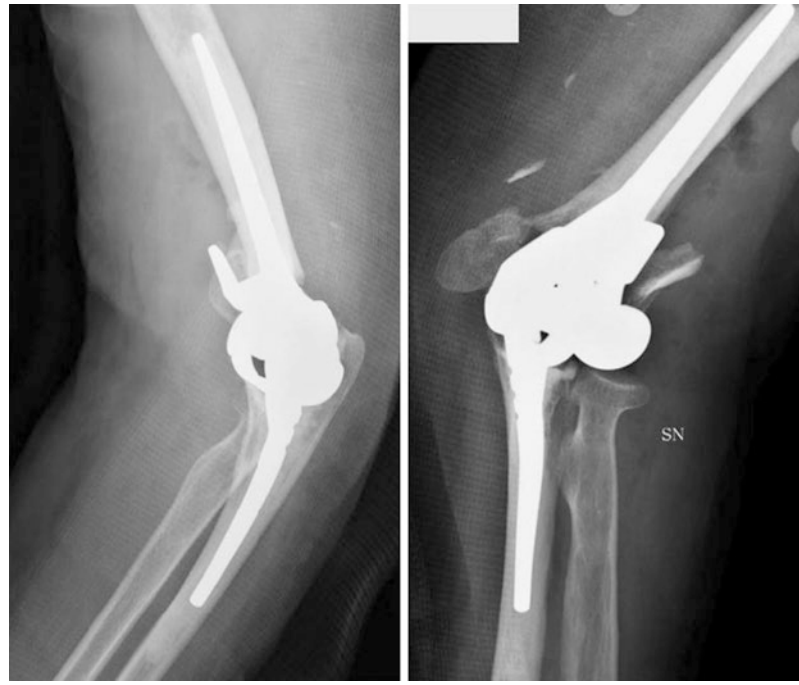

Fig. 8.8 Postoperative X-ray. Latitude total elbow arthroplasty with locking cap

rasps. After a trial ulnar implant is placed for adequate fit.

In the unlinked implants, the radial head can be preserved, excised, or replaced. If the proximal radioulnar joint and radiocapitellar joint are in good conditions, the radial head is conserved. Instead, if there are degenerative modifications of these articulations, the radial head is excised or replaced. The freehand technique or a radial cut guide is used to remove the correct amount of radial head. Then the trial radial head is screwed to the radial stem and fitted to the resected bone surface.

8.4.4.2 Implant Insertion

After the placing of proximal ulna and distal humerus trials (with or without radial head), an accurate evaluation of the elbow range of motion is performed. The implants must be properly seated so that the hinge portion of the implant is at the true axis of rotation and that full motion, especially extension, is achieved [2].

Radial capitellar joint should be checked in flexion/extension and supination/pronation to verify a reasonable tracking.

Pistoning of either the humeral or ulnar components may be indicative of impingement between the prosthesis and the bone [12, 17] or may be due to a malposition of the flexion-extension axis. Impingement is commonly related to osteophytes at the tip of the coronoid or olecranon, in these cases an accurate excision has to be performed.

Once a satisfactory position of the trial components has been achieved, the intramedullary canals are brushed, lavaged, and dried, and the definitive implants are cemented in place. In case of a linkable implant, we link humeral component to ulnar component (Fig. 8.9). In case of implant with an anterior flange, a bone graft is placed between the anterior flange of the prosthesis and the anterior humeral cortex, to promote bony consolidation.

8.4.4.3 Closure

In the posterior approach, the triceps is attached securely to the olecranon via transosseous nonabsorbable sutures when detached. With "triceps on approach," the extensor mechanism does not need to be fixed.

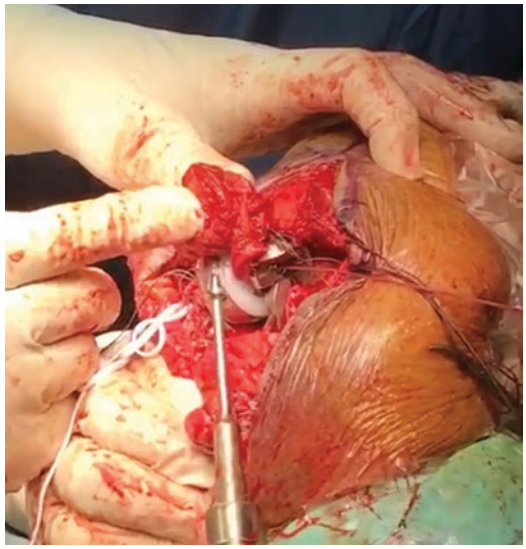

Fig. 8.9 The picture illustrates the screw placement to assemble the ulnar cap to the ulnar stem. This procedure allows to obtain a linked configuration of latitude implant

In the tongue approach, a meticulous repair of the triceps and adequate healing are key to functional recovery. Closure is generally performed in 60° of flexion to get appropriate triceps tension.

In the extensive Kocher approach, the key element is the reconstruction of the lateral compartment because the triceps attachment is preserved. Instead, in the Mayo-modified, if more than 50% of the attachment is released, the triceps must be securely reattached to the bone with transosseous nonabsorbable sutures.

The ulnar nerve may be left in situ or transposed based on the approach and surgeon preference.

The skin and subcutaneous tissue are closed in a routine manner. If excellent hemostasis is achieved, we frequently do not use a drain but have a low threshold to use one if necessary.

8.4.5 Postoperative Care

Postoperatively, we apply a plaster back slab with the arm in extension and with the arm elevated for 48 h. The slab is then removed, and the patient is allowed to begin active flexion and extension exercises. After the removal of the stitches, patients begin therapy in water.

8.5 Outcomes

8.5.1 Distal Humeral Fractures

Open reduction and internal fixation are considered the gold standard in most distal humeral fractures. In case of elderly patients and comminuted fractures, the elbow arthroplasty may represent a valuable alternative.

Several studies report satisfactory clinical outcomes of total elbow arthroplasty in selected patients with complex distal humeral fractures [10, 11, 18].

In a consecutive case series of 43 patients (mean follow-up of 7 years), Kamineni and Morrey founded a satisfactory Mayo Elbow Performance Score (MEPS) with mean arc of motion from 24° of extension to 131° of flexion [8]. However, nine patients required a reoperation.

In a comparative study, Frankle et al. [19] pointed out better clinical outcomes performing arthroplasty when compared to internal fixation in a series of 24 cases.

Prasad and Dent [20] compared total primary elbow arthroplasty for distal humeral fractures in the elderly, with the same procedure performed following failed internal fixation or conservative treatment. The mean follow-up was 56.1 months. No significant difference was found comparing the two groups.

8.5.2 Distal Humeral Nonunion

In the therapeutic strategy of distal humerus nonunion, elbow arthroplasty represents an excellent treatment option. Most distal humerus nonunions are treated with internal fixation and bone grafting. Instead, elderly patients with osteopenia and very limited bone stock may be benefit more from elbow arthroplasty.

Morrey and Adams published the results obtained in 36 patients treated with elbow arthroplasty for distal humerus nonunion (mean age of 68 years and mean follow-up of 4 years) [7]. This study reported satisfactory results in 86% of all cases; the authors also reported two infections and three patients with excessive polyethylene wear.

Cil et al. [14] reviewed 92 elbows treated with linked TEA and reported an MEPS improving in 85% of patients. Despite high complication rate seen, 44 elbows suffer minor complications, 32 needed additional surgery, and 23 required surgical revision.

In 2011, Sanchez-Sotelo [3] study revised the clinical results of 92 distal humerus nonunion. At a mean follow-up of 6.7 years (range, 2–20 years), 79% of the patients had no or mild pain, and mean range of motion was from 22° of extension to 135° of flexion. Complications included aseptic loosening in 16 patients, component fracture in 5 patients, deep infection in 5 patients, and bushing wear in 1 patient.

Pagliacomi et al. [21] showed results comparable to other study. In particular the use of a linked implant in 20 patients for distal humeral nonunions showed painless elbow rate of 80%. The mean MEPS in the affected arm improved from 51.3 preoperatively to 86 at follow-up. The patients were satisfied, and 90% reported excellent or good outcomes.

8.6 Complications

Due to thin soft-tissue envelope of the elbow, the deep periprosthetic infection is considered higher when compared with other joint replacement. It is estimated between 2% and 4%.

Given that, in elbow fracture and nonunion treated with TEA, the infection rate is higher if compared with other condition. This is attributed to the possibility of exposed fractures or higher risk of infection in patients with failed previous surgical procedures (nonunion) [4, 22].

The risk of ulnar neuropathy is considered around 5%. For this reason, most surgeons recommend a routine subcutaneous nerve transposition, especially performing posterior approaches.

The rate of extensor mechanism dysfunction is often related to a direct posterior approach. According to Little et al. [4] the incidence is 3% of all cases. This dysfunction often requires revision surgery to reconstruction of the extensor mechanism with the use of anconeus rotation flap or Achilles tendon allograft.

In linked arthroplasty, instability complication such as dislocation or subluxation is not reported in the literature.

Mechanical failure is considered when the following conditions occur: aseptic loosening, polyethylene wear, osteolysis, component fracture, and disengagement. According to Little et al. [4] the rate of aseptic loosening in linked TEA is 2% which represents the main limiting factor of implant durability.

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9 Total Elbow Arthroplasty in Rheumatoid Arthritis and Other Inflammatory Conditions: Unlinked or Linked Replacement?

Alessandra Colozza, Luigi Perna, Alberto Trimarchi, and Bernard F. Morrey

9.1 Introduction

The most common indications for total elbow arthroplasty are pain that significantly alters daily activities and dysfunctional instability. Pain is often related to rheumatoid arthritis or post-traumatic conditions. Instability is a typical feature of type IV rheumatoid arthritis and post-traumatic arthrosis with severe loss of bone or distal humerus non-union. Another indication for intervention is ankylosed elbow. This condition is related to juvenile rheumatoid arthritis, some forms of adult-onset rheumatoid arthritis, post-traumatic arthritis and other inflammatory conditions. In recent decades, improvement in medical therapies for the treatment of rheumatic conditions has led to a marked decrease in the incidence of rheumatoid arthritis (RA), thus greatly helping surgeons to deal with this systemic pathology. However, the medical management of this pathology can lead to complications, such as drug-induced osteoporosis, an increased infection rate and delayed wound healing.

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9.2 Rheumatoid Arthritis (RA)

Rheumatoid arthritis is an inflammatory condition, with an aetiology that is still not fully understood. The presence of HLA-DR4, the gene for major histocompatibility complex (MHC), is a known risk factor for developing RA [1]. Activation of immune cells, expansion of cells in pathologic lesions and a good response to immunosuppressive therapy suggest that RA is an immune-mediated process. The elbow is affected in 25–30% of patients with RA [2].

9.2.1 Clinical Presentation

According to current guidelines by the American College of Rheumatology, at least four of the following seven criteria need to be present for at least 6 weeks for a patient to be diagnosed with RA [3]:

1. Morning stiffness in and around joints lasting at least 1 h.
2. Arthritis of three or more joint areas (interphalangeal joint, metacarpalphalangeal, wrist, elbow, knee, ankle and metatarsophalangeal joints of either or same side).
3. Arthritis of joints of the hand, with at least one joint area involved.
4. Symmetric arthritis involvement of the two sides (interphalangeal, metacarpalphalangeal

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and metatarsophalangeal joint involvement doesn't require absolute symmetry).
5. Rheumatoid nodules observed by a physician.
6. Raised serum rheumatoid factor.
7. Radiographic changes should include typical erosion and/or periarticular osteoporosis.

One half of RA cases have an acute presentation, whereas this is insidious in the remaining cases. RA can present with a single joint involvement (21% of cases) or as typical polyarthritis (35%). At presentation, joints are typically painful, swollen and stiff. This is followed by joint deformity at a later stage (Fig. 9.1) [4]. Stiffness is typically present in the morning, which is thought to be related to swelling resulting from the redistribution of interstitial fluid that occurs during the night, when the joint remains immobilized for several hours.

Pain is due to joint inflammation (synovitis). This is worse when there is an increased amount of liquid in the joint, which leads to swelling and consequently to stiffness. RA at the elbow joint manifests with loss of extension. However, this sign often goes unnoticed by patients, as inflammatory symptoms and, later on, deformities affecting the hands and wrists are far more disabling and dominate the clinical scenario.

9.2.2 Classification

The Larsen and Mayo Clinic classifications, both based on radiographic features, are the most used to stage elbow involvement [5–7] as follows:

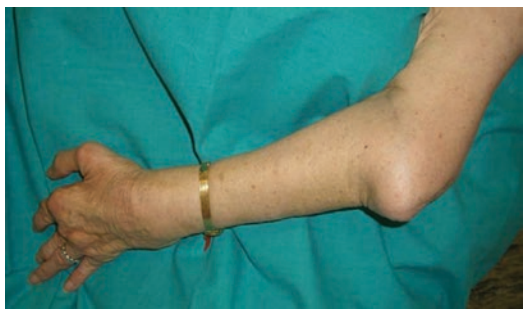

Fig. 9.1 Clinical features of advanced stage of rheumatoid arthritis (RA)

1. Stage 1 Larsen and I Mayo Clinic: involvement is limited to the soft tissues, and radiographic appearance is near normal.
2. Stage 2 Larsen and II Mayo Clinic: periarticular erosions and mild cartilage loss; evidence of soft tissue swelling and osteopenia on radiographs may be present.
3. Stage 3 Larsen and III A Mayo Clinic: radiographs show marked joint space narrowing.
4. Stage 4 Larsen and III B Mayo Clinic: advanced erosions penetrating the subchondral bone plate (Fig. 9.2).
5. Stage 5 Larsen and IV Mayo Clinic: Radiographs show advanced joint damage and loss of articular contour (Fig. 9.3).

9.2.3 Treatment

9.2.3.1 Conservative Management

Conservative management aims at relieving symptoms and preventing tissue destruction and disability. Several classes of drugs can be used, including analgesics, nonsteroidal anti-inflammatory, steroids and disease-modifying drugs (methotrexate, quinoline derivatives, gold compounds, sulfasalazine). Biologic response modifiers have also recently become available.

9.2.3.2 Surgical Treatment

Non-prosthetic treatment:

Synovectomy is indicated in patients with the following characteristics [8–11]:

1. Resistance to conservative treatment.
2. Larsen stage <3.
3. Larsen stage 3 or III A Mayo Clinic in patients younger than 50 years and pauciarticular disease.
4. Absence of instability.

This is rarely performed due to the impact of effective medical management.

Interposition arthroplasty was used before total elbow arthroplasty became available. This is still the treatment of choice in young patients who place high demands on the involved elbow

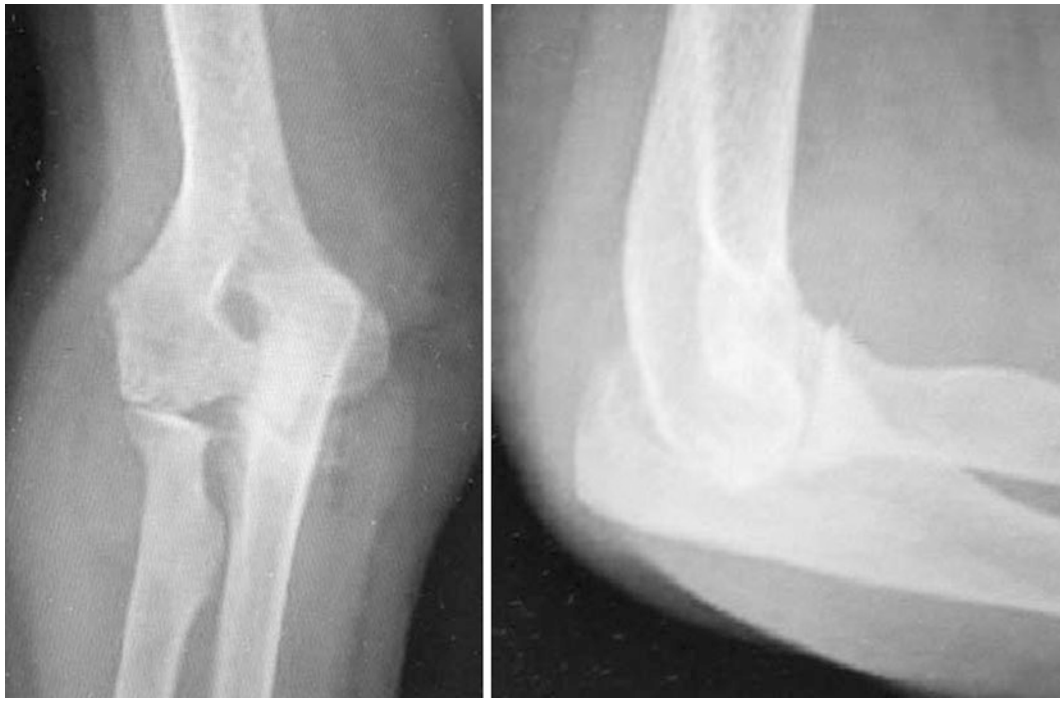

Fig. 9.2 Stage 4 Larsen or stage III B Mayo Clinic rheumatoid arthritis: bony erosion penetrating subchondral bone and joint narrowing are visible

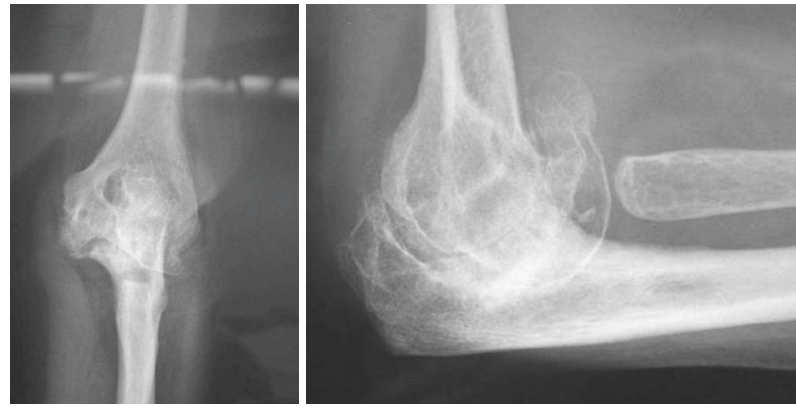

Fig. 9.3 Stage 5 Larsen or stage IV Mayo Clinic: radiographs show advanced joint damage and loss of articular contour

joint. Resection arthroplasty, with or without interposition of tissue (fascia lata, derma), is also no longer used, since it causes progressive bone erosion, thus increasing instability and poor surgical outcomes.

Another surgical option, which is no longer recommended, is hemiarthroplasty, as it is not readily available and can result in a stiff and painful joint.

9.2.3.3 Elbow Replacement

In advanced stages of RA (stages 4 and 5 Larsen, stages III B and 4 Mayo Clinic), total elbow arthroplasty (TEA) is the treatment of choice to decrease pain and restore functional range of motion. There are many commercially available types of prosthesis for TEA, and terminology can be confusing. Prostheses can be classified into constrained, non-constrained, semiconstrained,

linked, unlinked, hinged and non-hinged. The most commonly used types of TEA prostheses are either "linked" (with a mechanical connection between the humeral and ulnar components that prevents dissociation) or "unlinked". The choice of implant is usually based on three factors:

1. The disease affecting the elbow (RA, juvenile rheumatoid arthritis, post-traumatic, traumatic).
2. Specific needs of the patient (high versus low activity).
3. Surgeon preference and expertise (number of implants/year).

Unlinked implants rely on bearing surface architecture and soft tissue integrity: the constraint is the shape and the interaction of articular surfaces. Therefore, patient selection and technique are critical. Soft tissue condition, including collateral ligaments and muscle function (secondary stabilizer), and bone stock must be addressed. Linked implants do not rely on soft tissue balance but may cause stress to the bone-cement-stem interfaces and, therefore, increase the risk of wearing and aseptic loosening. To date, no prospective randomized trials comparing linked and unlinked TEA prostheses are available [12]. The revision rate of joint implants performed using linked or unlinked implants appears to be similar [13]. A review by Little et al. in 2005 concluded that linked implants (with a sloppy hinged) result in a better functional outcome in terms of range of motion and stability, compared to unlinked implants. The same authors also studied three groups of patients affected by RA and treated with different implants (Souter-Strathclyde, Kudo, Coonrad-Morrey) and reported that survival rate of Coonrad-Morrey implants was higher (90% at 5 years). In 16% of patients, periprosthetic osteolysis around the ulnar component was present and evolved in joint/prosthesis loosening.

Sanchez-Sotelo et al. in 2016 published a series of 461 implants with linked TEA prostheses (Coonrad-Morrey linked implant) in 387 patients affected by RA. The average follow-up was 10 years, and the overall revision rate was 11%, leading to a 15-year prosthesis survival rate of 83% and a 20-year prosthesis survival rate of 68%. Infection rate was 8%. Ulnar component loosening was the main indication for revision, and this was particularly frequent with the PMMA (polymethyl methacrylate) precoated components. The authors hypothesized that this problem could potentially be solved by plasma spray surface. Another weakness of the implant was polyethylene wear that decreased the survival rate around 15 and 20 years [14].

Some surgeons suggest using unlinked arthroplasty in the early stages of RA (Larsen III, Mayo Clinic III A) [15, 16]. Unlinked implants are the best choice in young patients with an adequate bone stock, good ligament balance and muscular strength. However, RA is a systemic disease characterized by joint instability due to synovitis, swelling and capsular laxity; hence diligent patient selection and careful surgical technique are mandatory when considering an unlinked TEA prosthesis as a treatment option. Moreover, a convertible unlinked implant should be chosen, since it allows the surgeon to make intraoperative decisions regarding elbow stability and convert to a linked implant without revising the stems. In case of laxity or bony marked erosion, a linked implant is the treatment of choice, since it provides good outcomes in terms of pain relief and functional recovery, with a high 5-year survival rate.

9.3 Juvenile Rheumatoid Arthritis

Juvenile rheumatoid arthritis (JRA) is a rare condition that affects 250,000 children in the USA alone. The diagnostic criteria include "arthritis that has been present in at least one joint for 6 weeks to 3 months in a patient younger than 16 years old" [17].

These patients present with a history of multiple previous surgeries (shoulder, hip, knee), and a polidistrectual evaluation is mandatory. At pre-

sentation, the elbow is typically painful and stiff, often ankylosed.

Because of the young age of these patients, synovectomy and interposition arthroplasty should be the treatment of choice [18]. Unlike RA, JRA is more likely to lead to ankylosis, rather than instability, and interposition arthroplasty can be considered. TEA is indicated when conservative therapy and non-prosthetic surgery fail. Extensive release of soft tissue is required to re-establish joint motion and achieve adequate exposure. For this reason, unlinked prostheses are generally not indicated in this condition. Moreover, circumferential arthrolysis and capsular and ligament release are necessary, and soft tissue balance can be difficult to achieve at the end of the procedure; instability or dislocation of the joint can lead to early implant failure. When planning the procedure, the size of the implant should be carefully selected, since the medullary canal could be very narrow. In some instances, the implant contour can be modified (the humeral component can be adapted to allow introduction into the humeral canal), or custom-made implants can be used. Baghdadi et al. recently published a series of 29 patients affected by JRA and reported a survival rate of 79% at 10 years follow-up. However, the improvement in joint motion was inferior to that reported in RA patients [19].

9.4 Seronegative Inflammatory Arthropathies

This group of disorders, which include spondyloarthropathies, crystalline-induced arthropathies and adult Still's disease, is characterized by the absence of rheumatoid factor and anti-cyclic citrullinated peptide (anti-CCP) antibodies. An accurate history and physical examination are necessary to make a diagnosis. It is fundamental to ascertain if the disease is monoarticular or polyarticular and systemic or local. Moreover, if the joint involved is only the elbow, infection must be ruled out. The clinical presentation can include olecranon bursitis, rheumatoid nodules, gouty tophi or sign of infection. Pain and stiffness are the main symptoms and are present in all seronegative arthritis.

9.4.1 Spondyloarthropathies

Spondyloarthropathies include:

1. Ankylosing spondylitis.
2. Inflammatory bowel disease.
3. Psoriatic arthritis.
4. Reactive arthritis.

To date, more than 30 genes have been reported to increase the risk of developing ankylosing spondylitis, which is the most common type of spondyloarthropathy. However, the major predisposing factor is the presence of the HLA-B27 antigen. HLA-B27-positive patients are also more likely to present with enteropathic arthritis. The diagnosis is made through a combination of clinical history, X-ray imaging (spine and sacroiliac joints are generally involved) and biochemical evaluation, which includes HLA-B27 testing. Since not all carriers of the HLA-B27 antigen have or will develop arthritis, the presence of the HLA-B27 alone is not sufficient to make the diagnosis of spondyloarthritis.

Clinical presentation differs from RA since (1) it is generally nonsymmetric, (2) spine and sacroiliac involvement is very common, (3) enthesitis is more common than synovitis and (4) extra-articular features are different (e.g. mucositis and uveitis are more common in ankylosing spondylitis).

Conservative treatment includes nonsteroidal anti-inflammatory drugs (NSAIDs), steroid shots, disease-modifying antirheumatic drugs (DMARDs) and tumour necrosis factor alpha (TNF-alpha) blockers. However, these drugs can increase the risk of infection.

The elbow involvement is different in the listed pathologies. In ankylosing spondylitis, the elbow is involved in 12%. Radiographic findings include joint space narrowing, osteopenia and periostitis [20]. In psoriatic arthritis,

the involvement is 25% and the articular damage pattern is erosive [21]. Inflammatory bowel disease affects the elbow in 35% of cases, with non-erosive and nondeforming X-ray features [22]. In reactive arthritis, elbow involvement is uncommon [23] (Figs. 9.4, 9.5, 9.6 and 9.7).

9.4.1.1 Surgical Treatment

Surgical treatment is indicated when conservative treatment fails. Synovectomy, interposition arthroplasty and non-prosthetic procedures can be used in younger and high-demand patients.

TEA is the treatment of choice in patients with severe joint damage, when a non-prosthetic

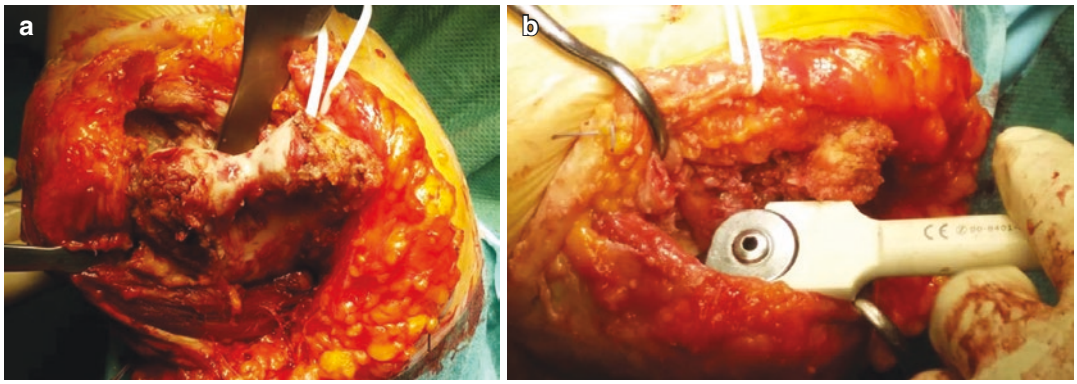

Fig. 9.4 (**a**) Intraoperative finding in RA. Triceps on approach is used. (**b**) Humeral component positioning

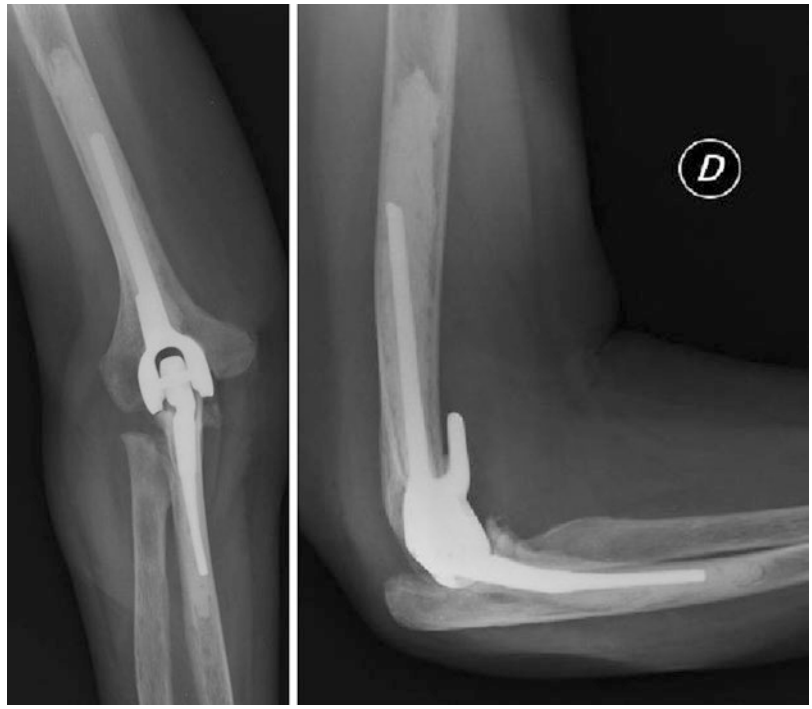

Fig. 9.5 Two years X-ray follow-up, Nexel implant (Zimmer Biomet) in a case of RA

Fig. 9.6 Clinical results, 2 months after surgery. Patient is pain-free

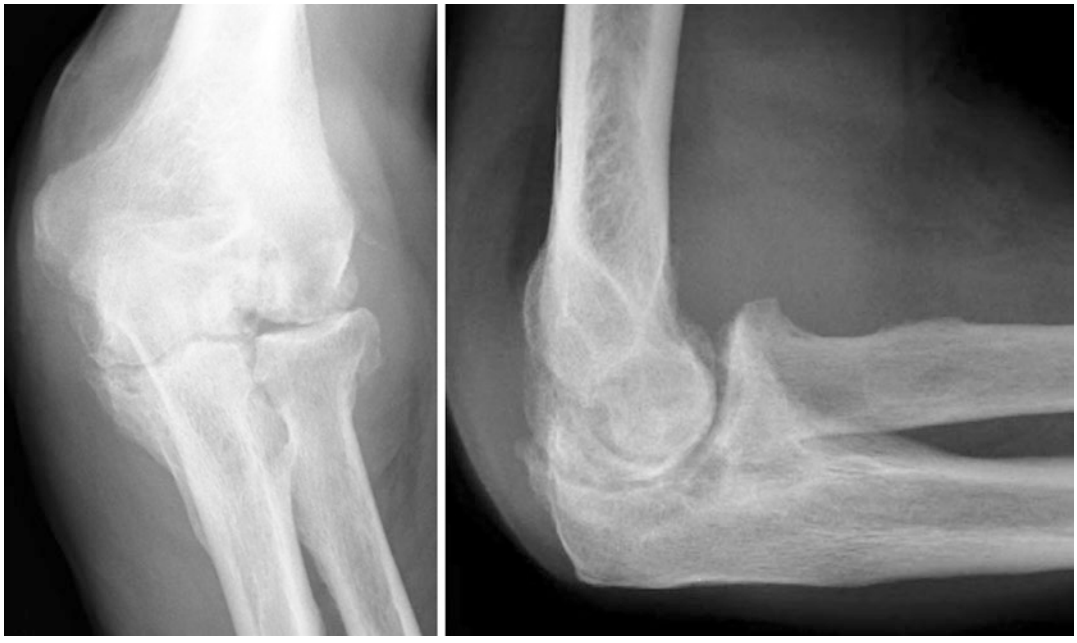

Fig. 9.7 Radiological pattern in psoriatic arthritis: joint space narrowing, bony erosion

approach is not indicated. A review of the literature showed that very few studies have been performed on the surgical treatment of the spondyloarthropathies alone. Patients with these conditions are often included in patient series when analysing the outcomes of TEA, but the outcome of spondyloarthropathies alone is not studied. Hemiarthroplasty has proven less effective in chronic conditions, such as inflammatory arthritis [24]. Both linked and unlinked implants are indicated. Implant selection is based on bone stock quality and collateral ligament and muscular tissue effectiveness.

In a series of 47 patients with arthritic, post-traumatic and traumatic aetiology, treated with hinged implants (Conrad-Morrey), Hildebrand et al. reported that the results are superior in patients with inflammatory arthritis to those in patients with a traumatic or post-traumatic condition [25]. However, among patients with spondyloarthropathies, those with ankylosing spondylitis have an increased risk of heterotopic ossification (HO) [26].

9.4.2 Crystalline-Induced Arthropathies

Crystalline arthropathies are a group of pathologies characterized by crystal deposition in the synovial space.

Gout and pseudogout are classified as crystalline arthropathies, and elbow involvement is 17–33% [27, 28] and 16%, respectively [29]. Gout is a pathology associated with the deposition of monosodium urate (MSU) crystals in the synovial fluid and synovial tissue. MSU crystals are long, needle-shaped and demonstrate negative birefringence under compensated polarized light. Uric acid levels can be elevated during gout attacks.

Clinical presentation in chronic cases is often related to presence of gout tophi. Olecranon bursitis is a typical location of tophi in chronic gout: patients complain of pain, swelling and redness in the olecranic area. This pathology is, in the majority of cases, extra-articular, with crystal deposition in the bursa, thus making intra-articular involvement rare. Radiography shows an erosion of the capitellum and bone absorption on the ulnar side.

Medical management of the acute phase includes NSAIDs, short-term oral corticosteroid, intra-articular corticosteroid injection or oral colchicine, allopurinol or probenecid to reduce serum uric acid levels.

Surgical procedures, such as tophi excision, can increase the risk of infection.

Pseudogout is characterized by deposition of calcium pyrophosphate (CPPD) crystals, which are rhomboid shaped and demonstrate positive birefringence under compensated polarized light, appearing blue. Crystals can be intracellular, and the low concentration in synovial fluid can lead to a false-negative report.

The clinical features and therapeutic approach are similar to that of gout. At clinical presentation, metabolic abnormalities of calcium metabolism should be excluded. Trauma and hyperparathyroidism can increase the risk of pseudogout [30].

9.4.3 Adult Still's Disease

Adult Still's disease (ASD) is a rare form of seronegative arthropathy. The clinical presentation includes fever (with temperature >39 °C), which may be continuous or intermittent, arthralgia lasting more than 2 weeks, typical rash, sore throat and leucocytosis (WBCs > 10,000/L). It shares many clinical features with JRA, but onset is typically in adulthood. The most commonly involved joints are knees and wrists; the elbow joint is involved in 4–44% of cases. Medical treatment is similar to that for JRA and includes NSAIDs, oral corticosteroids, methotrexate and biologic response modifiers [31].

There is little evidence on implant choice and outcomes after TEA in crystalline-induced arthropathies.

9.5 Conclusions

A wide spectrum of treatments is available for inflammatory arthropathies and includes medical therapies, physiotherapy and carefully chosen surgical procedures. A multidisciplinary approach, including rheumatologists and orthopaedic surgeons, is crucial to optimally manage these conditions. TEA provides pain relief and restores range of motion in cases with severe articular damage. Anatomo-pathological presentation may differ substantially, and the choice of implant should be tailored to each patient based on bone quality and stock, soft tissue balance, the patient's functional expectations and the presence of systemic disease. Unlinked implants can be considered in young, active patients with good bone and ligament status, but linked (or convertible) implants are the prostheses of choice as they reduce the risk of future instability.

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10 Linked Total Elbow Arthroplasty in Primary and Posttraumatic Arthritis: Peculiarities of Surgical Technique and Expected Results

Claudio Rovesta, Maria Carmen Marongiu, and Andrea Celli

10.1 Introduction

Primary osteoarthritis (*PO*) is not a frequent situation in the elbow, more frequent posttraumatic arthritis (*PTA*) after fracture-dislocation or articular plurifragmentated fracture. Patients with PO are over 50 years old, and patients with PTA are often young workers and sportsmen. For diagnosis in PO, X-rays are sufficient, but for PTA, CT scan and MRI are useful also to evaluate complexity of bone lesion and of soft tissue. Appropriate treatment depends on patients' symptoms, imaging, patients' necessity and expectations, and surgeon expertise. We can recognize PO and treat it by loose body removal or arthroscopic debridement and open arthrolysis to improve articular function and reduce pain before doing joint replacement. In severe PTA of young patients with pain in stiff elbow or instable elbow, it is possible to do arthrolysis or arthrodesis or interposition arthroplasty, and total elbow replacement has shown to be a reliable option in severe posttraumatic arthrosis after the failure of other techniques.

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10.2 Incidence and Etiology

The etiology of *primary degenerative osteoarthritis* (*PO*) of the elbow was generally believed to be secondary to unrecognized or repetitive trauma in the past. Furthermore, demographic studies have shown dramatic differences in the incidence of elbow arthritis in different races, but it is unclear if it is due to a genetic or an environmental influence. In addition to an increased awareness, there is some evidence that the actual incidence of the disease may be increasing. Men are, by far, more commonly affected with PO than women at a ratio of about 4:1. The age at initial presentation is about 50 years old, but many authors observed patients ranging from 20 to 65 years old. In about 60% of patients, occupations or avocations involving the repetitive use of an extremity are the most common factors. Sometimes we can see patients with neuropathic or arthritic conditions in lower extremities causing impaired ambulation and requiring continued use of crutches or wheelchair. The dominant extremity is involved in 80–90% of patients, and bilateral involvement is present in 25–60%.

Posttraumatic arthritis (*PTA*) is more frequent than PO because many are complex traumas of the elbow with dislocation, fracture-dislocation, and articular fracture exiting in a PTA. Patients with posttraumatic arthritis are often young and

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active. These patients, before injury and development of PTA, usually had a normal elbow, and some of them were sporty or heavy workers. The expectations of these patients often are high with the desire of returning to their previous level of activity. Therefore, posttraumatic arthritis poses many more difficulties in treatment because the painful condition is associated with stiffness, joint deformity, contractures, bone loss, instability, and numerous previous procedures resulting in a poor soft tissue of the elbow.

10.3 Clinical and Radiological Evaluations

In the early stages of *primary osteoarthritis* (*PO*), most patients have mild pain at the beginning of movement, and radiographic features show a maintenance of joint space in the presence of little osteophyte formations in the olecranon and coronoid. Loss of extension is the most common problem prompting medical attention. The characteristic pain in this stage is in terminal extension in almost all patients and of terminal flexion in about 50%. Less commonly, symptoms are present throughout the arc of movement and in prono-supination. The intensity of pain from mild becomes moderate and occasionally is described as severe. Examination reveals an arc of motion that averages about 30–120°. Forearm rotation is not restricted, or it is only minimally, because the radiohumeral and radioulnar joint are not severely involved. In 10–30% of patients, we can observe ulnar nerve irritation by excessive osteophyte formation. The radiographic study is diagnostic: the characteristic of primary osteoarthritis of the elbow is "marginal osteophyte formation." The lateral view reveals an anterior osteophyte of the coronoid and a posterior osteophyte of the olecranon process and a reduction of articular space. The anteroposterior view shows ossification and osteophytes and sometimes loose bodies in the olecranon or coronoid fossa and also the involvement of the radial head. Tomography may show subtle osteophyte formation, the presence and location of loose bodies, and precise position, size, and extent of the osteophytes on the humerus and ulna and in cubital tunnel as well.

In *PTA* clinical picture is of great variability because the painful condition could be of different intensity and associated not only to joint deformity but also contractures, stiffness, bone loss, and instability, coming from initial trauma (fracture of the humerus, radius, ulna; dislocation ligamentous lesions; etc.), initial treatment, and other procedures. In clinical evaluation, we consider not only ROM and pain but also instability, nervous deficit, and soft tissue lesion. CT scan and MRI are useful to define bone loss, lesion of articular cartilage, size and shape of ossification, presence of loose body, and lesions of capsula and ligaments. For bone loss, the preoperative pathology was graded according to the amount of distal humeral bone which have been destroyed at the time of injury or prior surgery and classified as follows: grade 1, articular surfaces damaged but trochlea and capitellum present; grade 2, absence of the trochlea but preservation of the medial and lateral supracondylar columns; grade 3, absence of either the medial or the lateral supracondylar column; and grade 4, loss of the whole distal humerus up to or above the level of the olecranon fossa. Ulnar bone loss was classified according to the presence or absence of the olecranon. The significance of a deficient olecranon is the lack of an osseous attachment for the triceps muscle [1].

10.4 Nonoperative Treatment

Symptomatic treatment in *PO* is appropriate especially in the early stages because symptoms are slowly progressive and well tolerated: these patients are treated with anti-inflammatory medication, and sometimes an intra-articular cortisone injection may be of value (hyaluronic acid seems to be not effective in the elbow). In this initial stage, it is important to explain to the patient the cause of pain and the natural history of the process and to recommend activity modification. However, many patients are in activity, and this advice usually goes unheeded or cannot be acted on.

In *PTA* sometimes rehabilitative treatment is useful to improve movement without pain, to potentiate muscular strength, to use orthesis to compensate instability.

10.5 Operative Treatment

In *PO*, the pain from mild becomes moderate during work or sports activities with restriction at the last degree of movements in extension or prono-supination with a diminished effect of anti-inflammatory medication. In these cases, Rx shows reduction of articular space with osteophytes also at the margin of the radial head, and loose bodies of different dimension and location are well identified by TC. Several surgical options exist in this stage and are evoked depending on the dominant symptoms (pain or movement limitation), radiographic alteration, and age and type of work and sport of the patient.

Removal of loose bodies or debridement with removal of prominent osteophytes is necessary by arthroscopy or in some more complicated cases also with arthrotomy with anterior and posterior capsular release and osteophyte removal, with or without ulnar nerve decompression (lateral column procedure). After these procedures, more than 90% of patients express satisfaction with relief of pain and improved arc of motion.

Ulno-humeral arthroplasty is indicated with extensive ulno-humeral osteophytes, capsular contracture and impingement pain, and ulnar nerve symptoms. In this case with a posterior incision, ulnar nerve is inspected and decompressed. Once medial half of triceps tendon is reflected, the tip of the olecranon is removed, and the olecranon fossa is foraminectomized, and with elbow flexion it is possible to remove anterior loose bodies and osteophyte of the coronoid.

In severe *PTA* the treatment depends on pain, stiffness or instability, bone loss, functional demand, and age of patients. In young patients, it is possible to do arthrolysis if there is stiffness with good articular surface or arthrodesis or interposition arthroplasty when we have not preserved the articular cartilage. But arthrodesis is not an attractive option, since bone fusion is difficult to achieve and it gives rise to considerable functional impairment. Soft tissue releases about stiff joints have had unpredictable results. Distraction arthroplasty shows promise for patients under the age of 60 whose main complaint is limitation of motion rather than pain.

10.6 Indication to Total Elbow Arthroplasty (TEA)

Primary osteoarthritis (*PO*) typically affects relatively young and active men, and for them several effective options (debridement, loose body removal, etc.) are available to address the various elements of the complaint: locking, stiffness, and impingement pain. Relative indications for total elbow arthroplasty in primary arthritis include age older than 65, if possible, and a patient who does not need or expect to make extensive use of the arm. Other options of treatment (e.g., debridement) must have failed or have been inappropriate for the lesion. Patients who have pain throughout the arc of motion, especially in the functional range or high grade of stiffness in older patients should be operated on. Patient must be willing to accept the activity limitation of a TEA because it has the potential to provide pain relief and improved function but could also be associated with a high rate of mechanical failure in the typical patient who develops primary osteoarthritis and has a higher baseline activity level than the historic inflammatory patient.

The primary indication for surgery in *PTA* is pain. In a few cases, the operation is considered a salvage procedure because of severe bone loss, and in other patients, indication is an ankylosed joint or one with less than 20° of motion. Another problem is prior surgery. We have to evaluate the number of prior surgical procedures and previous attempts at reconstruction (previously treated by manipulation and immobilization in a plaster cast or a single open reduction and internal fixation, or previous attempts at reconstruction as total replacements or resection or interposition arthroplasties presence of metallic items). We can have a stiffness with pain or end up with an instable joint.

At the time of presentation, we can consider prior complications as some degree of ulnar neuropathy or partial radial neuropathy, as the result either of the initial injury or of later surgery.

10.7 Surgical Technique for Total Elbow Arthroplasty (TEA)

When we have to choose prosthesis model, we know that linked, semiconstrained implants reduce forces on the prosthesis-bone interface, restore stability, and allow for more reliable and satisfactory outcomes, and for posttraumatic arthrosis, total joint replacement using the semiconstrained Coonrad-Morrey prosthesis, in selected cases, is the treatment of choice. In *PTA*, unlinked resurfacing implants are contraindicated because they require intact condyles and collateral ligaments; for stability and also deformity, bone loss is a relative contraindication. Acute or posttraumatic instability is not a contraindication to elbow replacement that involves the use of semiconstrained Coonrad-Morrey implant; in fact, the condition is well managed with this device. Owing to its hinge design, this implant gives immediate and durable stability. During approach for joint replacement, both collateral ligaments are released, and no attempts are made to repair these ligaments without any adverse effects observed. In contrast to unlinked implants, the Coonrad-Morrey device also provides valgus-varus and axial stability without the tendency of the components to disassemble [1].

Only the humeral diaphysis is required to obtain secure fixation of the Coonrad-Morrey implant. Rotational and anteroposterior stability is maintained by the anterior flange and bone graft. Thus this implant requires neither the condyles nor the distal humerus for mechanical support. Therefore non-united parts of the distal humerus can be resected before insertion of this prosthesis. This facilitates enormously total elbow replacement and constitutes a great advantage over those total elbow prostheses that need the condyles for stability. If the bone loss extends into the supracondylar area and into the shaft of the humerus, the humeral component can be cemented more proximally into the shaft. This results, however, in shortening of the humerus. If shortening exceeds 2 cm, it causes weakening of the muscles crossing the elbow joint. Traumatic loss of the proximal ulna is difficult problem and requires reconstruction with allograft or autograft from the iliac crest to restore the site of insertion of extensor mechanism and stability of ulnar component of the prosthesis.

Deformity of distal humerus (in varus or valgus, in retroposition or anteposition) is a feature often encountered in PTA. Long-standing deformity results in asymmetrical soft tissue contractures. Hinged semiconstrained prosthesis has the advantage of being able to correct deformity, but a marked preoperative deformity (more 30°) was associated with a significantly higher rate of complications [2].

Before operation in *PO* and *PTA*, general evaluation of patient is necessary to know the associated pathologies and to do hematic exams, Rx of the thorax and recent elbow Rx. In informed consensus of the patient, he must accept limitation in using the operated elbow even if it is pain-free.

General anesthesia and supine decubitus.

Incision is posterior to afford medial and lateral exposure (including posterior scars from previous procedures in PTA).

Exposition and decompression of ulnar nerve are to be anteriorly transposed in a subcutaneous pocket at the end of operation.

Triceps lateral reflection from the olecranon in continuity with the ulnar periosteum and the fascia of the forearm along with the anconeus muscle as described by Bryan and Morrey is used in PO (it is difficult if extension is limited in the last 45° in PO and in PTA).

With contractures greater than 60–70°, release of the common flexors with the medial ligament at the humerus and of the common extensor insertion with the lateral ligament is carried out.

In *PO*, extensive removal of ulnar and radial osteophytes and also of loose body is frequent. In PO usually, resection of the osteophyte and tip of the coronoid process is necessary to avoid impingement with the anterior flange, which would cause considerable distraction forces on the ulnar component. The radial head is maintained if there isn't significant malalignment or impingement. The periarticular bone is usually very hard, and cutting it requires a saw rather than a rongeur. To gain extension, the humeral component may need to be seated up to 5 mm

farther proximal than usual to help release the anterior soft tissue envelope in extension [3].

In *PTA* if the entire distal humerus is deficient, the triceps doesn't need to be detached from the olecranon for the approach, as it has been described for total elbow arthroplasty in patients who have a nonunion of the distal humerus or a sovra-intercondilar articular fracture [4]. Celli A. reported 20 consecutive patients with OA due to distal humeral and olecranon fracture malunion who underwent TEA by the anconeus-triceps lateral flap approach, which preserves the olecranon insertion of the medial portion of the triceps proper tendon with good results [5]. Moreover, the new approach provides optimum exposure of the olecranon also in patients with OA secondary to intra-articular fracture of the distal humerus and olecranon, where scarring and bone deformity usually hamper joint exposure. In PTA sometimes it is difficult to release articular extremities in anterior side from scar tissue and ossification. The elbow is flexed and anterior capsule excised. It is important to correct deformity to have a regular humeral intramedullary channel, to evaluate bone loss and to avoid excessive bone stock deficiency. Non-united condyles can be resected. An important element is the placement of a bone graft between the anterior flange and the distal part of the humerus to resist, after ingrowth, posterior displacement and rotational stresses on the humeral component.

In *PTA* with irregular olecranon (sequela of fractures), it is difficult to find normal intramedullary channel, and it is possible to create a wrong way for the rasp braking cortical bone. Too deep insertion of the ulnar component is another potential cause of anterior impingement. An intramedullary injecting system is used for optimal insertion of the cement containing some sort of antibiotics.

The tourniquet is released, and meticulous hemostasis is effected, and two drainages are placed.

The triceps insertion must be firmly secured.

Ulnar nerve anteposition, with fascial or subcutaneous flap, is performed.

Flexion-extension and prono-supination are performed to evaluate obtained mobility and stability of the prosthesis avoiding traction on the ulnar nerve.

10.8 Postsurgical Treatment

The arm is elevated with extended elbow in a splint with cryotherapy. Therapy for pain and edema control and also to avoid heterotopic ossification (celecoxib 200 mg die for 21 days) are started soon after operation. After 24 h one drainage is removed, and the patient starts passive and also active flexion-extension (motion is encouraged as tolerated and according to swelling and pain). The patient is usually discharged after 3 days.

The patient could be advised that the prosthesis does not tolerate the stress of heavy physical work; thus, after total elbow replacement, he has to avoid single-event lifting of objects that weigh more than 5 kg as well as repetitive lifting of any object that weighs more than 1 kg. Participation in heavy physical work is a relative contraindication for this procedure. We discourage playing golf, tennis, and other impact sports.

10.9 Results

Owing to the rarity of the diagnosis and reluctance to implant a TEA in those active patients, reports on outcomes after TEA for *PO* are limited [6]. At Mayo Clinic, among 1305 TEAs performed from 1984 to 2011, only 20 were performed in patients with PO (<1%). For this reason there is poor information in the literature regarding the outcome of TEA in primary osteoarthritis. An average of the recent work of Mayo Clinic [7] and a few papers reporting these results show that patients with TEA in PO patients are satisfied with the operation because they increased movement and decreased pain, but excellent results are about 40%, good 15%, and fair 45% because not all flexion and overall extension are recovered and sometimes a minimal pain persists. Pain and active range of motion are reported in MEPS score, and X-rays of the elbow are useful to see humeral bone graft union and radiolucent lines. X-ray radiolucency around the humerus or ulna is present in 30–40% of patients and heterotopic ossification in 30%, and bone graft is united in the majority of patients (Fig. 10.1).

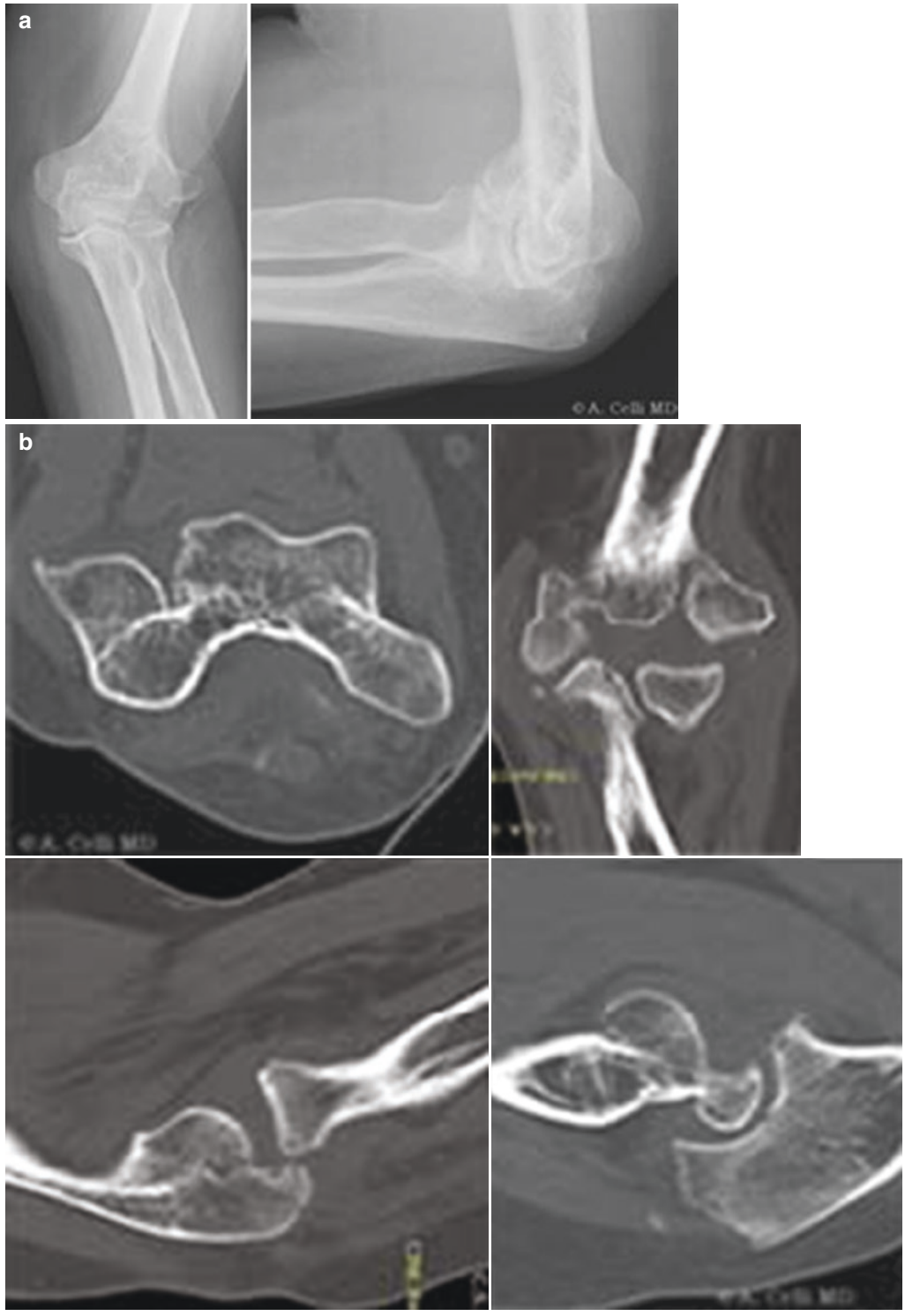

Fig. 10.1 (**a**) Posttraumatic osteoarthritis (PTA) C.R., female, 68 years old, retired, 4 months after trauma of the left elbow with articular fracture. Severe stiffness and pain. ROM F-E 90–70°. (**b**) TC elbow with malunion. (**c**) Anconeus-triceps lateral flap approach for total elbow arthroplasty. (**d**) Intraoperative aspect. (**e**) Implant of the prosthesis. (**f**) Rx of the left elbow after 5 years. (**g**) ROM F-E 10–125° without pain

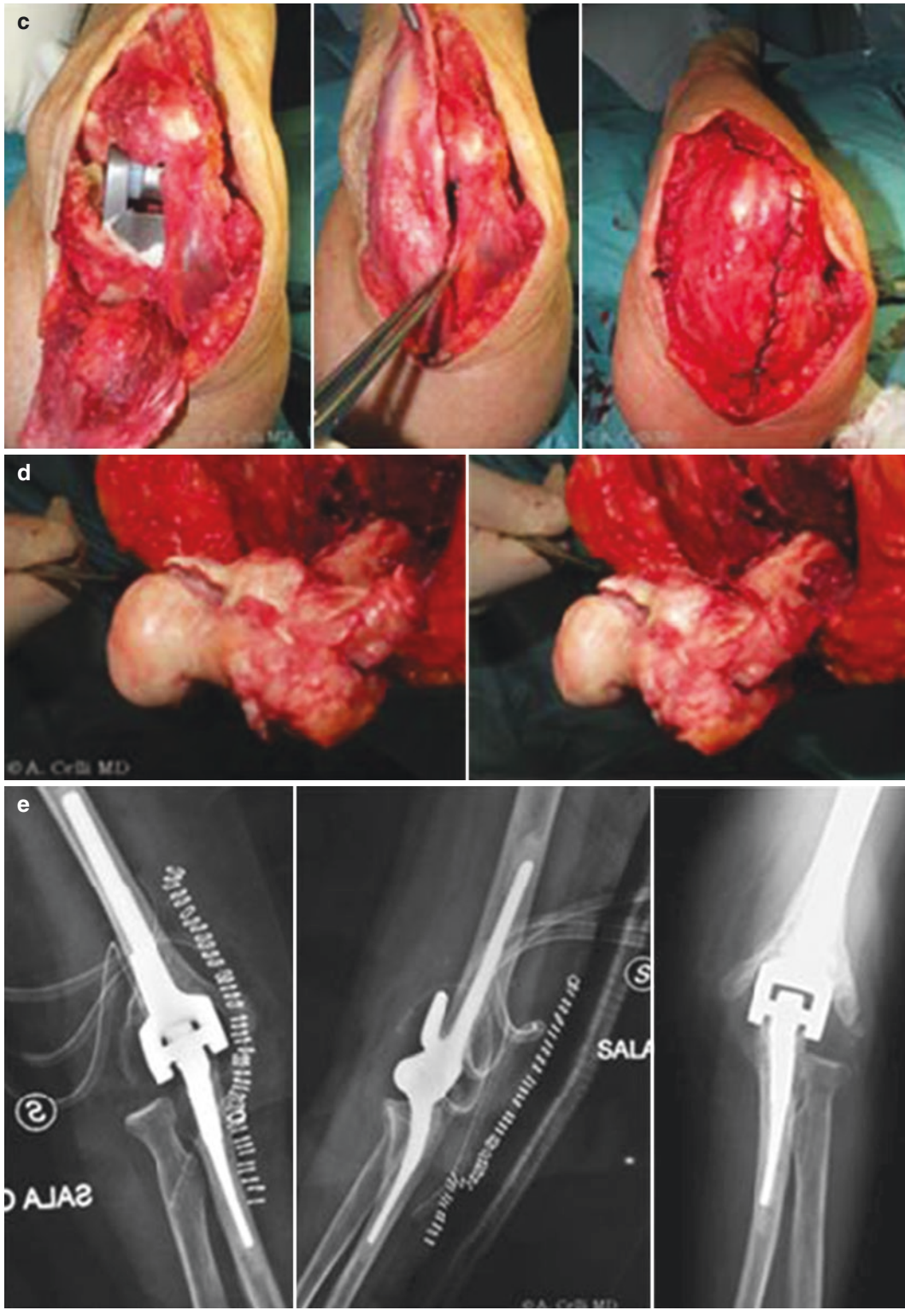

Fig. 10.1 (continued)

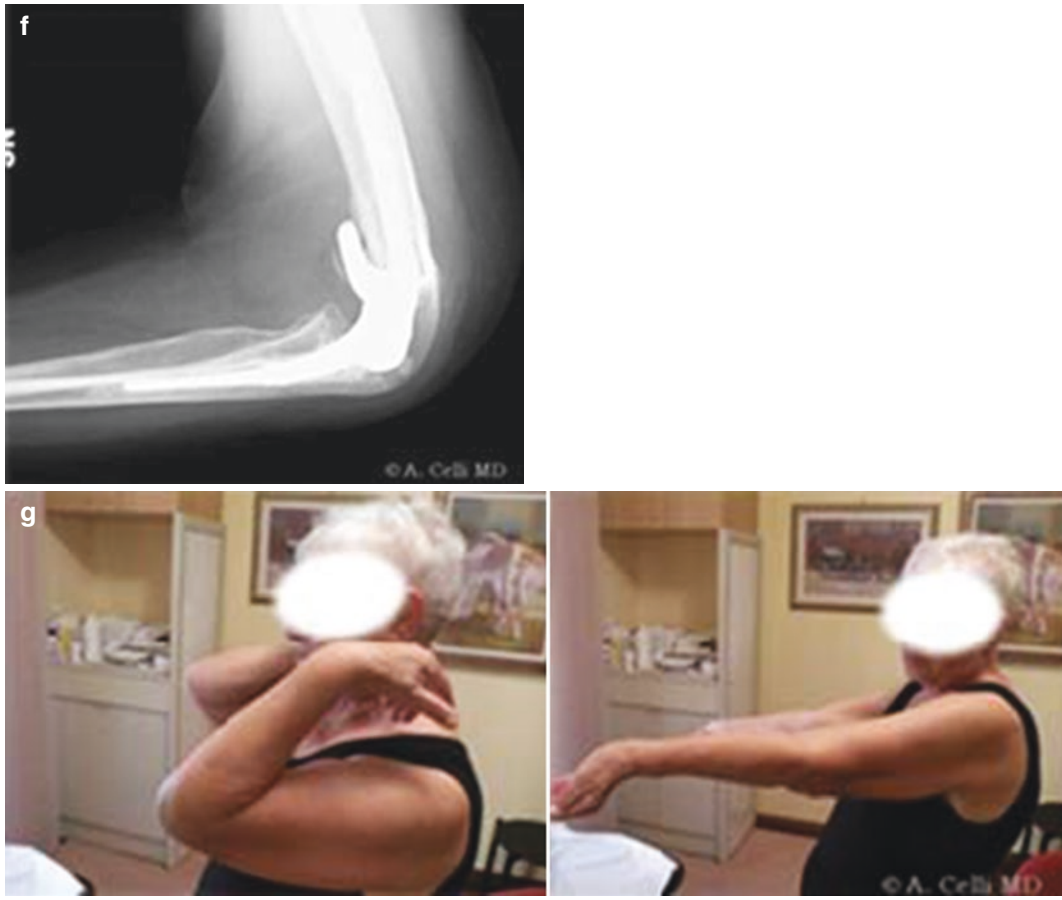

Fig. 10.1 (continued)

Results of TEA in *PTA* reported by Mayo Clinic in 1997 (41 patients) and Balgrist (16 patients) overall, 83% of all patients had a satisfactory objective outcome and 95% subjectively were satisfied with the operation. Preoperatively 90% of the patients had moderate to severe pain. After surgery 76% had no or mild pain. Using MEPS, 40% had an excellent result, 45% good, 10% fair, and 5% poor. At the follow-up, the mean arc of flexion-extension was 27–131° and mean arc of prono-supination 66–66°. On average, 4.8 out of the 5 activities of daily living could be performed by the patients [8]. Twenty consecutive patients with OA due to distal humeral and olecranon fracture malunion operated with TEA by the anconeus-triceps lateral flap approach are reported by Celli [9]. At a mean follow-up of 33 months, the mean Mayo Elbow Performance Score rose from 41.3 to 94.3. The mean pain score on the visual analog scale fell from 7.1 to 1.1. There were no patients with insufficiency, secondary detachment of the triceps tendon, or grade 4 to 5 of the Medical Research Council scale. These preliminary data suggest that preservation of the insertion of the medial portion of the triceps proper tendon enables earlier active rehabilitation. Moreover, the new approach provides optimum exposure of the olecranon also in patients with OA secondary to intra-articular fracture of the distal humerus and olecranon, where scarring and bone deformity usually hamper joint exposure. In PTA sometimes it is difficult to release articular extremities in anterior side from scar tissue and ossification (Fig. 10.2).

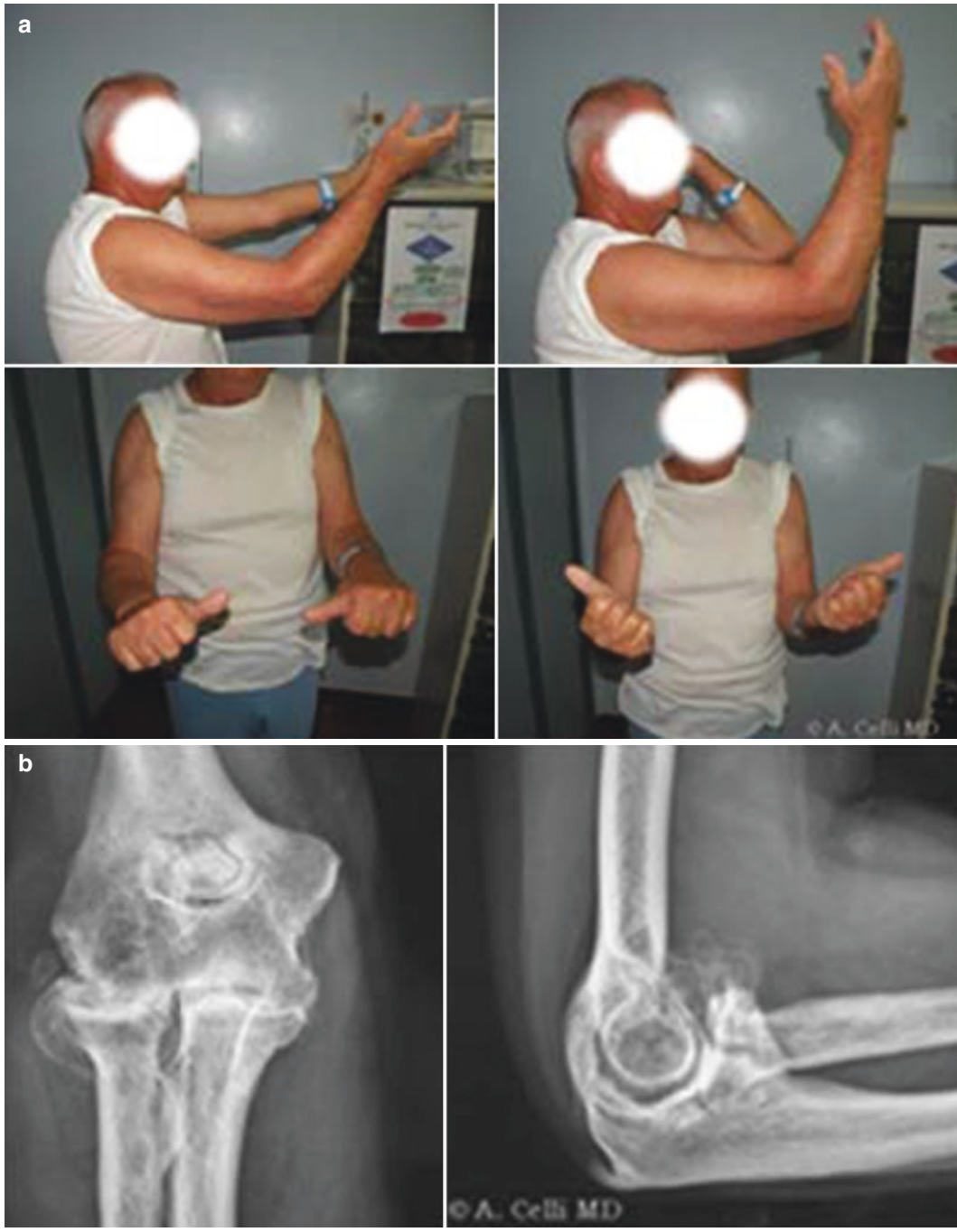

Fig. 10.2 Primary osteoarthritis (PO): (**a**) V.G., male, 72 years old retired. PO with severe stiffness and pain (VAS 6); (**b**) Rx of the right elbow; (**c**) intraoperative picture with erosion of cartilage; (**d**) linked total elbow arthroplasty; (**e**) follow-up of 2 years with good flexion, lack of 15° of extension and 20° of pronation; (**f**) pain free, he is able to put the hand on his head

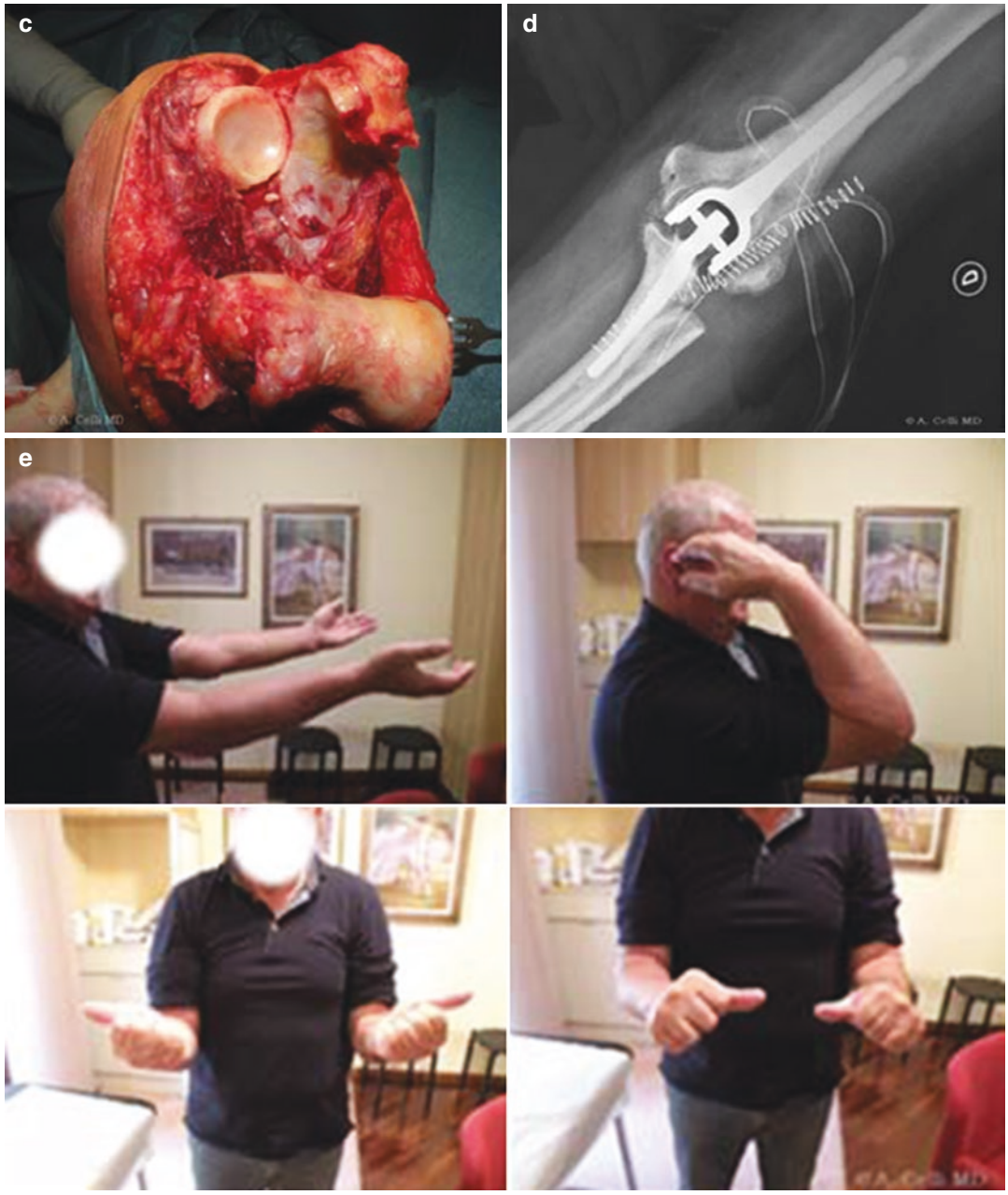

Fig. 10.2 (continued)

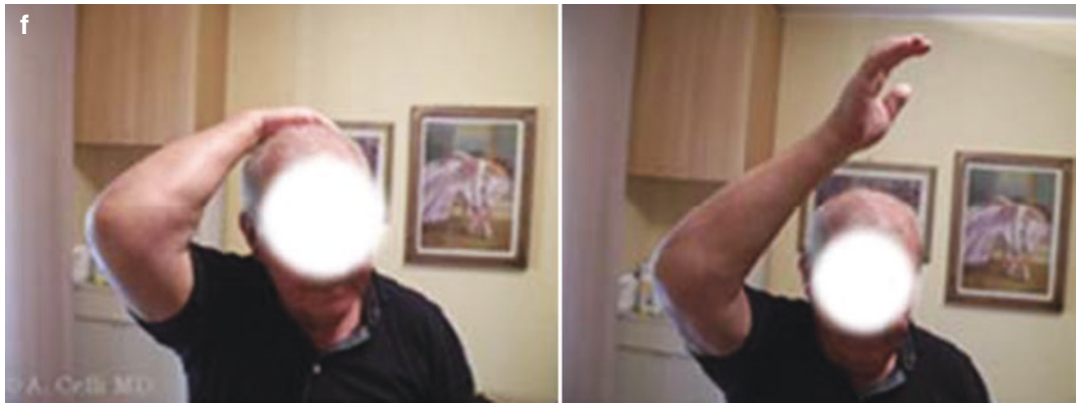

Fig. 10.2 (continued)

10.10 Complications

In TEA for *PO*, complications are frequent. Schoch and Morrey [10] reported complications in 9 of the 18 elbows studied. Minor complications occurred in seven elbows and did not require a return to the operating room (intraoperative fracture, cellulitis, hematoma, etc.), and three patients had acute major complications (fracture of the humeral component, debridement for suture intolerance). Late complications at follow-up at 10 years in three elbows have shown to have mechanically failed (periprosthetic humeral fracture, complete bushing wear) with an estimated survival, free of reoperation for any cause, of 89.4 at 10 years.

Other complications described in the literature and in systematic reviews are implant subluxation, heterotopic ossification, and ulnar neuropathy. Aseptic loosening was the prevalent reason for revision (38%), followed by deep infection (19%) and periprosthetic fractures (12%). Patients with PO tend to be active, and most are involved in manual occupations that place greater demands on the prosthesis and can cause fracture of humeral component or loosening from overuse.

In TEA for *PTA* many authors report a relatively high failure rate [11]. An understanding of these failures can lead to improved implant design and surgical technique.

In a recent paper of Mayo Clinic [12], 84 consecutive patients underwent 85 semiconstrained total elbow arthroplasties for the treatment of posttraumatic arthritis. Sixty-nine elbows with a retained primary prosthesis were followed for an average of 9 years. Clinical results were graded with use of the Mayo Elbow Performance Score. Radiographs were assessed for mechanical failure, and all complications were recorded. Sixteen primary arthroplasties (19%) failed. Causes of failure included isolated bushing wear (seven), infection (four), component fracture (three), and component loosening (two). The most common cause of early failure (failure after less than 5 years) was infection, whereas intermediate-term failure (failure after 5–10 years) typically was due to bushing wear. Late failure (failure after more than 10 years) was uncommon and involved component loosening or fracture. Seventy-five percent of the failures were in patients who were less than 60 years old at the time of surgery. Progressive radiolucent lines were noted around four implants, three of which had clinically important loosening. Total elbow arthroplasty was associated with significant improvements in terms of pain, motion, and the Mayo Elbow Performance Scores. Sixty-eight percent of the patients achieved a good or excellent clinical result, and 74% were subjectively satisfied. Kaplan-Meier analysis demonstrated a 15-year survival rate of 70% with revision or resection for any reason at the end point [12].

Among minor complications four heterotopic ossification of less than 1 cm in size with no clinical significance.

Heterotopic ossifications normally do not interfere with movement or limit active motion, but rarely they provoke a bridge from the humerus to radius with consequent ankylosis of the elbow. For this reason, we perform ever an anti-ossification therapy with indomethacin 50 mg/day for 20 days or celecoxib 200 mg/day for 3 weeks [11].

Cellulitis are treated with antibiotics.

Acute hematoma is possible with an insufficient or altered function of drainage (ever-useful two drainage, one anterior and one posterior).

10.11 Conclusion

Primary joint replacement in *PO* is indicated if the patient is older than 65 years and has aching discomfort most of the time, through the entire arc of movement and at night after using other nonoperative and operative techniques to improve symptoms. Careful attention to surgical technique to recover full extension in operative room and limited postoperative use, however, must be emphasized.

Posttraumatic arthritis (*PTA*) is often quite disabling due to pain and loss of motion; bone deficiency is common, and a flail limb may result from nonunion of a fracture. Such circumstances represent a relative contraindication to prosthesis. Unfortunately, there is no reliable alternative treatment. Fusion is not a good salvage procedure since the essential function of the elbow is to allow the hand to be placed in space by flexion and extension of the joint. Interposition arthroplasty, the traditional treatment for these conditions, has unpredictable results, and allograft replacement has as high complication rate as prosthetic replacement, with added risks of late deterioration. Prosthetic replacement, especially in the older age group, remains the best treatment. Nevertheless semiconstrained total elbow arthroplasty in patients with posttraumatic arthritis places high demands on the implant and is associated with a relatively high failure rate. Seventy-five percent of failures occur in patients less than 60 years of age, and infection continues to represent a frequent mode of early failure. Bushing wear and component loosening or fracture are seen more commonly in the intermediate and late term, whereas aseptic loosening remains relatively uncommon. At the beginning of TEA in PTA, elbow replacement was performed on some young patients, but as experience showed that failure was associated with youth for returning to strenuous labor or sport against the advice of surgeon, we later employed a more discriminative approach. We now impose strict limitations on the use of the limb; heavy work is not allowed, and a lifting limit of 4.5 kg is recommended. In this way prosthetic replacement of the elbow joint has continued to improve over time. Widespread implantation of certain designs has led to identification of a few successful elements of elbow arthroplasty, as well as several opportunities for improvement. Current hot topics in elbow arthroplasty include triceps-preserving exposures, implantation of components with better-expected wear performance, management of the ulnar nerve, prevention of infection, and the development of successful cementless components. Total elbow arthroplasty has the potential to improve pain, function, and quality of life for many patients with articular destruction secondary to degenerative arthropathy or as a consequence of trauma. Continued advances in this field are key to make this operation as reliable and lasting as hip or knee arthroplasty.

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11 Convertible Total Elbow Arthroplasty: Theoretical or Real Advantage?

Alessandra Colozza, Maurizio Fontana, and Shawn W. O'Driscoll

11.1 Introduction

Total elbow arthroplasty (TEA) is used to treat patients with severe degenerative changes of the elbow joint caused by rheumatoid arthritis (RA), inflammatory arthritis, osteoarthritis, or posttraumatic arthritis and also for distal humeral fractures and nonunions. The aim of the procedure is giving to the patient a functional, pain-free joint. Commercially available prostheses have traditionally been with linked or unlinked. There are advantages and disadvantages to both concepts. A more recent concept has become available in which the surgeon does not need to choose between the two options but can use a convertible implant. Convertible implants are versatile and allow the surgeon to convert from unlinked to linked arthroplasty intraoperatively or later at the time of a revision procedure.

11.2 Design Consideration

The term "unlinked" is preferred over the term "unconstrained" because total elbow arthroplasties (TEA) all have varying degrees of intrinsic constraint by virtue of the shape and interaction of their articular surfaces. In fact, a TEA may be highly constrained despite being unlinked. Kaminemi et al. documented this in an in vitro biomechanical study comparing five TEA implants and demonstrated that intrinsic constraint varied markedly according to the articular geometry [1]. The main advantage of unlinked implants is decreased stress transmission to the bone-cement and cement-prosthesis interface. Forces are absorbed by soft tissues (capsule, ligaments, and muscles) surrounding the prosthesis. Theoretically, this reduction in force transmission across the prosthetic articulation would result in reduced polyethylene wear and loosening rates. However, imperfect balance and component maltracking, due to uncorrected angulation or rotation, can lead to asymmetric polyethylene loading, decreased joint surface contact area, and increased wear. Of course, such imbalance can also predispose to instability of the joint.

Linked prostheses, often referred to as semi-constrained TEAs, have the ulnar and humeral components mechanically connected: dislocation and instability can only occur if the coupling mechanism fails (which indeed does happen). The disadvantage of linked prosthesis is that they have the potential to transfer larger stresses across the coupling mechanism and to the prosthesis-cement-bone interface. However, any stability derived from the remaining soft tissue will decrease the load on the linkage mechanism.

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Fully constrained (or so-called fixed hinge) implants are not used anymore [2].

Factors that might affect the surgeon's choice of implant include preoperative status of the bone and soft tissue and any potential for instability.

Bony condition: bone stock quality (osteopenia in RA or other inflammatory conditions), bone deformity (supracondylar nonunion), column integrity or chance to reconstruct them (column nonunion (Fig. 11.1), distal humerus fracture (Fig. 11.2)), and laxity secondary to skeletal shortening.

Soft tissue condition: ligament deficiency (posttraumatic or rheumatic cases), biceps or triceps muscular incompetence, or rupture.

In some cases in which an unlinked implant is thought preferable following preoperative planning, intraoperative conversion (or linking of a convertible implant) might be necessary. In posttraumatic stiff elbows, preoperative evaluation of ligament integrity is sometimes difficult, and instability can be underestimated because of the contracture. Circumferential arthrolysis is necessary to recover motion, and after doing so, instability can become evident. In these circumstances it is always desirable to have a linkable implant immediately available in the operating room, so the surgeon can shift from an implant to another. If unlinked and linked implants have a different design and instrumentation, repeat bony preparation is necessary, which is time-consuming. Furthermore, if instability is detected after component cementation, possibility to couple an unlinked prosthesis without removing the stems makes a convertible implant system even more appealing. Convertible prostheses give the advantage that to link the implant, a simple connection mechanism is applied on the components previously chosen, rather than changing prosthesis for another design [3]. Another advantage of a convertible implant is that the use of a single implant is helpful for the surgeon, for whom the learning curve is facilitated, and for hospitals, for easier management of inventories.

Another situation in which having a convertible system is very useful is when conversion

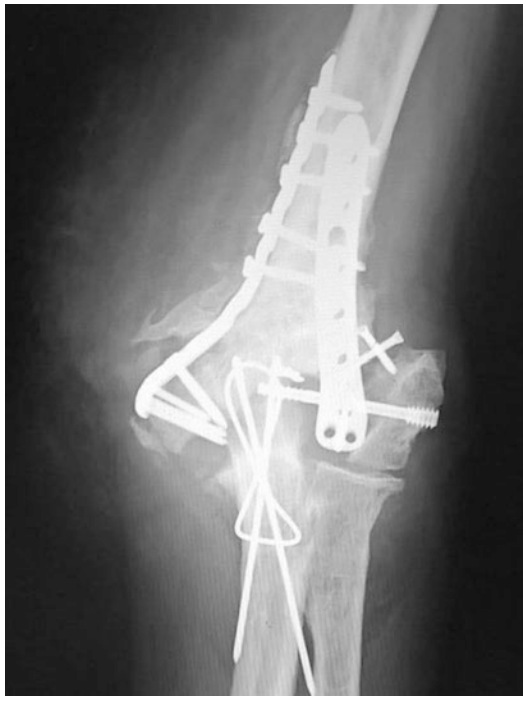

Fig. 11.1 Supraintercondylar nonunion. Patient presents gross varus instability due to lateral column nonunion

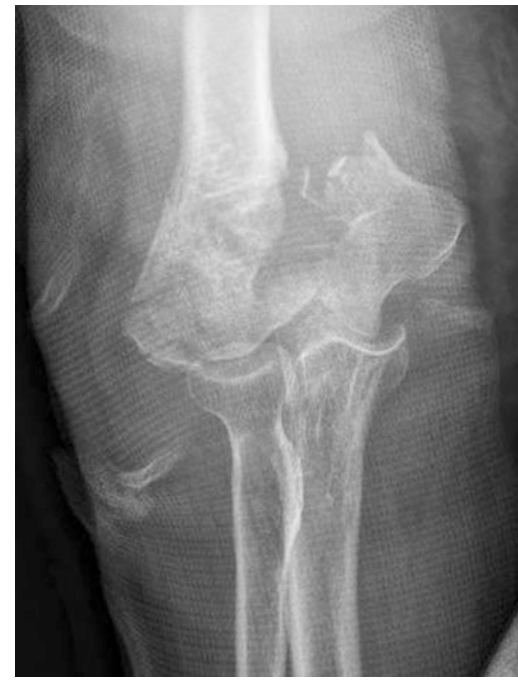

Fig. 11.2 Distal humeral fracture, both columns are involved by the fracture

from hemiarthroplasty to TEA is indicated. Hemiarthroplasty is becoming popular in Europe in treating comminuted distal humeral fracture or other conditions that affect distal humerus (nonunion, avascular necrosis) [4]. In the literature, there is evidence of reabsorption due to joint surface mismatch, with consequent pain [5]. In those cases, switching to a total elbow arthroplasty is necessary. Convertible implants make the procedure easier: the humeral stem does not need to be removed. The ulnar component is positioned, and the surgeon can choose between unlinked and linked implant, based on intraoperative instability of the elbow.

11.2.1 Radial Head

If the TEA design includes a radial head component, the radial head is generally replaced if it is arthritic (such in rheumatoid arthritis) but is often retained if it is intact as in some posttraumatic osteoarthritis or acute distal humeral fracture cases. It can be use as autologous graft in possible future revisions. In unlinked arthroplasty, balance of the joint is crucial. Radial head is essential for elbow valgus instability, mainly if medial collateral ligament is insufficient [6–8]. If the radial capitellar joint is not congruent, due to radial head maltracking, radial head replacement should not be performed, and the arthroplasty should be converted to a linked one [9]. Bipolar radial heads theoretically can better compensate for abnormal radiocapitellar joint kinematics, but they are also prone to uncoupling in such circumstances [3, 9]. In the absence of a radial head (prosthetic or native), some surgeons would recommend linking the prosthesis to prevent excessive valgus laxity and potential instability [10]. The senior author has not generally considered absence of a radial head to be an absolute indication for linking.

11.2.2 Latitude EV Implant

The Latitude EV implant (Tornier, Wright Medical, Texas) is the only convertible system available on the market at the time of this writing [2] (Fig. 11.3). The humeral and ulnar components

Fig. 11.3 Latitude implant (*Courtesy of Tornier Inc., Stafford, TX; with permission*)

are the same whether used for linked or unlinked applications. When the components are left unlinked, a short-stem ulnar component is typically used, while a standard-stemmed ulnar component is recommended when linking the prosthesis, because more forces are transmitted to the implant-cement-bone interface. Design characteristics are the following:

1. The lateral column can be preserved by retaining or replacing the native radial head.
2. The polyethylene ulnar articular surface is 8 mm thick anteriorly and 3 mm thick posteriorly, because joint reactive forces are concentrated anteriorly.
3. The prosthetic flexion extension axis is cannulated so that a heavy nonabsorbable suture can be passed through it and through the ulna as a temporary ligament linking the ulna and humerus to prevent instability until the ligaments have healed. It also facilitates repair of the humeral origins of the ligaments.
4. Locking cap to link the component, if necessary.

De Vos and others studied on cadavers varus and valgus laxity of the Latitude prosthesis in unlinked and linked models while preserving, excising, or replacing the radial head. Valgus laxity is decreased at 60° or more of flexion and in near full extension. Valgus stability is increased by linking the prosthesis. In the linked version, the radial head plays a small role in both varus and valgus stability. Unlinked implant is not advised by De Vos et al. in absence or inability to replace the radial head [10].

11.3 Instability After Tea

11.3.1 Implant Instability

Postoperative instability is one of the major complications with unlinked elbow arthroplasty, with reported rates ranging from 0% to 13% [11, 12]. Instability can range from slight maltracking called "jumped runners" (humeral and ulnar component are mismatched) to recurrent dislocation. Reported risk factors for instability are previous radial head resection, synovectomy, and lateral collateral ligament attenuation due to inflammatory disease or previous surgery [13, 14].

11.3.1.1 Classification [11]

Instability can be classified as immediate, early, or late.

"Immediate" instability (before hospital discharge) is typically related to component malpositioning.

"Early" instability ranges from the discharge from the hospital to 6 weeks postoperatively. It's often due to component malpositioning, insufficiency of ligaments (repetitive varus stress), or muscle deficiency (triceps failure).

"Late" instability: after 6 weeks. It can be related to component malpositioning, polyethylene wear, and trauma.

11.3.1.2 Causes of Instability

Implant design: as previously analyzed, unlinked implants have varying degrees of intrinsic stability due to component design. Implants can have a shallow articular contour in the ulno-humeral articulation or a deeper groove that can increase stability. The presence of a radial head prosthesis improves valgus stress and rotational stability of the elbow.

Surgical approach: With an unlinked implant soft tissue (ligament and muscular), competence is crucial to avoid implant instability. An intact triceps muscle-tendon unit is required for stability of an unlinked TEA. Therefore, any posterior approach that interrupts the triceps (by reflecting, detaching, or splitting it or by creating a tongue) puts the elbow at risk for instability if the triceps does not heal. Lateral approaches involve detaching the lateral collateral ligament, which must be repaired, protected against gravitational varus stress, and ultimately healed for instability to be prevented. The anterior bundle of the medial collateral ligament is sometimes inadvertently detached from sublime tubercle during proximal ulna preparation. Failure to recognize this and repair it might lead to instability.

Surgeon: Malpositioning of components results in incorrect position of implant axis and consequent maltracking and instability. For the humeral component, proximal-distal positioning and rotation of the axis of flexion-extension must be checked. In the original version of the Latitude, the anteroposterior offset was also separately selected. The Latitude EV offers only one anteroposterior offset, with the possibility of being wrong by up to 2 mm. For the ulnar component, valgus and mediolateral position and rotational alignment are the variables that have to take into account. Soft tissues need to be repaired properly. TEA instability related to component malpositioning or soft tissue deficiency can lead to wear and loosening. Futai et al. studied three-dimensional kinematics of unlinked total elbow arthroplasty in vivo. They analyzed 57 elbows (51 patients) who underwent an unlinked Osaka University Model Total Elbow System (OU-Elbow) under fluoroscopic examination in sagittal plane. Results show that humeral alignment influences the kinematic: the contact area of polyethylene decreases if the axis is more valgus. Valgus and internal rotational malalignment >10% can cause edge loading and increases risk of polyethylene wear and subluxation [15].

Patient: Significant bone loss, ligament incompetence, and tendon deficiency are risk factors for instability with unlinked implants. Intraoperative instability may be different than expected through preoperative evaluation. This can occur with severe elbow contracture that mimics a stable elbow, and instability becomes evident after soft tissue release. Therefore instability can be underestimated.

Postoperative management: Gravitational varus stress must be avoided in the postoperative period. Varus stretches the lateral collateral ligament with consequent posteromedial and posterolateral rotatory instability.

11.3.1.3 Evaluation

On physical examination, the posterolateral rotatory drawer test and varus stress are performed to detect lateral collateral ligament status. Stress radiograms or evaluation under anesthesia is useful to assess varus, valgus, posteromedial, or posterolateral rotatory instability. Wagener et al. assessed stability of the medial collateral ligament pre- and postoperatively testing the elbow at 60° of flexion: the joint was stressed in valgus overload. Instability was classified by the amount of medial side joint opening as grade 0, no instability; grade 1, mild instability; grade 2, moderate instability; and grade 3, severe instability. The aim of evaluation and classification was to compare pre- and postoperatory (after TEA) elbow stability [16]. Plain radiograms show component malpositioning or malalignment of radial head.

11.3.1.4 Treatment [11]

Treatment of the unstable elbow arthroplasty is determined by the timing of instability (immediate, early, and late) and causes.

In early phases from surgery, it can be approached by *closed reduction and immobilization* to allow ligament healing. Correct component positioning is the prerequisite for conservative treatment. Closed reduction is made under anesthesia, and the elbow is evaluated as previously described. If the elbow is stable at more than 60° of flexion, a cast immobilization is considered for 3 weeks.

If the elbow is grossly unstable after reduction and components are positioned correctly, *soft tissue repair* should be considered. Anchors or nonabsorbable sutures are used. Triceps is reattached to the olecranon if it is avulsed. Adequate tissue for the repair or reconstruction is needed. If instability is chronic (more than 6 weeks), ligament reconstruction using a graft (auto- or allografts) is necessary. Standard technique must be adapted to avoid impingement with the implant [17].

If the cause of instability is component malpositioning, one or both the components should be revised. Often stems are well fixed, and removal of the implant and cement is a complex procedure with a high risk of complication, such as humeral or ulnar perforation. If *revision* of an unlinked prosthesis is considered, conversion to a linked system has more predictable result, rather than component revision and ligament reconstruction. Consequently, having a system that easily converts from unlinked to linked is

attractive. With a convertible system, conversion can be performed at the time of the initial arthroplasty or at a subsequent revision procedure.

Conversion technique: The approaches commonly used are triceps on and triceps tongue approach. Surgical approaches are described elsewhere (Chap. 5) [18]. Triceps on approach gives the advantage of early postoperative active motion, and extensor mechanism-related complications are decreased. Triceps tongue approach allows better visualization of the joint surfaces. If a triceps on is used, Chafik et al. suggest a 1–2 cm longitudinal split in the triceps tendon, proximal to its insertion, to improve proximal ulnar visualization and preparation. If a linked implant is chosen, this exposure and flexion of the elbow to about 90° is required to insert the ulnar cap and the screw (Figs. 11.4 and 11.5). At the end of the procedure, nonabsorbable sutures should be used to close the triceps incision as a marker for the triceps split location. The same approach can be used if the implant needs to be linked or unlinked in the future [2]. Linkage of the implant is performed after the cement is cured to avoid component displacement and suboptimal cement bonding [9].

11.3.1.5 Clinical Reports

In the experience of the senior author (S O'Driscoll), who is a designer of the Latitude TEA, 81 cases were performed using the Latitude or Latitude EV in the unlinked mode from 2001 to 2016. There were no dislocations or recurrent dislocations. One patient was converted from unlinked to linked for recurrent subluxation, and two patients had failure of the triceps mechanism and were converted from unlinked to linked at the time of triceps repair. Some of the cases were revisions, and some had significant bone loss, contractures, angular

Fig. 11.4 Ulnar cap to convert from unlinked to linked implant (*Courtesy of Tornier Inc., Stafford, TX; with permission*)

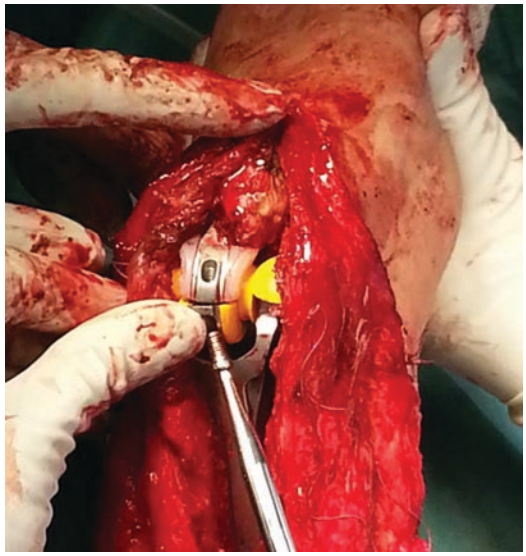

Fig. 11.5 Ulnar cap positioning in a revision procedure (trial)

malalignment, no radial head, or a combination of these apparent risk factors. The author attributes the low instability rate to three factors: (1) the extended coronoid prominence of the prosthesis, which makes dislocation difficult, (2) the use of the temporary ligament (FiberWire suture through the humeral prosthesis linking the ulna and humerus together while the ligaments heal, and (3) the use of a surgical approach in which the ligaments are detached from the ulna instead of the humerus.

Wagener et al. reported a 69 TEAs series (in 63 patients) using a triceps tongue approach. Conversion from unlinked to linked Latitude was made in two cases. In both the patients, instability onset after 3 years was treated by implanting the link component. Only in one patient instability has improved and pain decreased and satisfaction increased in both. Both the patients were affected by rheumatoid arthritis [16].

Leclerc et al. reported a case of conversion in a 59-year-old woman with rheumatoid arthritis originally treated using an unlinked TEA (Latitude). After 6 months the patient presented with instability due to both ligaments not healing and radial head polyethylene dislodgement. The implant was converted to linked by adding the ulnar cap [9].

11.4 Conclusions

Instability of unlinked TEA is a potentially severe complication. This problem needs to be approached accurately, understanding timing and causes of instability. Little is documented concerning the role and efficacy of noninvasive or minor surgical solutions such as closed reduction, casting, and ligament reconstruction. Unfortunately, implant revision puts the patient at significant risk of very serious complications. Convertible implants give the chance to the surgeon to solve the problem with an easy and less traumatic procedure. The authors think that this is a valuable technical option.

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12 Infection Management in Total Elbow Replacement: Do Effective Guidelines Exist?

Celli Andrea, De Luise Guglielmo, and Celli Luigi

12.1 Introduction

Total elbow joint replacement, a safe and effective procedure that restores function and enhances patients' quality of life, is increasingly used to treat post-traumatic arthritis and chronic inflammatory joint disease [1]. After its development in the early 1970s [2], elbow arthroplasty has undergone continuous improvement in terms of implant design as well as surgical technique. Outstanding challenges include aseptic (mechanical) prosthesis loosening, joint instability, ulnar neuropathy, and periprosthetic joint infection (PJI) [3–10].

Infection after total elbow arthroplasty (TEA) is a severe complication with reported rates ranging from 1.9% to 13.3% [9–13]. The recent literature has highlighted a reduction in the infection rate. This may be related to a number of improvements in the surgical technique, such as better tissue handling and incision selection, decreased tourniquet time, early postoperative immobilization, and use of antibiotic-impregnated cement. This notwithstanding, the infection rate after TEA is still markedly higher than those related to hip or knee arthroplasty [5, 6, 8–10].

Other reasons for such higher incidence include the facts that the elbow is a subcutaneous joint with a thin soft tissue envelope. Moreover, some patients are immunocompromised due to the drugs used to treat their primary disease, e.g., rheumatoid arthritis (RA) or traumatic arthritis, and the soft tissue envelope may be of poor quality due to medications or previous surgical procedures.

Infections can arise from direct inoculation into the joint, for instance, due to ulceration of the thin posterior skin, entry of organisms into the wound during surgery, hematogenous spread and recurrence of sepsis after a previous local infection, or contiguous spread of infection from a local source [13, 14]. Patients with RA may be particularly susceptible, due to a history of corticosteroid or immune-modulating medications.

The most frequent infecting microorganism is *Staphylococcus aureus* followed by *Staphylococcus epidermidis*, although gram-negative organisms are not uncommon [5, 6, 15].

12.2 Clinical Signs

The clinical signs of TEA infection largely depend on organism virulence, mode of initiation, host immune response, and structure of the periarticular soft tissues. Commonly reported signs and symptoms include pain, joint swelling or effusion, erythema or warmth around the joint, fever, drainage, a sinus tract communicating with the prosthesis (Fig. 12.1), and radiolucent lines around the implant on radiographs.

Infection may be diagnosed in the presence of one or more of the following criteria:

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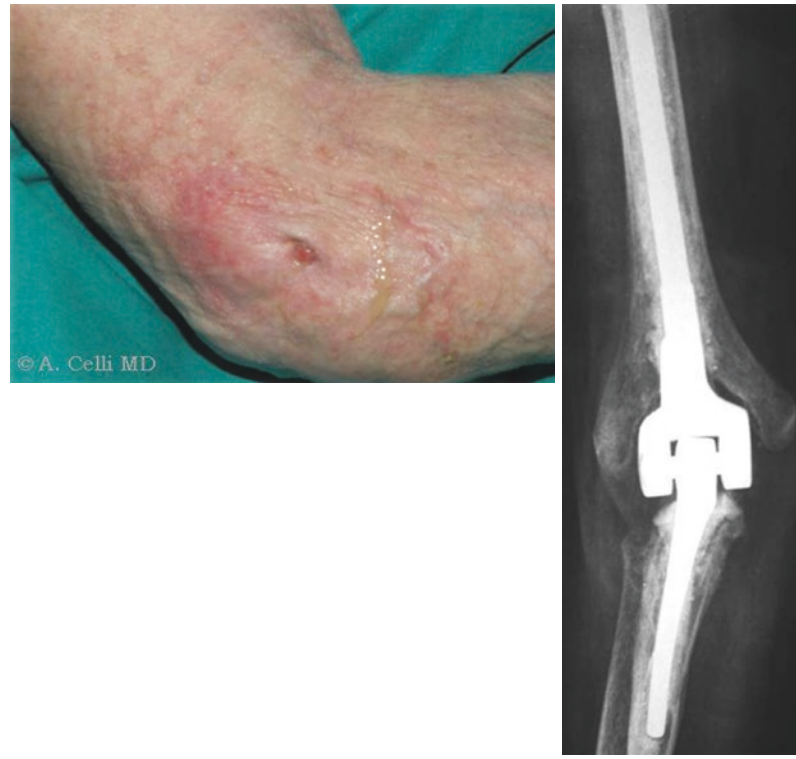

Fig. 12.1 Sinus tract communicating with the prosthesis

1. Visible purulence of the preoperative aspirate or of intraoperative periprosthetic tissue.
2. Presence of a sinus tract communicating with the prosthesis.
3. Microbial growth in the preoperative joint aspirate, in intraoperative periprosthetic tissue, or in sonication fluid of the explanted device.
4. >1700 leukocytes/L or >65% granulocytes in synovial fluid, as determined in previous studies for total knee arthroplasty [16, 17]
5. Elevated serum C-reactive protein and erythrocyte sedimentation rate, elevated synovial fluid white blood cell count, and elevated polymorphonuclear neutrophil percentage in synovial fluid.

12.3 Diagnostic Imaging

Plain radiographs should be obtained in all patients with suspected PJI (Fig. 12.2).

Magnetic resonance imaging (MRI) and computed tomography (CT) have a direct role in diagnosis but can also help identify other causes of joint pain/failure [18–24].

CT and MRI have the advantage of high resolution and allow evaluating signs of periprosthetic tissue infection. One study has found that CT was highly sensitive (83%) and specific (96%) in detecting joint distention in patients with suspected hip prosthesis infection [23]. The use of these techniques is limited by imaging artifacts due to the metal prosthesis. In addition, MRI can be performed only with certain metals, such as titanium or tantalum. Adjustments in the image acquisition parameters can lessen but not abolish these artifacts.

Three-phase bone scintigraphy is one of the most widely used imaging approaches to diagnose PJI. In this technique, a radioactive isotope is attached to a compound that preferentially collects in bone and accumulates in areas characterized by high metabolic activity, emitting gamma

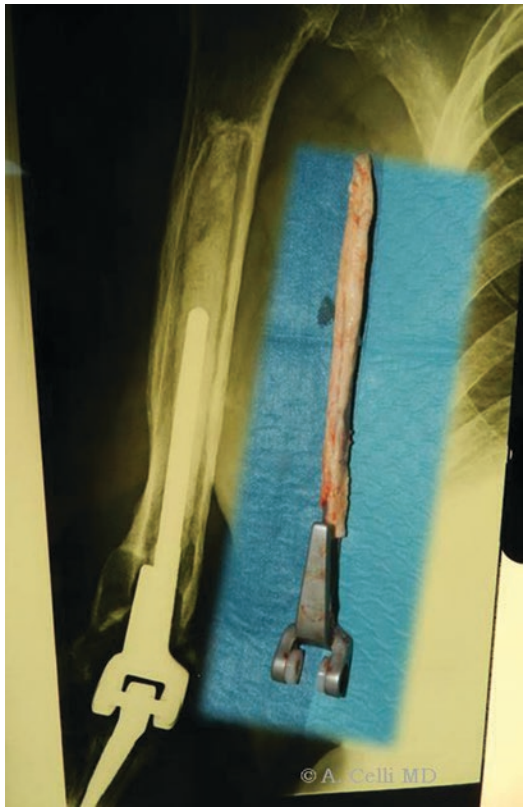

Fig. 12.2 Plain radiographs should be obtained in all patients with suspected of component loosening

rays that can be detected by a gamma camera. Uptake intensity after injection of the agent is measured in the circulation (immediate), in the blood pool (15 min), and at a later time point (2–4 h) [20]. A limitation of the technique is lack of specificity, since uptake is frequently detected in asymptomatic patients by delayed-phase imaging in the first 1–2 years after implantation [21].

Other imaging modalities may be performed in conjunction with bone scintigraphy to increase specificity. Radioactive 111 in is frequently used to label autologous leukocytes, which are then injected; images are then obtained at 24 h. A positive scan typically documents uptake of the labeled leukocytes and no or reduced uptake at the same location on the late-phase scan [22, 23].

[18F]Fluoro-2-deoxyglucose positron emission tomography (FDG-PET) is widely used in cancer care and treatment and has emerged as a diagnostic modality for PJI. A meta-analysis of 11 studies involving 635 prosthetic hip and knee arthroplasties has found that FDG-PET had pooled sensitivity and specificity values of 82.1% and 86.6%, respectively, for PJI diagnosis [24]. A limitation of this technique is its high cost.

12.4 Time of Presentation

PJI of the elbow has been divided:

- Into three types according to the interval from surgery to the appearance of the first signs and symptoms [25, 26]:
- early infection, developing within the first 3 months of surgery; delayed infection, appearing between 3 months and 2 years; and late infection, arising at more than 2 years
- Into three types according to the route of infection: perioperative, through microorganism inoculation into the surgical wound during surgery or immediately thereafter; hematogenous, through blood or lymph spread from a distant focus of infection; and contiguous spread, from an adjacent focus of infection (e.g., penetrating trauma, preexisting osteomyelitis, skin and soft tissue lesions).

12.5 Causative Microorganism

- ***S. aureus***. It is an important pathogen due to its virulence and frequency and one of the most common causes of serious invasive infections of total prostheses, including nosocomial and healthcare-associated bloodstream infections, which can subsequently lead to deep infection [27–30].
- **Coagulase-negative *Staphylococcus* species.** A number of species comprise the microorganisms defined as coagulase-negative staphylococci. Several are ubiquitous members of the human microbiome found on the skin. *S. epidermidis* is the most frequently identified member of this group, which causes total joint arthroplasty infection primarily through its ability to adhere to prosthetic materials and to produce biofilm [31–33].

- ***Streptococcus* spp.** *Streptococcus* is a diverse genus with a prominent role in human disease, but it causes less than 10% of total arthroplasty infections. A number of beta-hemolytic *Streptococcus* species cause deep infection [34, 35].
- ***Enterococcus* spp.** enterococci are infrequent causes of total arthroplasty infection; they account for up to 12–15% of cases of early-onset deep infection, often as part of polymicrobial infections [36, 37].
- **Aerobic gram-negative bacilli.** Similar to enterococci, aerobic gram-negative bacilli are more common in early-onset prosthetic infections, where they are found in up to 45% of cases in some studies [36, 37] bial infections [38] and may be a cause of hematogenous infection, which tends to be monomicrobial [39].
- ***Propionibacterium acnes*.** This anaerobic, gram-positive bacillus, characterized by relatively low virulence, is normally found on human skin and sebaceous glands and is typically inoculated at the time of surgery. It is a cause of infection in shoulder prostheses more often than in other joints, due presumably to the proximity of the axilla [40, 41].
- **Other bacteria.** Case reports and a small case series have described a myriad of other less common bacterial causes of prosthetic infection. Several *Corynebacterium* species have been implicated as a cause of deep infection [42–45].
- **Fungi.** Less than 1% of prosthesis infections are caused by fungi. Among these, *Candida* spp. are responsible for at least 80% of cases [46, 47]. Concomitant bacterial infection occurs in 15–20% of cases.
- **Culture-negative infection.** Patients with culture-negative arthroplasty infection have non-microbiological evidence of infection, such as periprosthetic purulence, acute inflammation as determined by histopathology, or a sinus tract communicating with the joint, without a causative microorganism. The main risk factor for culture-negative prosthetic infection is previous antimicrobial therapy [48].

12.6 Microbiological Diagnosis

Fluid aspirate (Fig. 12.3) and intraoperative tissue (more than three but no more than six distinct samples should be sent for aerobic and anaerobic culture) were cultured, the isolated microorganisms were identified, and their antimicrobial susceptibility was tested by standard microbiological techniques [25, 26].

Aspirated fluid and intraoperative periprosthetic tissue specimens were cultured on aerobic and anaerobic blood agar and incubated at 35 °C for 8–10 days.

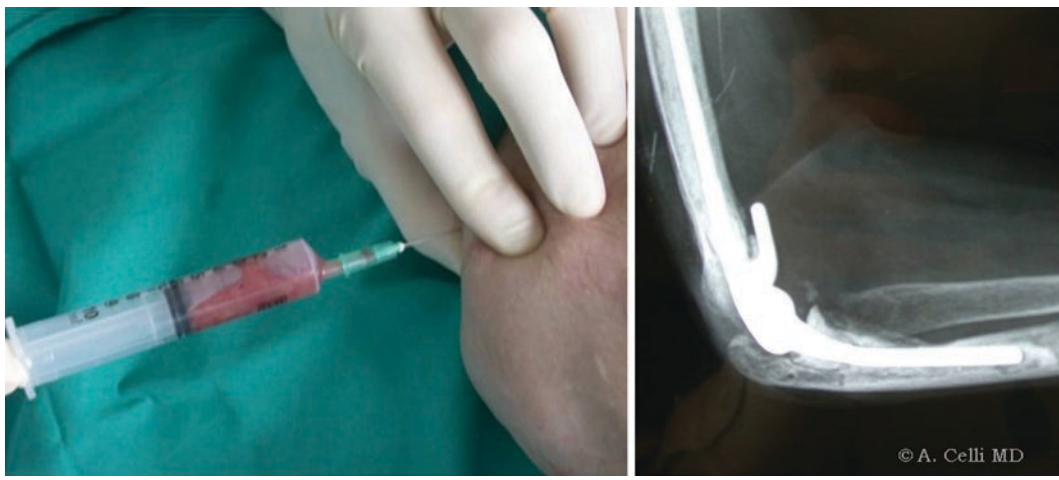

Fig. 12.3 Intra-articular fluid aspiration should be sent for aerobic and anaerobic culture

In addition, bone and soft tissue and explanted elbow prostheses were sent for sonication to improve the detection of biofilm-forming bacteria [49]. The explanted elbow prostheses were aseptically removed in the operating room and transported to the microbiology laboratory (Fig. 12.4). Ringer's solution was added in the containers, and the prostheses were processed within 48 h of removal by vortexing (30 s) and sonication (1 min) using an ultrasound bath (Ultrasonic Bath 5.4 L Usl 500 t VWR, Belgium). The sonication fluid was vortexed again to achieve a homogenous distribution and plated onto aerobic and anaerobic sheep blood agar plates. Cultures were incubated at 37 °C for 8–10 days and inspected daily for bacterial growth (Fig. 12.5).

Fig. 12.4 The explanted elbow prostheses were aseptically removed in the operating room and transported to the microbiology laboratory

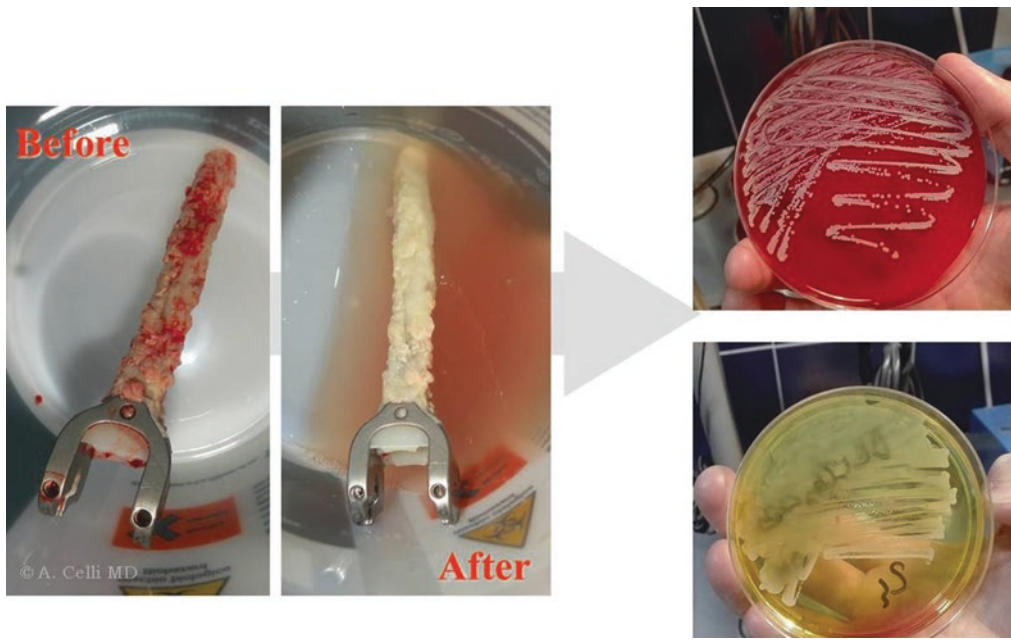

Fig. 12.5 The sonication fluid was vortexed again to achieve a homogenous distribution and plated onto aerobic and anaerobic sheep blood agar plates. Cultures were incubated at 37 °C for 8–10 days and inspected daily for bacterial growth

12.7 Key Points

In patients undergoing revision elbow arthroplasty, infection should always be excluded prior to or at the time of surgery.

No single diagnostic test has sufficient accuracy to detect prosthetic elbow joint infection; therefore, a combination of preoperative and intraoperative tests is needed for diagnosis.

Inflammatory marker serology is useful to identify patients who benefit from more invasive diagnostic procedures.

The optimization of traditional tissue culture and biofilm-dislodging techniques has improved the identification of the causative agent [50].

12.8 Treatment Options

The goal of treatment of prosthetic joint infection is to eradicate biofilm-dwelling microorganisms while preserving joint function and patient quality of life.

12.8.1 Antibiotic Treatment

Previous antibiotic therapy increases the risk of culture-negative prosthetic joint infection [49–52]. Therefore, antibiotic treatment should not be started until multiple intraoperative specimens have been collected, except in the case of septic joints, where treatment should not be delayed. In patients with delayed or late infection, who have been administered antibiotics before the intraoperative culture results, definitive surgery may be delayed by 2–4 weeks after the end of the antibiotic course.

The antibiotic therapy is based on culture findings and is monitored by the infectious disease specialist (Table 12.1) [25, 26, 53, 52].

12.8.2 Surgical Treatment

The type of revision was chosen among three approaches: (1) debridement and implant retention, (2) one-stage removal, or (3) two-stage removal (Table 12.2).

Table 12.1 Antibiotic treatment of the prosthetic joint infections (modified from Zimmerli et al. [26, 53])

(a) Staphylococcus aureus or coagulase-negative staphylococci
• Methicillin-susceptible:
– Rifampicin plus 450 mg every 12 h PO/IV
– (Flu)cloxacillin 2 g every 6 h IV
For 2 weeks, followed by
– Rifampicin plus 450 mg every 12 h PO
– Ciprofloxacin or 750 mg every 12 h PO
– Levofloxacin 750 mg every 24 h PO to 500 mg every 12 h PO
• Methicillin-resistant
– Rifampicin plus 450 mg every 12 h PO/IV
– Vancomycin 1 g every 12 h IV
For 2 weeks, followed by
– Rifampicin plus 450 mg every 12 h PO
– Ciprofloxacinr 750 mg every 12 h PO
– Levofloxacin 750 mg every 24 h PO to 500 mg every 12 h
– Teicoplanin 400 mg every 24 h IV/IM
– Fusidic acid 500 mg every 8 h PO
– Cotrimoxazole 1 forte tablet every 8 h PO
– Minocycline 100 mg every 12 h PO
***(b) Streptococcus* (except *S. agalactiae*)**
• Penicillin G2 or five million U every 6 h IV
• Ceftriaxone 2 g every 24 h IV
For 4 weeks, followed by
– Amoxicillin 750–1000 mg every 8 h PO
***Enterococcus.* (penicillin-susceptible)**
• Penicillin G or five million U every 6 h IV
• Amoxicillin 2 g every 4–6 h IV
For 2 to 4 weeks, followed by
– Amoxicillin 750–1000 mg every 8 h PO
Enterobacteriaceae (quinolone-susceptible)
– Ciprofloxacin 750 mg every 12 h PO
– Cefepime or ceftazidime plus 2 g every 8 h IV
For 2 to 4 weeks, followed by
– Ciprofloxacin 750 mg every 12 h PO
Anaerobes
– Clindamycin 600 mg every 6–8 h IV
For 2 to 4 weeks, followed by
– Clindamycin 300 mg every 6 h PO
***(c) Mixed infections* (*without methicillin-resistant staphylococci*)**
– Amoxicillin/clavulanic acid 2.2 g every 8 h IV
– Piperacillin/tazobactam 4.5 g every 8 h IV
– Imipenem 500 mg every 6 h IV
– Meropenem 1 g every 8 h IV
For 2–4 weeks
Followed by individual regimens
According to antimicrobial susceptibility

Antimicrobial agent, dose, route PO = orally; IV = intravenously; IM = intramuscularly

Table 12.2 The type of revision was chosen according to the conditions

Condition	Surgical procedure
Duration of symptoms >3 weeks + Stable implant + Absence of sinus tract + Susceptibility to antibiotics	Debridement with retention of the components
Loosening of one the components with intact or only slightly damaged soft tissue	One-stage exchange
Loosening of the components with damaged soft tissue and sinus tract	Two-stage exchange with short interval (2–4 weeks) with spacer
Microorganism resistant or difficult-to-treat	Two or more stages exchange with long interval (6–8 weeks)
No functional improvement by exchange of the implant	Implant removal without replacement

Retention is allowed only if all the following conditions are met:

1. Short duration of the infection, including early postoperative infection (within 3 months of surgery) or acute hematogenous infection.
2. Short duration of clinical signs (not longer than 21 days).
3. No severe damage to surrounding soft tissue.
4. Availability of antimicrobial agents active against biofilms.

If one or more of these conditions was not fulfilled, retention was considered inappropriate and the implant was removed.

The procedure was performed in a single stage in patients with intact soft tissues and infection with organisms that were not difficult to treat or in two stages in the other cases. Difficult-to-treat organisms included rifampin-resistant staphylococci, enterococci, nutritionally variant streptococci, and fungi [25, 26] (Table 12.1).

12.9 Irrigation and Debridement with Component Retention

Patients selected for irrigation and debridement should have a short symptom duration, a stable implant, no sinus tract, acute infection for less than 3 months, well-fixed components, and not highly virulent infecting organisms.

If the agent is resistant or difficult to treat, e.g., methicillin-resistant *S. aureus* (MRSA), small-colony variants of staphylococci, enterococci, or fungi, two-stage revision is preferred. Notably, radiolucency around the implant in the absence of mechanical loosening does not appear to predict treatment failure.

The presence of a sinus tract has been associated with an increased risk of treatment failure, likely reflecting symptom duration and the quality of periprosthetic soft tissues.

Patients where irrigation and debridement fails typically undergo two-stage implant removal [54–56].

12.9.1 Surgical Technique

With the patient supine, the previous skin incision is used for the standard triceps anconeus lateral flap approach [57] or for an extensile triceps-sparing approach. The aim is to preserve the integrity of the triceps insertion in continuity with the distal forearm fascia. Once the distal humerus is exposed, removal of the medial and lateral condyle is necessary to expose the articulating pin. Component stability in the bone is evaluated after disarticulation of the joint and removal of the bushings. This is an important stage of the procedure. If both components are well fixed, the joint is debrided of all necrotic debris and irrigated using pulsative lavage. Antibiotic cement beads are placed around the components. Irrigation and debridement are usually performed three to four times. Removal of a well-fixed component can result in serious complications, which can be avoided by irrigation and debridement. Pathogen identification and assessment of antimicrobial susceptibility enable selection of the appropriate antimicrobial therapy. Most clinicians adopt intravenous antibiotics for the first 2 to 6 weeks following the surgical procedure (Fig. 12.6).

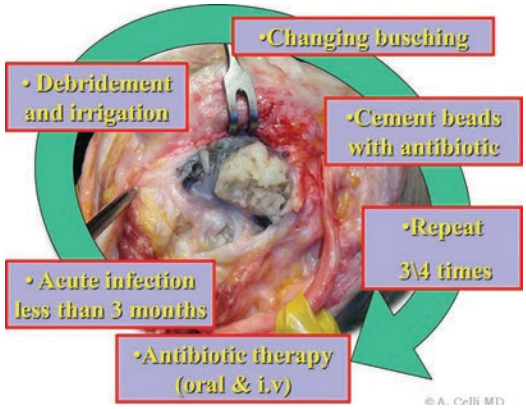

Fig. 12.6 Irrigation and debridement with component retention surgical steps

12.9.2 Results

Yamaguchi et al. [5] have reported a long-term (mean follow-up, 71 months) success rate of 50% of irrigation and debridement of infected TEA at the Mayo Clinic. The bacteriology played a significant role; treatment failed in all four patients with *S. epidermidis* infection, whereas it successfully eradicated *S. aureus* infection in six of eight patients. The result of this procedure depends on symptom duration and bacteriology.

Wolfe et al. [7] have described how all except 2 of 12 patients underwent wound exploration, irrigation and debridement of necrotic material and sinus tracts, and closure of the wound over a suction drain. Antibiotics were administered for 4 to 6 weeks. Irrigation and debridement had to be repeated in eight (75%) patients.

Ten prostheses were removed, two immediately and eight after salvage had failed. Most were converted to an excision arthroplasty by removing the infected material and retaining the humeral condyles for stability. Only one patient with a low-grade infection underwent reimplantation at 6 weeks; two patients were treated by arthrodesis.

The authors conclude that attempted salvage needs to be restricted to the immediate postoperative period.

12.10 Staged Exchange Arthroplasty

This procedure involves prosthesis removal and implantation of a new prosthesis in the same or in a later surgical procedure. If the microorganism responsible for the infection can be treated easily, the interval until reimplantation is short (2–4 weeks), and a temporary antimicrobial-impregnated bone cement spacer may be used. If the microorganisms are difficult to treat, a longer interval (>8 weeks) is preferred, and a spacer is not used.

12.10.1 One-Stage Exchange Arthroplasty

One-stage exchange, or direct exchange arthroplasty, is performed less frequently than two-stage exchange. Open arthrotomy and debridement are performed as in the irrigation and debridement technique and are followed by complete removal of prosthesis and cement. Aggressive debridement is critical for the success of this strategy. A new prosthesis is implanted in the same session, typically using antimicrobial-loaded polymethyl methacrylate (PMMA) to fix the new implant in place. The antimicrobials used in the PMMA are selected based on preoperative identification of the pathogen or are chosen empirically, if the pathogen or its susceptibility is unknown.

Several antimicrobial strategies can be used in one-stage exchange procedures. The regimen used most commonly includes 4 to 6 weeks of intravenous antibiotics, followed by oral antibiotics for 3 to 12 months [58–60].

12.10.2 Results

Gille et al. [15] reviewed 6 (1.9%) of 305 primary TEA in patients with deep infection. Mean follow-up after revision was 6.8 years (range, 6 months to 16 years), and mean patient age at the time of revision was 62.7 years (range, 56–74). All six patients with infection had RA

and had been treated with steroids. The infecting organism was *S. aureus*. Four elbows showed radiolucency around one or the other component. Single-stage exchange with antibiotic-loaded cement was successful in five patients. In the sixth, recurrence of the infection required removal of the revision implant. The functional result was good in three elbows, fair in one, poor in one, and fair in the patient with resection arthroplasty. The authors recommend the single-stage operation, because its simplicity may involve a lower rate of mechanical complications and its functional results are promising. A single operation provides a significant advantage in debilitated or elderly patients.

12.10.3 Two-Stage Exchange Arthroplasty

Two-stage exchange arthroplasty, or staged exchange, is considered as the most effective strategy in terms of infection eradication and preservation of joint function. The approach involves at least two procedures. In the first, cultures are obtained, the infected tissue is debrided, and the implant components and the PMMA are removed. An antimicrobial-impregnated PMMA spacer is usually implanted in the joint space prior to closure to deliver local antimicrobial therapy and preserve limb length. Pathogen-directed antimicrobial therapy is usually given intravenously for 4–6 weeks, followed by an antibiotic-free period of at least 2 to 6 weeks [61], in which the patient is evaluated for signs of ongoing infection typically using inflammatory markers and synovial fluid aspiration. If there is evidence of ongoing infection, a repeat debridement procedure may be performed, typically followed by further antimicrobial therapy before attempted reimplantation.

At the time of reimplantation, biopsy specimens are obtained for histopathological examination as well as culture, and a new prosthesis is implanted, typically using antimicrobial-loaded PMMA.

The surgical technique is similar to the debridement and irrigation technique with wide exposure of the ulnar and humeral side (Fig. 12.7).

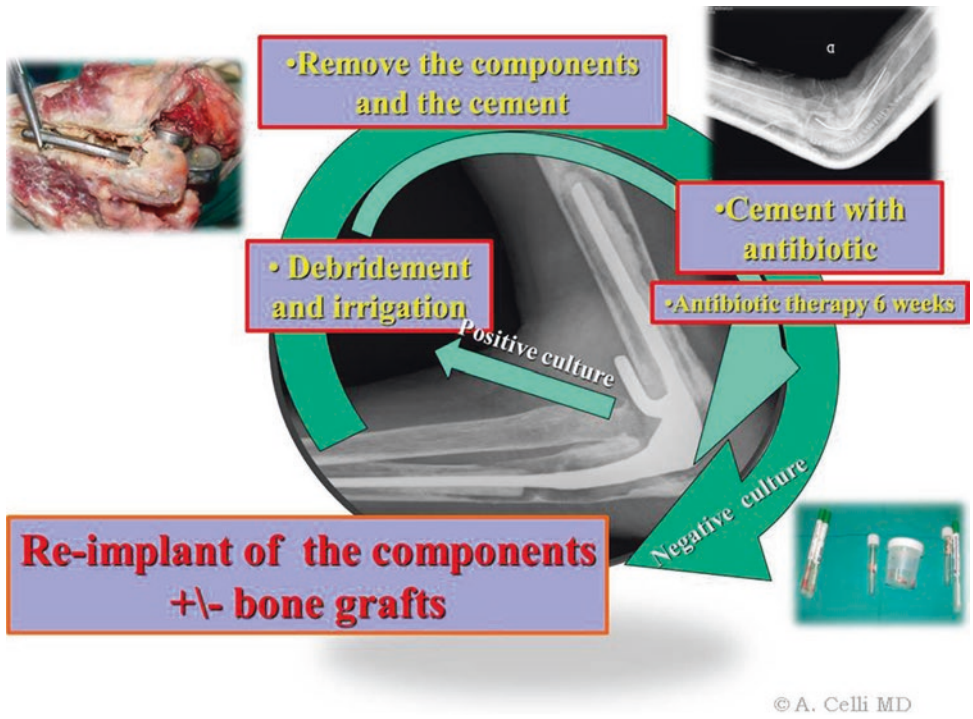

Fig. 12.7 Two-stage exchange arthroplasty surgical steps

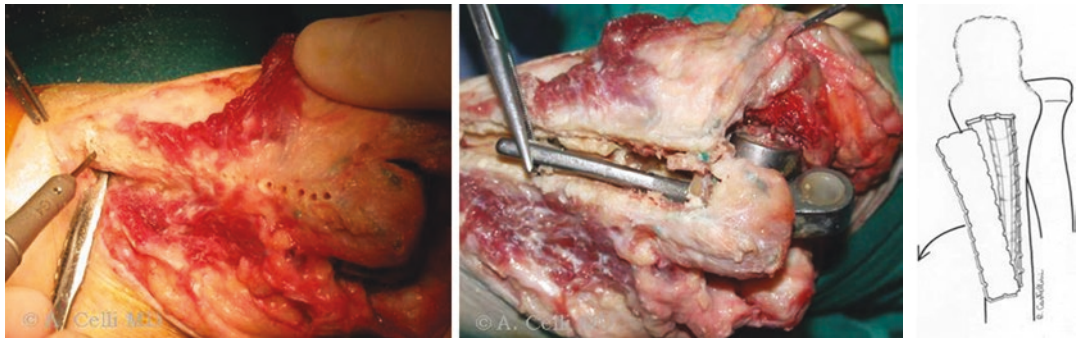

Fig. 12.8 Fenestration of the ulnar diaphysis may be useful to achieve complete PMMA removal

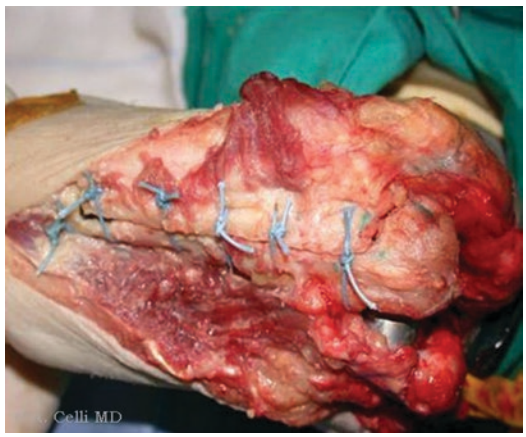

Fig. 12.9 The bone fenestration is closed with transosseous sutures

During the first procedure, fenestration of humeral and/or ulnar diaphysis may be useful to achieve complete PMMA removal (Fig. 12.8). The bone fenestration is closed with transosseous sutures (Fig. 12.9). Risk factors for failure of two-stage exchange arthroplasty can be broadly categorized into host-related, pathogen-related, and treatment-related. Local or systemic host factors include the presence of a sinus tract [62–64], prior joint revision [62, 65], and RA [65].

12.10.4 Results

Peach et al. [66] reported their experience with staged revision surgery in a series of 33 consecutive patients (34 infected TEA) treated from 1998 to 2010. A first-stage procedure with component and cement removal and insertion of antibiotic-impregnated cement beads was undertaken in 29 (85%) elbows, whereas 5 (15%) elbows required 2 or more first-stage procedures. The organism isolated most frequently was coagulase-negative *Staphylococcus*. A second-stage procedure was performed in 26 TEA (76%). Seven patients (21%) had functional resection arthroplasty with insertion of antibiotic beads and required no further surgery, whereas in one patient, persistent discharge prevented further surgery. Three (11.5%) patients who underwent a second-stage procedure suffered from infection recurrence at a mean interval of 8 months (range, 5–10). The mean Mayo Elbow Performance Score (MEPS) in the patients who underwent a second-stage revision without infection recurrence was 81.1 (65–95). The authors concluded that staged revision surgery is successful in patients with an infected TEA and is associated with a low rate of recurrence.

12.10.5 Failure After Two- or More Stage Exchange Arthroplasty

Failure may be due to recurrent infection with the same pathogen or to infection with a new microorganism. Options for failure management after two-stage exchange include antibiotic therapy without surgical treatment, debridement and irrigation with retention of the components followed by antibiotic therapy, repeat two-stage exchange, resection without reimplantation, arthrodesis, and amputation. As in the other cases, manage-

ment depends on comorbidities, bone stock and soft tissue integrity, and the patient's desire for and ability to undergo additional surgery.

12.11 Resection Without Reimplantation

This is typically a salvage strategy to avoid amputation after failed treatment attempts or to treat patients who cannot undergo debridement and irrigation without component retention or staged exchange arthroplasty. Patients with other comorbidities that limit their functional abilities may also elect to undergo resection without reimplantation (Fig. 12.10).

The antimicrobial treatments used after resection arthroplasty are similar to those used with two-stage exchange, with most patients receiving a 4- to 6-week course of intravenous antimicrobials following resection.

12.12 Arthrodesis

Joint fusion is considered as a major limb salvage procedure for patients with failed elbow PJI.

It may be performed following resection, to provide additional mechanical support than simple resection arthroplasty. Fusion can be obtained using a long plate and a bone graft (Fig. 12.11).

12.12.1 Minimization of the Risk of Infection

Several measures are taken to minimize the risk of infection at the time of the primary arthro-

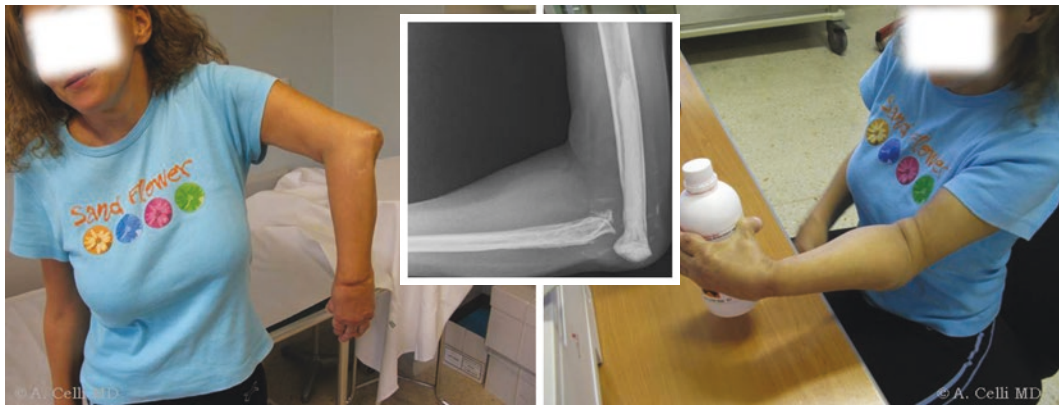

Fig. 12.10 Elbow resection without reimplantation

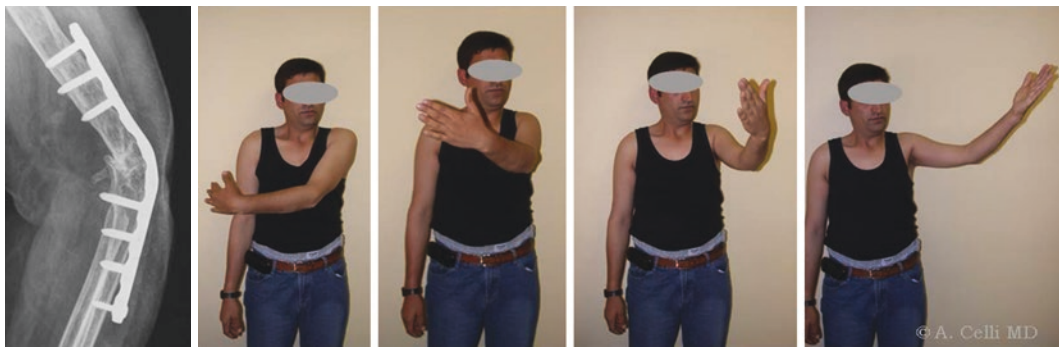

Fig. 12.11 Elbow arthrodesis

plasty. Some have been found to reduce the risk, whereas others are held to be useful, although their value has not been demonstrated. The most important measures include:

- Antibiotics before and after surgery. Antibiotics are given within 1 h at the beginning of the procedure (usually in the operating room) and are continued at 24 h intervals thereafter.
- Short operating time and minimal operating room traffic.
- Preoperative screening of nasal passages for bacterial colonization: screening (particularly for *Staphylococcus* spp.) several weeks prior to surgery may help prevent joint infection.
- Preoperative chlorhexidine wash.
- Use of antimicrobial-loaded PMMA to fix the new implant.
- Antibiotic prophylaxis. The American Academy of Orthopedic Surgeons (AAOS) recommends that clinicians consider preventative antibiotic use for joint replacement patients prior to any invasive procedure that may allow bacteria to enter the bloodstream.

12.12.2 Antibiotic Prophylaxis Following Total Elbow Replacement

Bacteremia can be caused by a variety of sources, including intraoperative contamination and hematogenous seeding of bacteria on joint implants either in the early postoperative period or for many years after implantation [67]. Other causes are related to normal daily life and to dental, urological, and other surgical and medical procedures [67–70].

Bacteremia associated with acute infection of the skin; oral cavity; respiratory, gastrointestinal, and urogenital systems; and/or other sites can and do cause late implant infection. Patients with joint replacement undergoing invasive procedures or suffering from other infections are at increased risk of hematogenous seeding. Antibiotic prophylaxis may be considered for those patients who have had previous prosthetic joint infections and for those with other conditions that may predispose them to infection [71, 72].

The AAOS provides recommendations to help orthopedic surgeons in their clinical judgment regarding antibiotic prophylaxis for patients with a joint prosthesis (Table 12.3).

Table 12.3 The AAOS provides recommendations to help orthopedic surgeons in their clinical judgment regarding antibiotic prophylaxis for patients with a joint prosthesis

Procedure	Antibiotic	Dose	Timing
Dental	Cephalexin	2gm IV	1 h before procedure
	If allergic to cephalexin or penicillin clindamycin	600 mg IV	1 h before procedure
Orthopedic	Cefazolin	1–2 g IV	1 h before procedure
	Cefuroxime	1.5 g IV	Prior to procedure (prior to inflation of tourniquet)
	Vancomycin	1 g IV	
Vascular	Cefazolin	1–2 g IV	1 h before procedure
	Vancomycin	1 g IV	1 h before procedure
Gastrointestinal	Cefazolin	1–2 g IV	1 h before procedure
	Neomycin + erythromycin	1 g IV	1 h before procedure
Head and neck	Clindamycin Gentamicin Cefazolin	600–900 mg IV 1.5 mg/kg IV 1–2 g IV	1 h before procedure
Obstetric and gynecological	Cefoxitin, cefazolin	1–2 g IV	1 h before procedure
	Ampicillin/sulbactam	3 g IV	1 h before procedure
Genitourinary	Ciprofloxacin	500 mg PO 400 mg IV	1 h before procedure

12.13 Conclusion

TEA infection will continue to present a diagnostic and management challenge to clinicians. The therapeutic approaches to deep infection, especially the optimal strategies to treat the various microorganisms, are still debated. A greater understanding of the role of biofilm in the pathogenesis of prosthetic joint infections and evaluation of the activity of the diverse antimicrobial agents against biofilm-associated microorganisms is expected to provide important information to guide therapy and surgical indications and approaches.

Declaration of Conflict of Interest No potential conflicts of interest are related to this manuscript.

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13 Periprosthetic Fractures in Total Elbow Replacement: Classification and Current Treatment Algorithm

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13.1 Epidemiology and Risk Factors

Periprosthetic fractures can either occur intraoperatively during component implantation or postoperatively. The reported prevalence of postoperative periprosthetic elbow fractures varies between 5% and 29% in primary replacement [1–3]. However, the extension of the indications for elbow replacement and the lowering of the age threshold for surgery combined with the aging of the population will probably lead to an increase in the volume and prevalence of periprosthetic elbow injuries [4, 5].

Postoperative fractures can occur due to either a single traumatic event or secondary to massive loss of bone stock [6, 7]. Bone stock loss plays such an important role in the etiopathogenesis of periprosthetic fractures that up to 57% of patients are not able to identify a traumatic event, but only a worsening of pain during the performance of daily activities [7].

13.2 Classification

Periprosthetic elbow fractures can be categorized according to the Mayo classification described by O'Driscoll and Morrey [1] based on the Vancouver classification for hip periprosthetic fractures [8].

Fractures may occur both on the humeral (H) and ulnar (U) sides. First, the location of the fracture is identified:

- Type A: Periarticular.
  - Humerus: Condyle, epicondyle.
  - Ulna: Olecranon, coronoid.
- Type B: Around the prosthetic stem.
- Type C: Distal to the prosthetic stem.

In type B fractures, it is necessary to evaluate the component stability and the bone stock, as these aspects profoundly change the therapeutic approach:

- Subtype 1: Well-fixed, adequate bone quality.
- Subtype 2: Loose, adequate bone quality.
- Subtype 3: Loose, severe bone loss or osteolysis.

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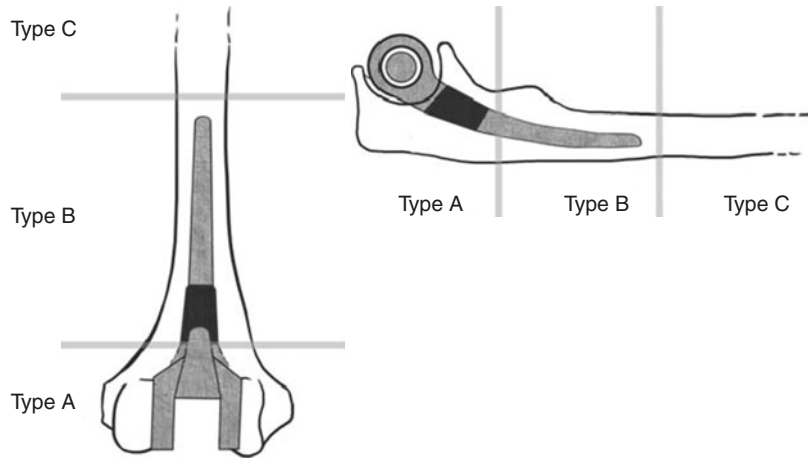

Fig. 13.1 Mayo classification of elbow periprosthetic fractures

The final classification of a periprosthetic fractures must take into account what is observed intraoperatively as well as the type of surgery performed (Fig. 13.1).

Bone loss is a crucial factor to evaluate when planning for surgery as the type of implant and the need for bone grafting depends on its location and severity. On the humeral side, bone loss can be classified as follows [9]:

- Grade 1: Bone loss around the articular part of the prosthesis up to the olecranon fossa.
- Grade 2: Bone loss around the prosthetic stem.
- Grade 3: Bone loss proximal to the prosthetic stem.

On the ulnar side [9]:

- Grade 1: Bone loss around the olecranon process including the triceps tendon attachment.
- Grade 2: Bone loss around the prosthesis stem.
- Grade 3: Bone loss proximal to the prosthesis stem.

13.3 Clinical Presentation

13.3.1 History

The anamnestic collection should be focused on the fracture mechanism in order to identify possible causes of bone stock loss: fractures can either occur after a trauma to healthy bone or superimposed on periprosthetic bone loss secondary to an implant failure process.

In order to plan for surgery, it is important to know as much as possible about any previous surgeries: initial indication for replacing the joint, prosthesis used, component sizes, year of implantation, surgical approach, management of the ulnar nerve, and any perioperative complications (especially of a septic nature).

In cases of fractures that occurred in a non-traumatic setting, symptoms leading to an acute pain worsening over time have to be annotated. Pain should be evaluated according to its onset, progression, intensity, and aggravating and alleviating factors and if it is present at rest.

In every case it is necessary to rule out infection through clinical history and a simple blood test including leukocyte count and C-reactive protein level. If there is any suspicion of infection, a two-stage revision should be considered. Even if there are no clinical or laboratory signs, intraoperative swabs and tissue sampling for bacteriological culture examination are important, and, if possible, an α-defensin test and implant sonication should be used [10].

13.3.2 Imaging

X-rays are the first exam to be performed. Anteroposterior and anterolateral views of the elbow are usually enough to diagnose periprosthetic fractures. Oblique views and secondary CT

scans, especially if metal artifact reduction sequences are available, can be useful to determine bone stock, cortical perforation, and cement extrusion.

X-rays and CT scan help the surgeon understand several aspects. First, the fracture type (location, orientation, extension, displacement, and comminution). Second, the prosthetic component stability: mobilized components can have surrounding radiolucent lines, thinning of the cement mantle or cracks within it. A comparison with a previous X-ray can help elucidate the mechanism of failure: the presence of radiolucent lines or initial osteolysis on both prosthetic components suggests an acute failure with a fracture superimposed over a slower process of septic or mechanical failure. On the other hand, loosening affecting only one component suggests poor-quality cementing technique or a specific design problem. Third, the bone stock: osteolysis progression can be evaluated according to the guidelines of Mansat et al. [9]. Cortical bone has to be analyzed for previous perforation with cement extrusion and thinning areas as these are at risk for intraoperative fractures. The presence of bone insufflation with wide intramedullary canal has to be noted as impaction grafting may be needed during revision surgery [11].

13.4 Treatment

Treatment should be planned according to the Mayo classification. Another important aspect to consider for treatment is the timing, i.e., intraoperative versus postoperative periprosthetic fractures.

13.4.1 Humeral Condylar Fracture (H—Type A)

Humeral condylar fractures are the most common type of periprosthetic fracture and occur more frequently intraoperatively.

The epicondyles are weakened by the bone cuts for the component insertion. Fractures can happen as a result of the tension generated either by the common flexor and extensor tendons or the collateral ligaments or during component insertion. The treatment depends on the type of prosthesis implanted or about to be implanted: unlinked designs require integrity of the humeral columns for stability, so fractures must be stably fixed (with sutures, tension band, or plate and screws) or should be considered an intraoperative conversion to a linked total implant. Linked prosthetic designs do not need condyles for stability; therefore, it is possible to attempt the fixation or simply resect the broken condyle [12, 13] and suture the common flexor/extensor tendon to the intermuscular septum and margin of the triceps tendon. Condyle retention and condyle resection have shown no clinical difference in elbow function [14]. However, the resection should be limited to small fragments since both columns would be needed for a resection arthroplasty technique to succeed in the future should septic complications arise [5].

Postoperative fractures are usually subsequent to heavy use of the musculature or to osteolysis. In constrained prosthesis designs, these fractures are treated conservatively as they usually heal to a stable fibrous nonunion or sometimes they even fully heal. If the stability of the implant is compromised, surgical treatment is a must.

13.4.2 Olecranon Fracture (U—Type A)

Ulnar type A periprosthetic fractures include coronoid fractures, even if these are extremely rare, and olecranon fractures, which constitute the most common scenarios.

The olecranon is susceptible to fracture in patients with rheumatoid arthritis because of erosive thinning of the semilunar notch of the ulna. Fractures can occur intraoperatively during ulnar canal preparation or component implant, and, in most cases, it is appropriate to reduce and fix it. Nonabsorbable suture through drill holes in the ulna can be used if the bone is thinned and the fragment small. In cases with good bone stock and bigger fragments, cerclage wires, tension band techniques, and plates can be used. However, the risk of wound complications connected to the presence of more devices can increase [1].

Postoperative olecranon fractures can be subsequent to direct blows or falls on the outstretched arm and, in cases of thinned cortical bone, subsequent to forceful triceps contraction or stress fracture. Treatment is based on the functionality of the extensor mechanism: if the patient is able to actively extend the elbow against gravity, conservative treatment should be considered. These fractures usually heal to a stable fibrous nonunion, and, if painless active extension is preserved, no further treatment is usually needed. Surgical treatment is indicated in cases of extensor mechanism deficit or unstable nonunion. In cases of good bone stock, simple open reduction and fixation is enough, while cases with metaphyseal bone loss are better approached using corticocancellous bone graft [15, 16].

Coronoid fractures usually occur intraoperatively. If small or non-displaced, they are not of significance. However, if the fragment affects the stability of the ulnar component, it can be fixed with circumferential sutures or wires.

13.4.3 Humeral and Ulnar Shaft Fracture (Around or at the Tip of Stem; H/U—Type B)

Fractures around or at the tip of the implant stem constitute less than 2% of cases. These usually happen postoperatively but can occur intraoperatively during canal preparation or implant positioning especially in weakened and deformed bone by rheumatoid arthritis or during revision surgery removing a well-fixed component [17]. The treatment of postoperative fractures depends on the component fixation status and the remaining bone stock according to the Mayo classification [5] (Fig. 13.2).

13.4.3.1 Well-Fixed Implants (H/U—Type B1)

Fractures involving well-fixed implants are rare and usually occur at the tip of the stem. The treatment, either conservative or surgical with open reduction and internal fixation, depends on the displacement and stability of the fracture and patient-related factors.

Humeral non-displaced and stable fractures can be treated conservatively with the arm in a long cast for 2–3 weeks followed by customized brace protection until consolidation is achieved. Ulnar non-displaced and stable fractures can be treated with a long cast for 3 weeks followed by a short cast that allows elbow mobilization for an additional 3–5 weeks [5].

When deemed necessary, in cases of displaced and unstable fractures, surgical treatment consists of open reduction and internal fixation usually with plate and screws with or without cerclage wiring.

13.4.3.2 Loose Implants with Good Bone Stock (H/U—Type B2)

13.4.3.3 Loose implants typically demand revision surgery. If the bone stock is preserved, in selected cases, fractures can be treated with implant revision with a longer stem, bypassing the fracture site by at least two bone diameters, with or without cerclage wire fixation for additional stabilization [18].

In cases with fracture patterns that extend to the diaphysis, revision alone either would not provide enough stability or would require stems that are too long. Hence, component revision has to be associated with either plating or strut splinting. Bone stock around the elbow is anatomically small and could be further reduced by the pathological process that led to joint replacement in the first place, previous revision, and osteolysis. In these cases plates and screws might not provide enough stability and lessen the remaining bone stock. Allograft struts have been advocated to stabilize fractures in frail osteolytic bone fragments both on the humeral and the ulnar sides [18, 19]. This technique has the advantage of eventually improving bone stock.

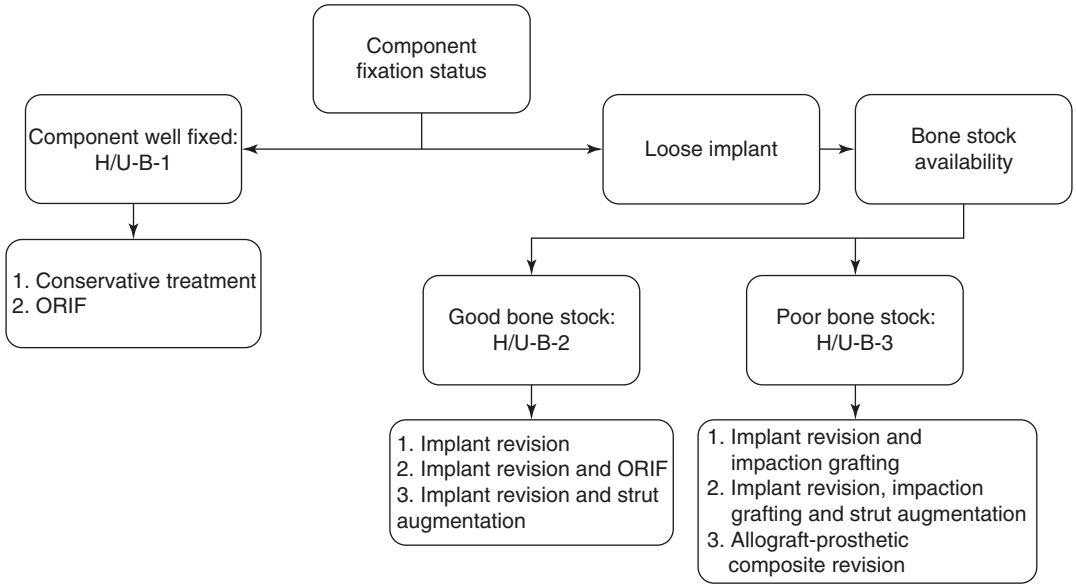

Fig. 13.2 Treatment algorithm for type B periprosthetic elbow fractures [5]

13.4.3.4 Loose Implants with Poor Bone Stock (H/U—Type B3)

When the implant is loose and the bone stock is poor, revision surgery generally has to be combined with bone augmentation procedures.

In the metaphyseal region, bone loss can appear as cortical bone insufflation with increased intramedullary canal diameter. Considering its success in other joints [20, 21], impaction grafting can be performed in the elbow to restore the intramedullary canal using allograft cancellous bone and to allow the use of non-custom prosthetic components [11].

Bone loss or cortical perforations extending to the diaphysis require strut allograft augmentation, with or without impaction grafting. Regarding the humerus, two strut grafts are generally required (anterior and posterior). One or two strut grafts can be required for the ulna.

When the bone stock is insufficient to support a conventional implant, the use of an allograft composite prosthesis (APC) can be indicated: a whole circumferential structural allograft is used to reconstruct the meta-diaphyseal bone loss [9]. This type of reconstructive surgery is indicated in humeral defects larger than 8 cm. This can be done because the humerus can be shortened by 2 cm without losing significant strength, and a bone loss of 6 cm does not compromise the implant stability when a long stemmed and long flanged humeral component is used. On the ulnar side, APC is indicated if bone loss affects the whole olecranon and metaphysis, spanning at least 6 cm [5]. Contact area between the host bone and the allograft and their stable fixation are the key elements to bone union. In order to improve contact and maximize bone integration, three types of host-allograft configuration have been described [22]:

- Type 1: Intussusception of the allograft-prosthetic composite into the host bone when insufflation of intramedullary canal is present.
- Type 2: Insertion of the distal aspect of the stem into the host canal with strut-like extension of the graft coapted externally to the cortex. This type of interface is useful in cases with extensive metaphyseal bone loss.
- Type 3: Side-to-side contact between the cortices of the allograft and the host bone is indicated when, in addition to metaphyseal bone loss, prosthetic stability is compromised by malalignment.

Custom implants and megaprostheses can be used to treat severe bone deficit around the elbow in post-traumatic deformities, advance rheumatoid arthritis, and post-tumor resection [23–26], but the use in cases of periprosthetic fractures is not reported.

13.4.4 Humeral and Ulnar Fracture beyond the Tip of the Stem (H/U—Type C)

Fractures beyond the tip of the stem are treated either conservatively or with open reduction and internal fixation according to their location and displacement. Surgical options are limited only by the presence of the prosthetic stem, which prevent the use of intramedullary nails.

13.5 Outcomes and Complications

Periprosthetic fractures are the third most frequent reason for revision, after aseptic loosening and infection [27]. However, since total elbow replacement is not frequent, the literature on the topic consists of few retrospective case series focused on type B-2 and B-3 fractures [7, 18], case reports [28–34], and cases described in larger series broadly focused on elbow replacement revision surgery [11, 19, 22].

13.5.1 Periprosthetic Ulnar Fractures

The largest series on periprosthetic ulnar fractures has been described by Foruria et al. [7] in 2011 and consists in 30 cases of type B-2 and B-3 fractures. In two cases fixation was achieved by simple revision arthroplasty, 20 elbows were treated with allograft strut and cerclage (8 of these in combination with impaction grafting), 3 cases underwent impaction grafting as an isolated revision technique, and the remaining 5 elbows were treated with allograft-prosthetic composites for severe bone loss. At a mean follow-up of approximately 5 years, all 21 fractures of the available patients healed, and the mean Mayo Elbow Performance Score (MEPS) was 81. The results were graded as excellent for ten elbows, good for five, fair for four, and poor for two. The most common complication was infection (deep in four cases and superficial in one case). They also reported one case of aseptic loosening associated with olecranon fracture and a periprosthetic humeral fracture.

Tokunaga et al. [28] reported on a patient affected by ulnar type B-3 fracture treated with a two-stage approach. The first stage consisted of fracture fixation using a plate, screws, and cerclage augmented with iliac crest bone graft. After radiographic evidence of healing, the implant was revised with a longer stem and impaction bone grafting. At around 1 year of follow-up, the elbow was pain-free. There were no signs of loosening around the ulnar component; the patient was satisfied with the result and could perform activities of daily living.

13.5.2 Periprosthetic Humeral Fractures

Sanchez-Sotelo et al. [18] reported a retrospective case series of 11 patients with type B-2 fractures treated with implant revision and allograft struts. In this series no periprosthetic infections were reported. However, one patient had a fracture nonunion complication, one was affected by postoperative permanent ulnar nerve palsy, one had a triceps insufficiency, one had aseptic loosening with olecranon fracture, and another had sustained a non-displaced humeral fracture. Three of these patients underwent revision surgery. After 3 years of follow-up, among the eight patients who did not undergo revision surgery, the mean MEPS was 79, and the results were rated as excellent in four patients, good in four, and poor in three. All the patients had a functional arc of motion except one.

In contrast with the treatment principles stated in the paragraphs above, Fang et al. [29] treated two patients with humeral type B-2 fractures around a loosened long-stem prosthesis using only locking plates and cerclage. In both patients

rotationally stable osteosynthesis with re-established stability was evident after 2 years.

Kawano et al. [30] reported on a custom solution for a complex case of humeral type C fracture nonunion in a patient who had already undergone a two-stage revision for deep infection. Since the patient refused an allograft for religious reasons, a hollow intramedullary nail was customized to serve as a sleeve in which the stem of the humeral component was impacted. Union was achieved after 4 months, and, at the 3-year follow-up, the elbow was pain-free with a range of active elbow flexion between 10° and 120°.

Two case reports [31, 32] describe the successful treatment with plating for simple type C fracture. Type C fractures occurring between shoulder and elbow arthroplasties are more challenging. Carroll et al. [33] stabilized the fracture with three lag screws and a rigid 90–90 dual plating construct. The patient was pain-free and had healed without complication at 7-month follow-up. An even more challenging case of interprosthetic fracture was reported by Kieser et al. [34]: a fracture between a shoulder hemiarthroplasty and a revision long-stemmed elbow arthroplasty with strut allograft. Open reduction revealed that the distal humerus had no signs of healing and the component was unstable. So, revision surgery with a type 2 APC stabilized with plate and cerclage was performed. At 1-year follow-up, the patient had minimal pain and had returned to all normal day-to-day activities without restriction.

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14 Failure of Semiconstrained Elbow Arthroplasty: Aseptic Loosening and Revision

Celli Andrea, De Luise Guglielmo, and Celli Luigi

In the past decade, the applications of elbow arthroplasty have been expanded to the treatment of degenerative and post-traumatic conditions.

Advanced arthritis with relentless pain, stiffness, and instability that have failed to respond to conservative treatment are the main indications for joint replacement.

Replacement to manage trauma-related conditions is controversial except in case of complex acute intra-articular fractures and in elderly patients with chronic malunion/nonunion of the distal humerus, who in recent years have increasingly been treated by total elbow arthroplasty (TEA).

TEA is contraindicated in patients with active sepsis, an inadequate soft tissue envelope, and neuropathic elbow disease and in those where the functional limitation due to TEA would involve poor early or long-term compliance. High-demand patients also have a relative contraindication.

Complications arising at the time of surgery result in implant failure and severe disability and lead to implant revision. The most common complications include aseptic loosening, infection, periprosthetic fracture and triceps insufficiency, implant instability, and ulnar neuropathy. The incidence of clinically significant aseptic loosening is 7–15%, but the rate of periprosthetic radiolucency without clinical symptoms is even higher [1, 2].

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According to Morrey et al. [3], the loosening rate of semiconstrained prostheses is under 8% at 10–15 years in patients with rheumatoid arthritis and about 10% at 15 years in those with post-traumatic arthritis.

Semiconstrained implants have a loose hinged mechanism with 7–10° varus-valgus laxity and 7–10° axial rotation. Unlinked implants mimic elbow anatomy more closely and rely on the reconstructed ligaments for stability. In these prostheses, energy is dissipated by the periprosthetic soft tissues, whereas semiconstrained linked implants are inherently more stable and support a greater amount of stress during elbow flexion and extension.

Since the bone-cement interface in a coupled implant is exposed to greater stress, the most common failure types are loosening, bushing wear, and implant fracture. Linked implants require a larger stem and firmer fixation.

14.1 Risk Factors for Component Loosening

Despite improvements in implant design and surgical techniques, aseptic loosening is still frequent. Anatomical replacement provides restoration of the flexion/extension axis and preservation or restoration of the moment arm of the muscles, enabling balancing of the active forces and control of the functional motion of the linking mechanism.

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Frequently, the pathological condition induces a distortion of the articular bone surface such that the axis of rotation can no longer be identified. Its restoration poses considerable technical difficulties but does not improve function; moreover, it predisposes to a higher rate of complications such as component loosening. Aseptic loosening is the most frequent cause of long-term implant failure.

Although component loosening may be related to several causes, the most common risk factors include:

1. Mechanical failure.
2. Inadequate surgical technique.
3. Patient non-compliance.

14.1.1 Mechanical Failure

- Polyethylene (PE) wear at the hinge depends on the thickness of the PE layer on the loose-hinged mechanism and on the amount and type of loading.

  PE bushings are used in most linked elbow prostheses. Overuse and repeated shear loading on the very thin PE edge induce wear, increasing varus/valgus and rotational motion at the hinge, which accelerate the wear process. Severe PE wear results in metal-on-metal contact and eventually in metal wear with formation of particulate debris that ultimately induces synovitis and osteolysis. In such cases, periarticular osteolysis is typically due to wear of the PE component. The tissue reaction elicited by the PE particulate without metal contact is not black, but paler. In patients with clinical and radiographic evidence of progressive osteolysis of the periprosthetic component, surgical revision is required to prevent further bone loss and attendant complications. During revision surgery, the black metal debris close to the prosthesis must carefully be removed, to prevent the enzymatic reactions that promote bone resorption [4]. According to the recent literature, extensive distal osteolysis is related to stem loosening, not to PE wear.
- Failure of the polymethyl methacrylate (PMMA) precoating of the ulnar component also causes aseptic loosening.

  Mechanical failure of ulnar components precoated with PMMA exhibits distinctive features, including severe proximal osteolysis (distal or global) caused by the black metal debris produced by the contact of titanium against cement, as well as burnishing when the component pistons back and forth in the cement mantle. In the past few years, plasma spray treatment of the surface of the ulnar component has reduced stem loosening due to osteolysis without metal contact. In these cases, the tissue reaction due to the particulate debris tends to be paler than black. Severe osteolysis is sometimes detected at the distal end of the ulnar component due to failure of the plasma spray layer, which in turn may be the result of micromotion between the implant and the cement mantle or, often, of an inadequate cementing technique. PE, metal, or cement debris promotes macrophage-induced osteolysis at the bone-cement or bone-implant interface and progressive bone loss. In patients with severe osteolysis, even a minimal trauma can cause a periprosthetic fracture.

14.1.2 Inadequate Surgical Technique

- Component malposition.
  Any prosthesis can be affected by component malposition. A humeral stem fixed in valgus, varus, or rotation malposition often causes alterations in elbow function without damaging the stem itself. An excessively proximal humeral component reduces flexion strength due to muscle shortening, whereas too distal a fixation reduces elbow extension and involves a higher rate of complications.

  Malposition of the ulnar component may be influenced by the rotational positioning and depth of the ulna implant. External rotation can limit extension (mean deficit, 30°), whereas an excessively deep-seated implant can impinge on the humeral component, limiting flexion [5, 6] (Fig. 14.1).

  After coronoplasty, correct seating of the ulnar component allows full elbow flexion,

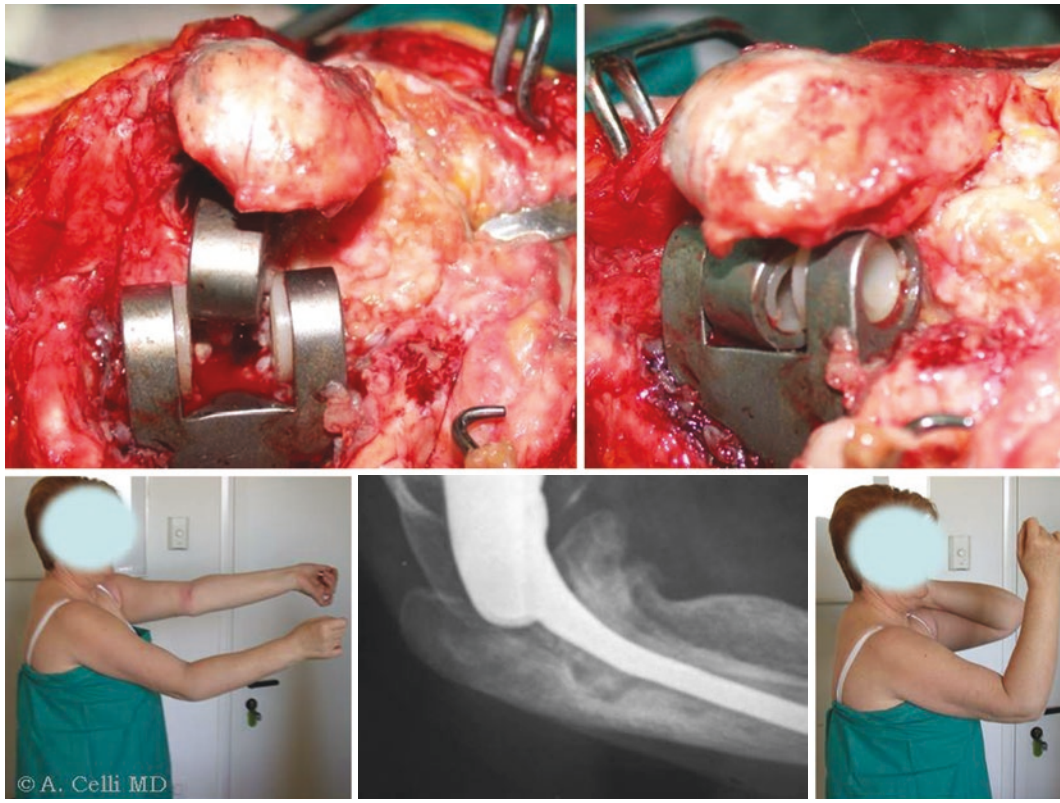

Fig. 14.1 Malposition of the ulnar component may be influenced by the rotational positioning and depth of the ulna implant

whereas an excessively deep fixation involves impingement with the anterior flange of the humeral component, impairing flexion. This is a preventable cause of mechanical loosening of the ulnar component in a linked TEA.

Distraction forces between the ulna and the ulnar component arise when the elbow is forced in passive hyperflexion (Fig. 14.2). The pistoning effect on the ulnar component, seen in patients with anterior impingement (due to the coronoid, heterotopic bone, component malalignment, or just bulky soft tissue), creates an anterior fulcrum that results in proximal to distal and distal to proximal movement of the component in the canal [7] (Fig. 14.3). This problem can be prevented at the time of surgery by trimming away excess cement, a prominent coronoid, or any osteophytes after checking for anterior impingement in trial flexion and extension.

- Inadequate cementing technique.
- The conventional manual cementing technique may provide an irregular cement-bone interface with insufficient stem fixation. During elbow flexion against resistance, the weight forces create a distraction force that causes micromovement and abrasion of the inner cortex, with possible generation of particulate metal debris. Loosening of the cement mantle then damages the feeble bond between the bone and prosthesis.
- Stem loosening may be due to primary failure of the bone-cement interface; micromotion causes formation of stem debris and loosening with or without bone loss.

Advanced cementing techniques involve irrigation of the medullary canal, placement of an intramedullary cement plug, and cement delivery with a cement gun. After removal of all bone debris in the medullary canal, the plug allows cement pressurization, preventing its escape beyond the stem and reduction of

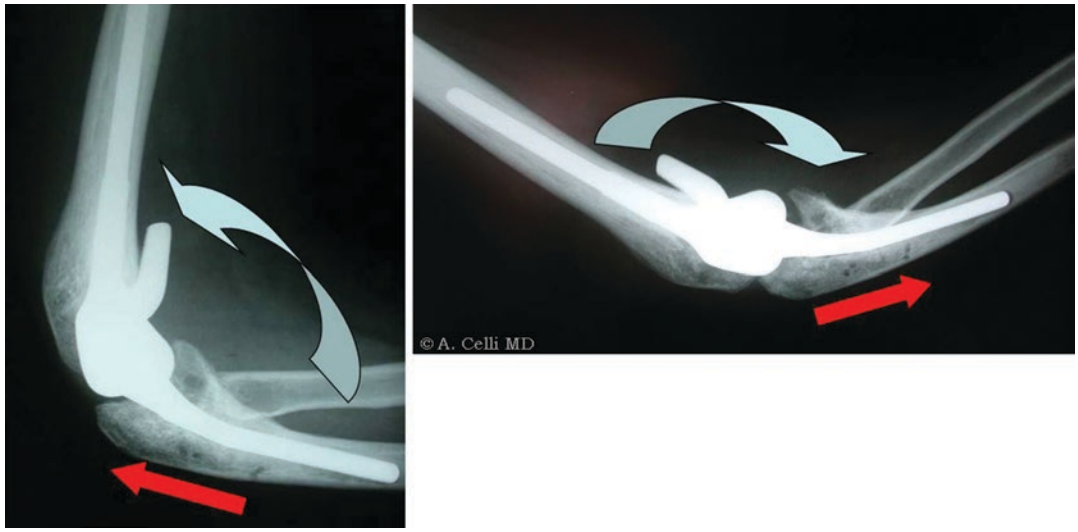

Fig. 14.2 Distraction forces between the ulna and the ulnar component arise when the elbow is forced in passive motion

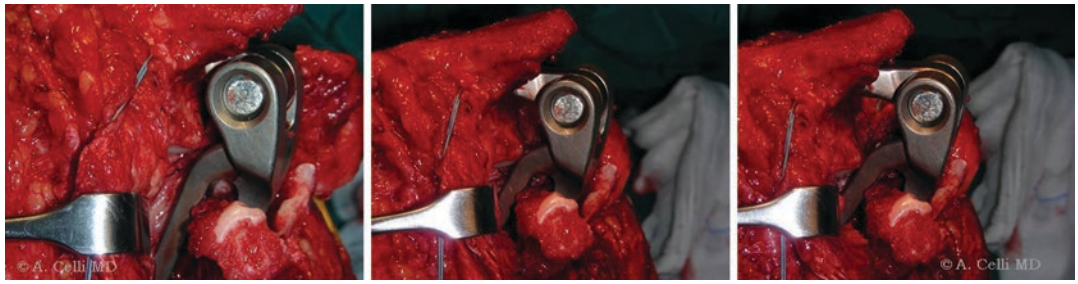

Fig. 14.3 The pistoning effect on the ulnar component, seen in patients with anterior impingement, creates an anterior fulcrum that results in proximal to distal and distal to proximal movement of the component in the canal

the cement mantle at the bone-prosthesis interface. The cement gun and an appropriate nozzle provide for uniform filling of each medullary canal, reduction of voids and lamination, and stronger fixation.

14.1.3 Patient Non-compliance

The patient's ability to cooperate after TEA is critical, particularly where young active individuals are involved. These patients are at risk of mechanical failure of the implant due to the demands of their job or of their leisure activities. Patients have to accept permanent restrictions. Heavy manual labor is an absolute contraindication for TEA. The stress exerted on implant and cement by repetitive cycle loading involves axial bending and torsional forces that are sufficiently strong to induce component micromotion and loosening and eventually significant bone atrophy. Repetitive elbow flexion/extension to the limit of varus-valgus laxity increases the risk of early implant failure through PE bushing wear, inducing osteolysis and ultimately loosening. In these patients, the most common failure mechanism is through rotational stress of the component in the sagittal plane relative to the bone with excess of the elbow varus/valgus range allowed by the hinge during repetitive flexion/extension. Malrotation of the ulnar component increases this risk. Schuind et al. [6] have reported that

during manual activities, the valgus/varus limits in semiconstrained elbow prostheses were reached with only 10° of internal/external rotation of the humeral component.

According to clinical studies [8, 9], the incidence of aseptic loosening is influenced by patient activity. Younger, high-demand patients with post-traumatic arthritis are more likely to experience earlier bearing wear and earlier and higher rates of aseptic loosening. Shi et al. [10] have reported failure rates of 40% in patients with post-traumatic arthritis and of 19% in patients with rheumatoid arthritis at an average follow-up of 7 years. In a review of 49 patients aged 40 years or less, implanted with a Coonrad-Morrey semiconstrained prosthesis at least 5 years previously, Celli and Morrey [11] found a 22% revision rate at a mean follow-up of 91 months; the rate was significantly higher in patients with post-traumatic compared with inflammatory arthritis.

Patients aged less than 60 years must be informed that they should not lift objects weighing more than 4–5 kg (single event) or repetitively lift objects weighing more than 1 kg [12]. Sports such as golf and tennis and manual tasks should also be discouraged, although according to a Mayo study 94% of their TEA patients performed moderately demanding activities and 40% engaged in high-demand use of the upper extremities, especially men treated for post-traumatic conditions [13].

14.2 Clinical Presentation

An elbow prosthesis may fail acutely or insidiously. Acute, dramatic failure may be the result of infection or of periprosthetic or component fracture, whereas implant loosening involves a slower failure with elbow pain, synovitis, and usually an insidious onset in a previously well-functioning implant. The activities limited by pain increase, and pain becomes more constant even at rest. Patients with X-ray evidence of implant loosening may be asymptomatic but need to be monitored with periodic radiographs to follow progression and determine when surgical revision of the prosthesis becomes necessary. The indication for surgical revision is based on the assessment of elbow function, pain-limited activities of daily living, and pain at rest. The physical examination includes the signs that suggest infection, i.e., erythema, warmth, swelling, and sinus tract.

The joint should be examined for range of motion in flexion/extension and pronation/supination as well as for laxity and abnormal tracking. An axial push-pull test under imaging control is useful to assess component movement in the medullary canal, whereas varus/valgus testing allows detecting bushing wear with increased laxity at the hinge and metal-to-metal impingement. Pistoning of the ulnar component may be demonstrated clinically by a history of squeaking, clinking, or grinding [7]. The clinical examination should be completed by the assessment of any comorbid conditions such as diabetes and allergies and current medications. The arm's muscular and neurological status can also be assessed, particularly the extensor mechanism. Shoulder and hand function must carefully be documented. The ulnar nerve should be palpated and its course followed as far as possible, also using Tinel's sign, and sensory and motor hand function should be assessed. A blood work-up should be routinely performed to assess white cell count, erythrocyte sedimentation rate, and C-reactive protein, three markers of inflammation that may be elevated in patients with infection. Clinical and radiographic findings suggestive of infection should prompt joint aspiration with white cell count and culture of the aspirate. A three-phase bone scan (technetium 99 m phosphate imaging) accurately identifies patients with septic loosening through increased uptake. Labeled leukocytes are also highly sensitive for the diagnosis of sepsis.

14.3 Diagnostic Imaging

Radiographic evaluation assists in staging and depicts the main features of implant loosening. Plain anteroposterior and lateral radiographs are usually obtained Computed tomography (CT)

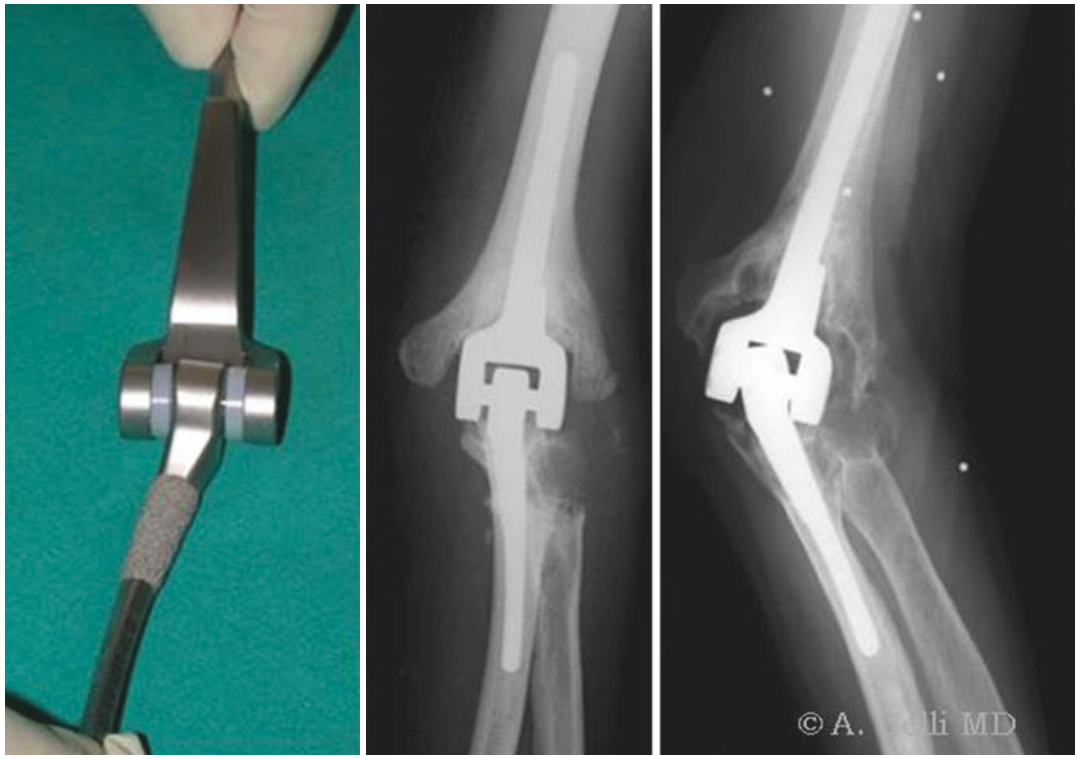

Fig. 14.4 Stress radiographs allow assessing PE bushing wear

may be useful to gauge the extent of stem loosening and bone loss, despite the significant metal artifacts, as well as cortical bone integrity and implant alignment. Stress radiographs allow assessing PE bushing wear (Fig. 14.4). A varus and valgus arc greater than 7° indicates moderate wear, and one greater than 10° indicates extensive wear [14]. An axial push-pull test under dynamic fluoroscopic examination may depict ulnar component pistoning and component loosening. Lateral standard radiographs are taken with the elbow in 90° of flexion: while the examiner stabilizes the upper arm with one hand, he/she pulls or pushes the forearm in anteroposterior direction, to assess loosening of the ulnar component, and in supero-inferior direction, to assess loosening of the humeral component [15].

Radiolucent lines at the bone-cement interface are the radiographic sign of aseptic loosening and osteolysis at the bone-implant interface. Gross loosening is usually associated with severe osteolysis. Morrey et al. [8] have classified the status of the bone-cement interface based on the extent of radiolucency as follows:

- Type 0: No radiolucency.
- Type 1: Nonprogressive radiolucency involving <50% of the interface.
- Type 2: Nonprogressive radiolucency involving >50% of the interface.
- Type 3: Progressive radiolucency ˂50%.
- Type 4: Progressive radiolucency ˃50%.
- Type 5: Gross loosening of the implant.

Mansat et al. [16] (Fig. 14.5) have classified the bone loss around the component into:

- Humeral bone loss.
  - Grade 1: Involving only the articular portion up to the olecranon fossa.
  - Grade 2: Loss around the stem of the prosthesis.
  - Grade 3: Loss proximal to the prosthesis stem.

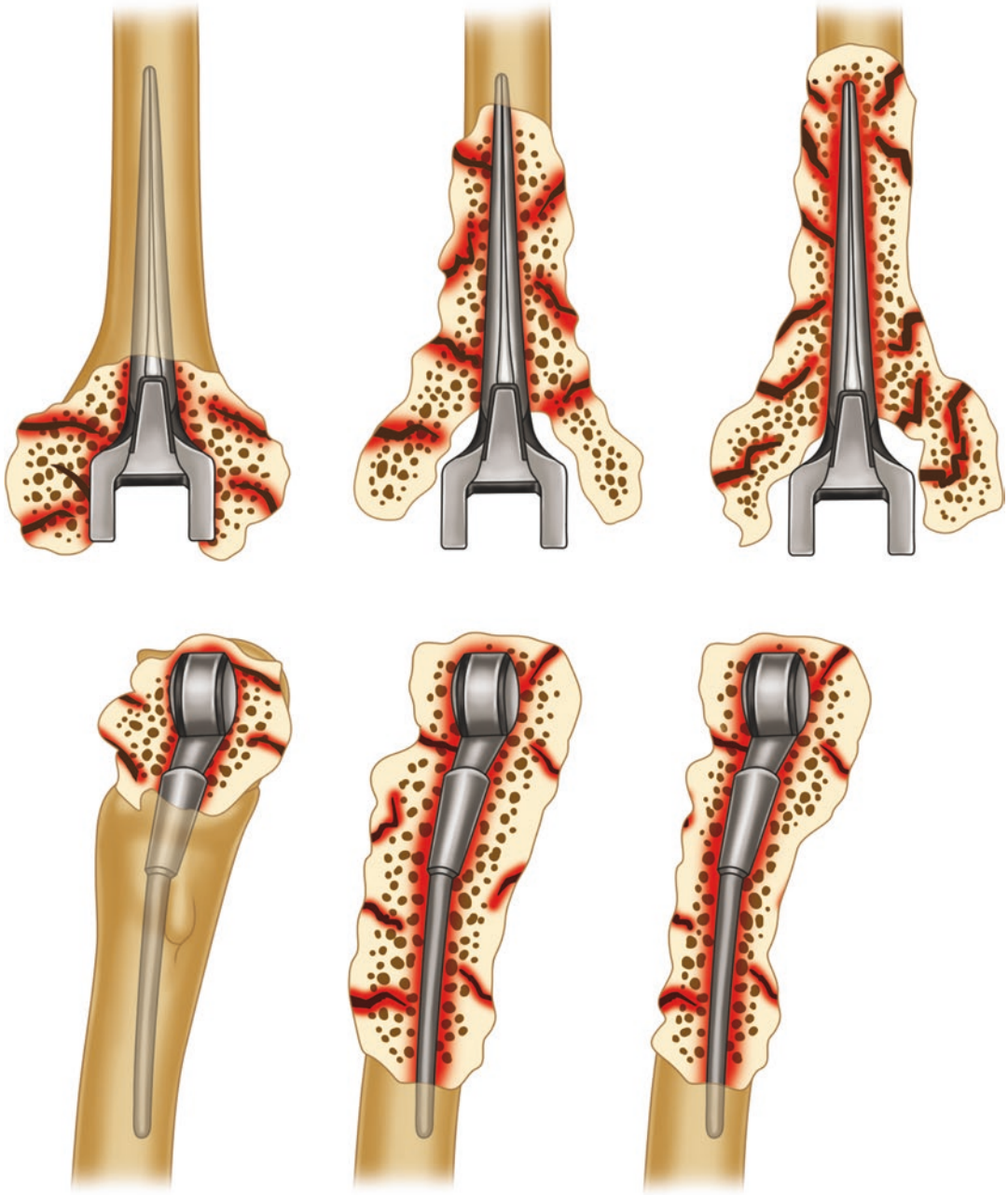

Fig. 14.5 Mansat et al. [16] have classified the bone loss around the components

- Ulnar bone loss.
  - Grade 1: Involving only the olecranon process.
  - Grade 2: Loss around the stem of the prosthesis.
  - Grade 3: Loss distal to the stem.

- If septic loosening is suspected, blood tests for the infection markers (white cell count, erythrocyte sedimentation rate, C-reactive protein) and joint aspiration with aspirate examination (gram staining and white cell count) should be performed prior to revision.

14.4 Surgical Treatment

Surgical revision is usually indicated in patients with PE wear or symptomatic loosening of linked semiconstrained prostheses. It should also be considered in patients with progressive radiolucency or extensive osteolysis even in the absence of symptoms. However, the failure mode should be evaluated before planning reoperation and implant revision. Patient history and physical examination and imaging findings should carefully be assessed. The success of revision depends on bone quality, since loss of significant amounts of bone complicates the reconstruction. When TEA failure is associated with limited or minimal bone deficiency, replacement with a longer stem can be performed by bypassing the bone defect. Extensive bone loss complicates stable implant fixation as it requires a cancellous bone autograft, impaction grafting, or a strut allograft. Humeral and ulnar bone quality directly correlates with revision success.

Preoperative planning requires imaging data to gauge:

- Bone stock status and quality.
- Osteolysis.
- Component loosening and implant status.

– Bone stock quality depends on the presence of cortical thinning, ballooning, or fractures.
– Progressive osteolysis can be diagnosed based on:
  - Widening of the bone-cement, bone-prosthesis, or cement-prosthesis interface.
  - Cement fragmentation or absence.
  - Bead shedding in porous-coated prostheses.

  The mechanical status of the loose component can be assessed by analyzing:
– Bushing wear.
– Component migration or subsidence.

Bushing wear is diagnosed on plain anteroposterior radiographs of the fully extended elbow taken after the index arthroplasty: a line is drawn parallel to the hinge of the humeral component, and another is drawn parallel to the medial or lateral articular surface of the ulnar component (Fig. 14.4). An angle exceeding 10° indicates wear. Bushing wear may also be evaluated by fluoroscopy on varus/valgus stress radiographs.

Component migration can be assessed under imaging control with an axial push-pull test at 90° of elbow flexion. Its position before and after the test may depict stem migration in the medullary canal.

14.5 Surgical Management

The most common indications for reoperation following aseptic loosening are:

- Bushing replacement.
- Reimplantation.
  – Without bone augmentation.
  – With bone augmentation.

14.6 Surgical Technique

The same patient position and incision are used for all options. The scar of the previous operation should be used. The ulnar nerve should always be identified, decompressed, freed of scar tissue, and protected throughout the procedure. The radial nerve must be identified, isolated, and protected while the cement is being removed from the humerus and when the new prosthesis is being implanted, because violation of the humeral cortex may result in extrusion of hot cement and nerve damage. Then the medial and lateral aspect of the implant is released and the lateral and medial epicondylar tendon insertion is detached. Triceps management and exposure of the failed prosthesis vary in relation to the revision procedure. Where possible, the triceps is left attached to the olecranon, carefully avoiding its fracture while disarticulating the humeral and ulnar component, especially in patients with rheumatoid arthritis. If adequate visualization of the joint is not achieved with the triceps-sparing approach, a triceps-splitting approach is recommended. We prefer the anconeus-triceps lateral flap approach [17, 18], where the olecranon insertion of the medial triceps head is not detached, while the lateral tri-

ceps expansion in continuity with the anconeus allows good exposure of implant, periarticular soft tissue, and distal humeral and proximal ulnar bone.

14.7 Bushing Replacement

Full-thickness fasciocutaneous flaps are raised based on the earlier skin incision; the ulnar nerve is isolated if symptomatic, otherwise it is palpated and dissected only if it is at risk of iatrogenic injury.

- If possible, the triceps insertion is not detached from the olecranon and a triceps-sparing approach is used. The prosthesis linkage is exposed through the release of the anterior, medial, lateral, and posterior capsule and of the muscle attachments.
- Accurate synovectomy is performed if metal debris is present. Metallosis involves further damage to the bone-prosthesis interface besides bone erosion and implant loosening. After excision of the blackened tissue, sufficient bone is removed to expose the locking mechanism (Fig. 14.6a, b).
- Exposure of the locking mechanism often requires bone removal from the lateral and medial humeral column.
- Before the joint is uncoupled, the implant is evaluated in varus/valgus angulation, and alignment is assessed. The implant is then checked for loosening by stressing the components and looking for abnormal movements, which may be subtle and minimal.

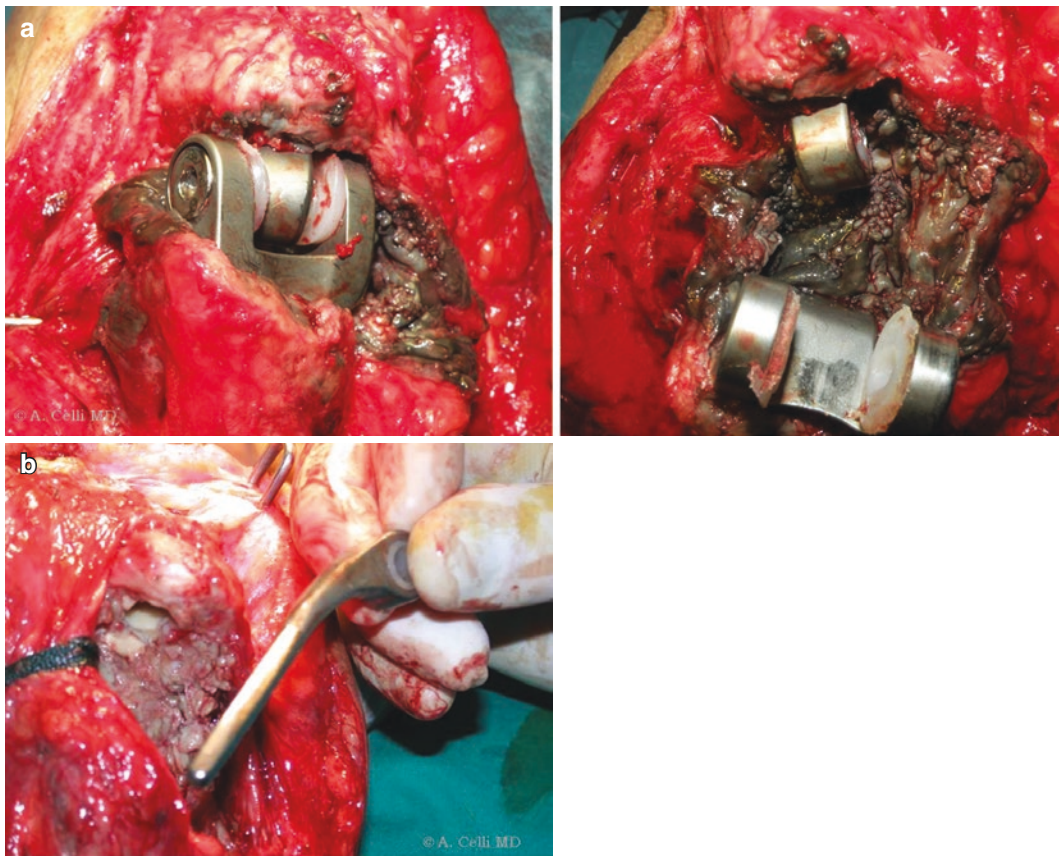

Fig. 14.6 (**a**, **b**) Excision of the blackened tissue; sufficient bone is removed to expose the locking mechanism

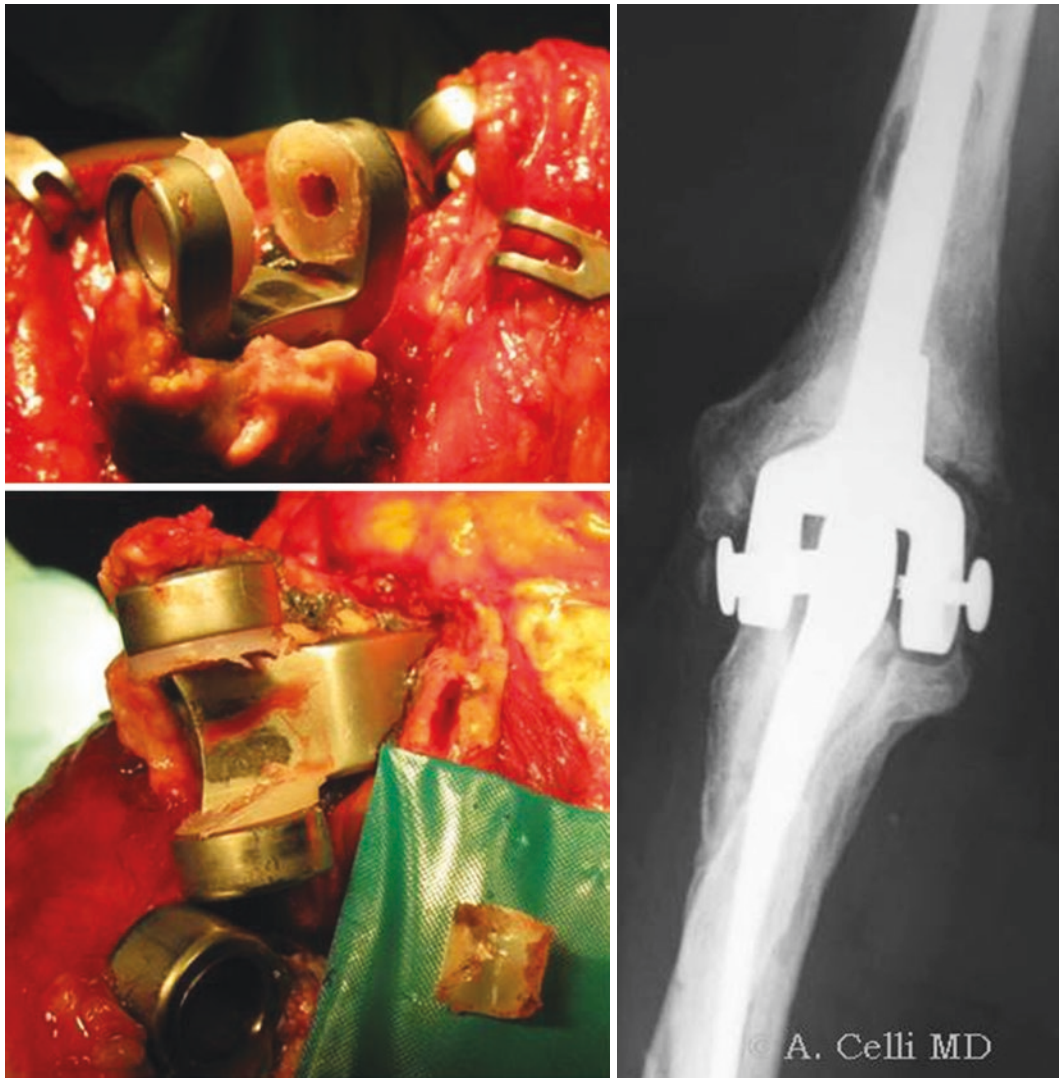

Fig. 14.7 The linkage is uncoupled, the joint is disarticulated, and the PE bushings on the humeral and the ulnar component are removed

- Soft tissue debridement at the prosthetic joint allows identifying bony voids. In these patients the bone-implant interface is examined for bone resorption. Loosening at the joint is commonly related to metal wear, whereas extensive osteolysis is more often due to stem loosening. If according to the preoperative x-rays and the intraoperative findings the surface wear is sufficient to compromise support of the prosthesis and bushings, or if the component is malaligned, the implant should be replaced to avoid bearing failure.
- The linkage is uncoupled, the joint is disarticulated, and the PE bushings on the humeral and the ulnar component are removed (Fig. 14.7).

The defect around the joint prosthesis is filled with PMMA bone cement. The new bushings are fitted and the joint is coupled.

- Restricted joint range of motion and ulnar implant maltracking may reflect soft tissue imbalance or component malalignment.

14.8 Aseptic Loosening and Reimplantation Procedure

In patients with extensive cortical osteolysis, bone-stem fixation may be partly preserved or it may have loosened.

- The most common cause requiring removal of a fixed component is progression of aseptic loosening with extensive periarticular osteolysis and implant malposition.
- Aseptic loosening with progressive bone resorption, cortical thinning, and enlargement (ballooning) of one or both canals weaken the bone and may predispose it to fracture. Before this occurs, surgical revision is indicated if the patient reports pain related to daily activities, even if the component is stable.
- After disarticulation of the humeral and ulnar component, all cement is removed from around their metaphyseal area using a fine osteotome or a high-speed bur, carefully avoiding damage to the bone stock. The components are inspected for loosening by stressing them and looking for any movement.
- An extraction tool may be attached to the implant and a longitudinal traction force applied. A slap hammer often provides a suitable direct force to break the bond between the implant and cement. Loose implants are easily removed (Fig. 14.8).

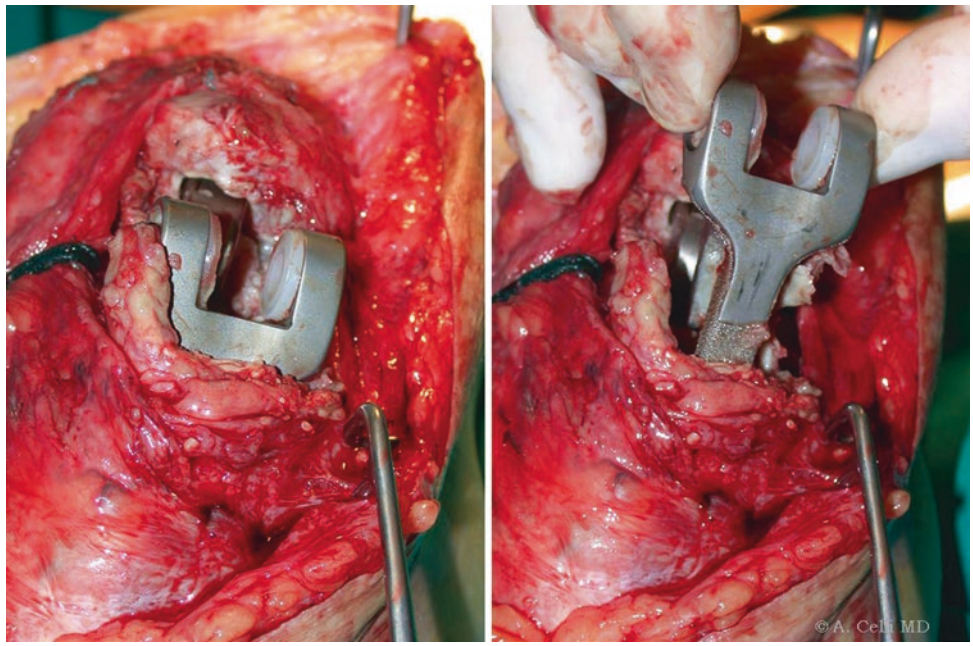

Fig. 14.8 Loose implants are easily removed

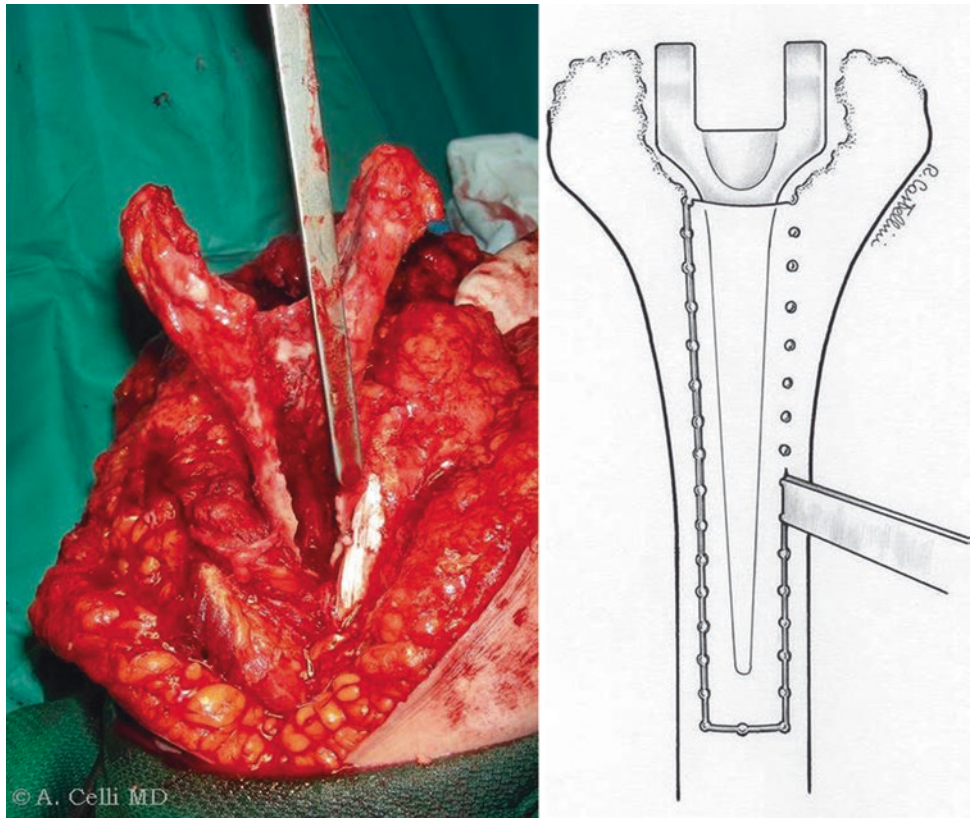

Fig. 14.9 A trapezoidal humerus osteotomy is created on the posterior aspect of the distal humeral cortex and extends proximal to the articulation and distally to the tip of the implant

- Failure to free the implant requires removal of the cement mantle, especially the bead-coated portion of the stem. Iatrogenic penetration of the humeral cortex may occur despite the use of small osteotomes and bur, increasing the risk of fracture of the thin cortical bone and of radial nerve injury. This may be avoided by a controlled osteotomy of the humerus and ulna.
- Humerus osteotomy (Fig. 14.9).
- A controlled trapezoidal osteotomy is performed on the posterior aspect of the distal humeral cortex, just proximal to the joint, taking care to preserve the lateral and medial column and the humeral condyles. The osteotomy can be extended all the way to the tip of the implant, to remove the cement beyond it and enable implantation of the new, longer component. An image intensifier should be used to ensure that the osteotomy is made at the correct site.
- Predrilling the humerus can be helpful. The bone window provides access to the cement, enabling safe removal of the implant and the cement. The bone window is closed and secured in place with cerclage wires before insertion of the revision prosthesis (Fig. 14.10).
- After cerclage fixation, an autogenous iliac crest graft is inserted along the osteotomy space to close any bony defects, enhance healing, and avoid cement extravasation. In patients with poor bone quality, the osteotomy site can be reinforced with a strut allograft.
- The humeral canal is cleared with pulsatile irrigation, and a cement restrictor is placed proximally to ensure that the humeral stem (long-stemmed implant) bypasses the site of the osteotomy by at least 2–3 cm. Also, sufficient bone must be preserved for the long

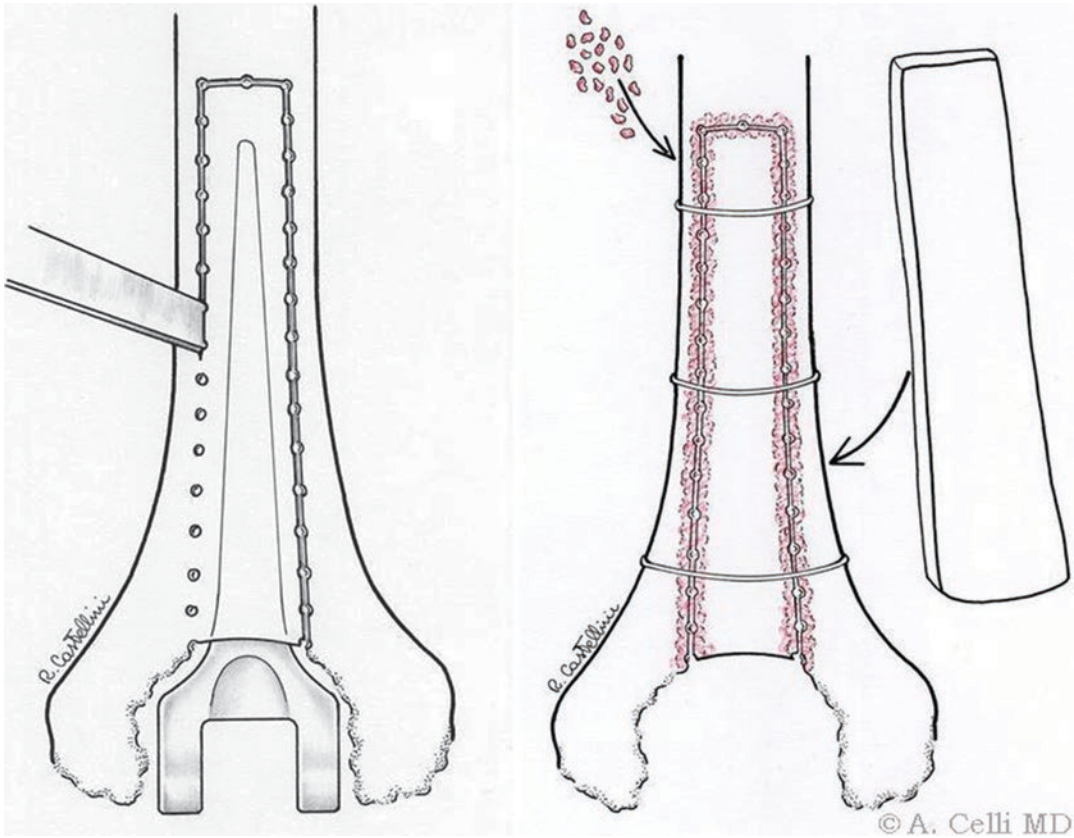

Fig. 14.10 The bone window is closed and secured in place with cerclage wires before insertion of the revision prosthesis

anterior flange of the revision humeral component.
- Cement is reapplied using a gun, choosing a nozzle size that fits the canal. Finally, the component is introduced into the canal.

14.8.1 Ulnar Osteotomy (Fig. 14.11)

- In patients with a fixed implant, the ulna may be osteotomized to expose and remove the prosthesis component and the cement mantle. The osteotomy is performed with a linear saw as a trapezoidal window on the medial aspect of the proximal ulna. Also in this case predrilling may be helpful. The osteotomy extends from the sigmoid notch to just past the distal tip of the component (2–3 cm). Often, the osteotomy includes not only the bone but also the cement. A small osteotome or a pencil bur is used to remove the cement surrounding the implant, to enable removal of the component with a slap hammer. The cement may be removed using a narrow osteotome and a bur. In the absence of infection, well-fixed cement can be left in place when it does not hamper insertion of the new component.
- The bone window should be reduced and fixed with cerclage wires before inserting the new implant. A bone autograft or allograft can be used to reinforce it (Fig. 14.12).
- The new ulnar component is cemented, carefully avoiding malrotation which would induce rapid bushing wear and component loosening.

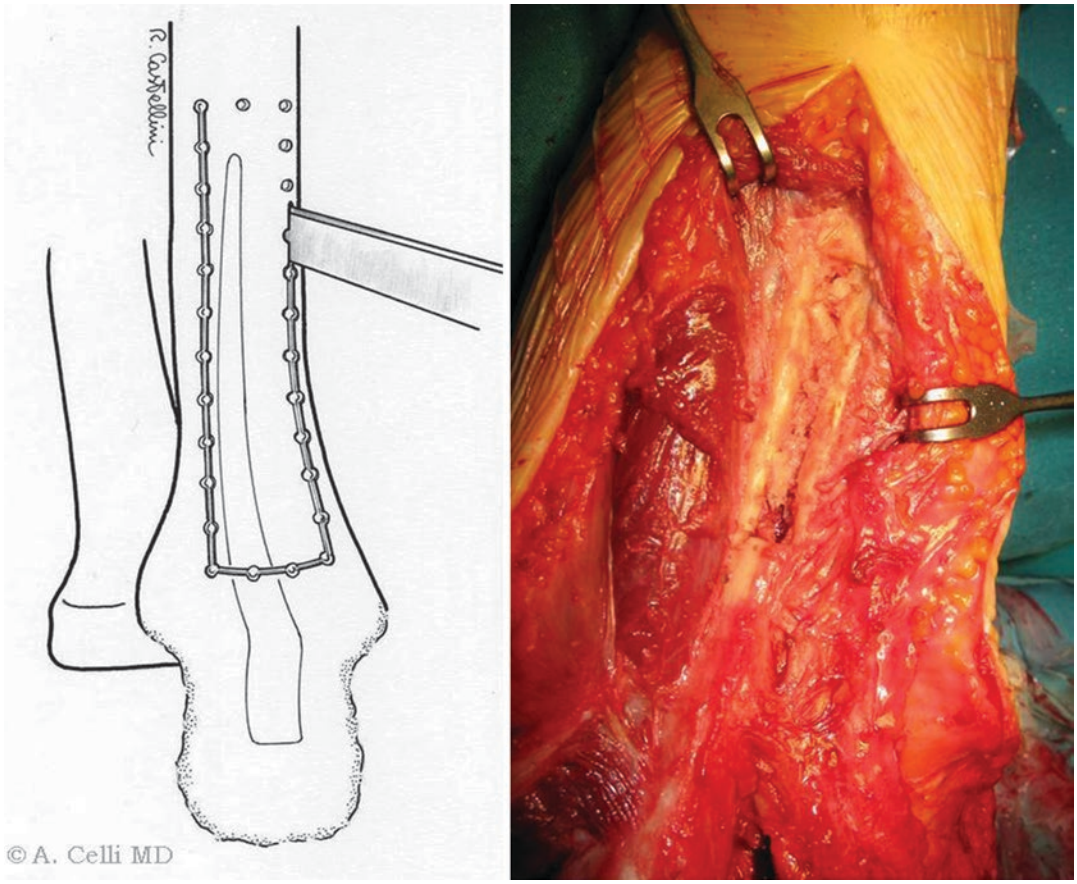

Fig. 14.11 The ulnar osteotomy is created on the posteromedial aspect of the proximal ulna. The trapezoidal bone window has to allow access proximally to the portion of the component and distally to the tip of the implant and distal cement

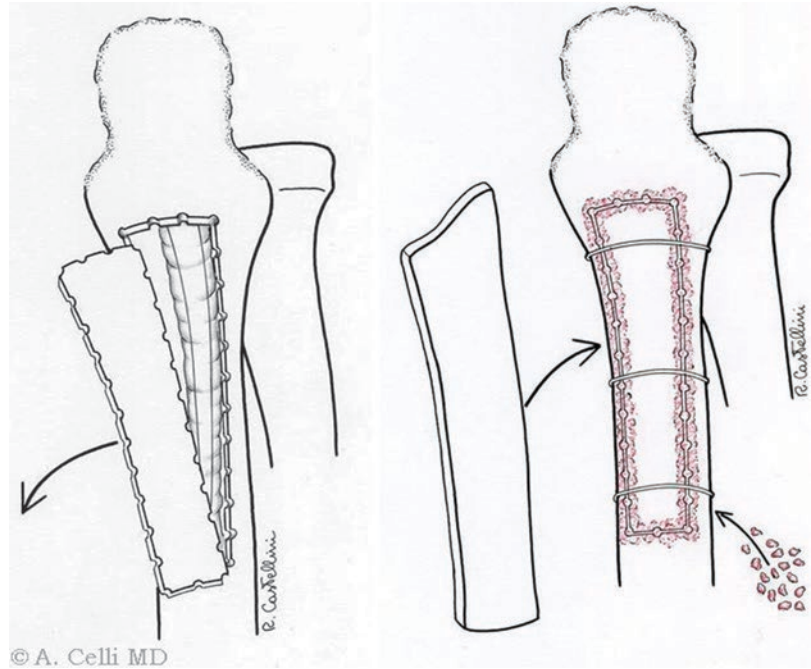

Fig. 14.12 The bone window should be reduced and fixed with cerclage wires before inserting the new implant. A bone autograft or allograft can be used to reinforce it

14.9 Impaction Bone Grafting Technique (Figs. 14.13, 14.14, 14.15, 14.16 and 14.17)

- Impaction grafting with a bone allograft uses cancellous chips measuring a few millimeters to treat patients where osteolysis induces cortical ballooning. It can be applied alone, to repair defects confined to the cortex, or else in combination with a strut allograft when thinned and fragile cortex requires strengthening.
- During removal of the loose component, membranous tissue, and cement mantle, care should be taken to avoid perforating the thinned cortex. Strut grafts are used to repair cortical defects.
- The intramedullary canal is then cleaned, and the portion beyond the affected tract is prepared for the new implant using stan-

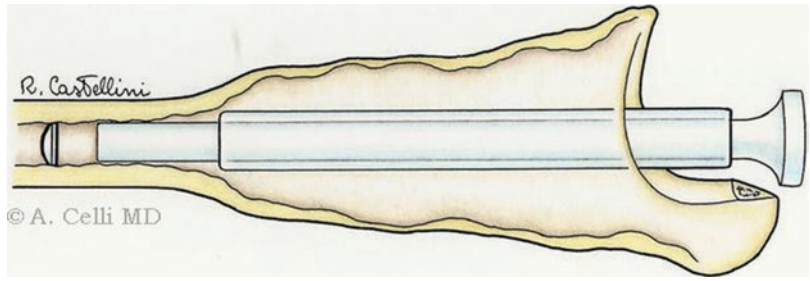

Fig. 14.13 A small diameter inner tube is placed into a larger diameter tube, and both are inserted through the intramedullary canal. The inner tube extends for 2–3 cm distally to the larger tube into the normal bone

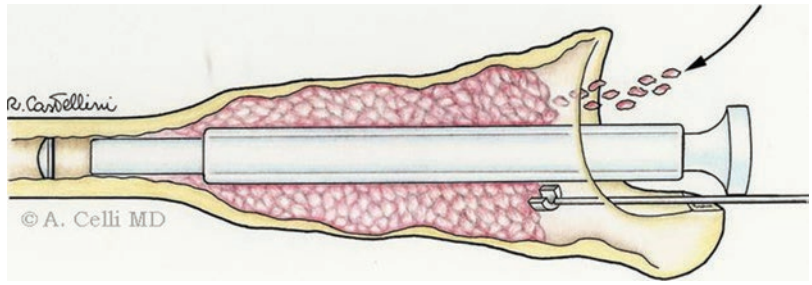

Fig. 14.14 The outer large tube has to be placed to the depth of the osteolytic cortical expansion (ballooning). The bone allograft as a fine mush or 2–3 mm fragment can be impacted around the larger tube

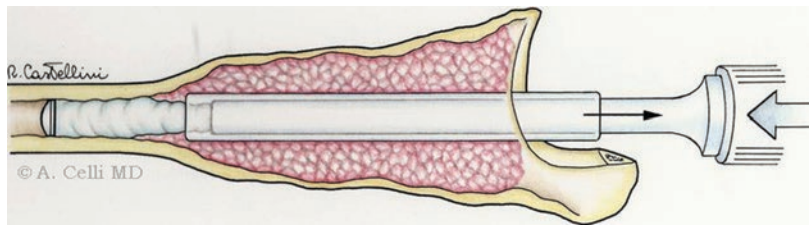

Fig. 14.15 The cement injected through the inner tube expands into normal intramedullary canal and delivers down into the uninvolved shaft

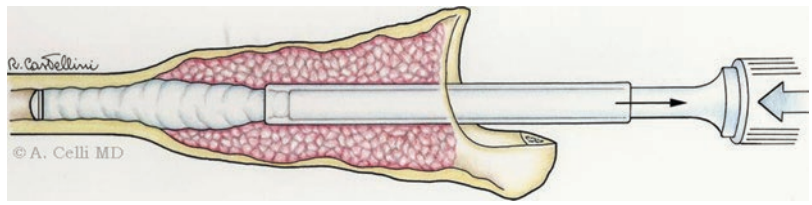

Fig. 14.16 The cement fills up into the void area created by the larger tube and the impacted bone graft, while both tubes are removed together

dard long-stemmed components. A long guide wire and fluoroscopic guidance can be useful not only to identify the unaffected area, thus avoiding additional injury to the cortex, but also to introduce the tubes for impaction grafting in correct position into the canal.

- A larger tube 1 cm in diameter is inserted across the expanded bone; a smaller tube is inserted through it and driven into normal host bone [19].
- Bone chips measuring 2–3 mm are collected, often with a small acetabular reamer used for femoral head allografts. The allograft must have a thick, soft, fine mush consistency.
- The bone graft is tightly packed around the larger tube against the expanded host cortex.
- After the ulna or humerus has been filled with allograft bone, the cement cartridge is attached to the adapter of the cement delivery system and to the inner tube.
- The cement is delivered into the uninvolved bone, and then the two tubes are withdrawn together as cement is delivered into the canal.
- The long-stemmed revision component is inserted through the cement and the impacted bone graft into normal host bone.
- Impaction grafting may also be performed without tubes. In this case space for the implant and the cement mantle is preserved by inserting the largest trial implant and holding it in the center of the canal; the bone chips are packed into the defect and gently impacted around the implant with a bone puncher until the canal has been filled. The trial implant is then removed and a narrow cement nozzle is introduced into the canal. The definitive long-stemmed implant is then cemented. During extraction of the trial implant and the introduction of cement, care should be taken to prevent the graft material from obstructing the canal, thus blocking implant insertion [19] (Figs. 14.18 and 14.19).

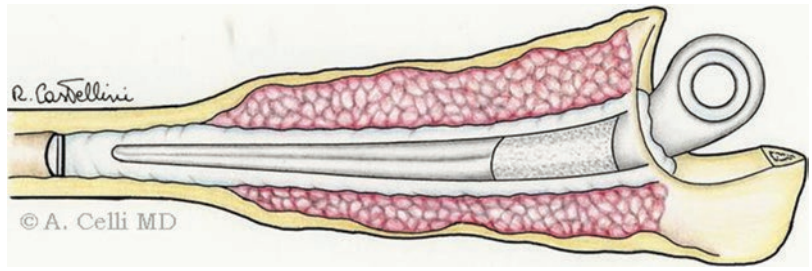

Fig. 14.17 The long stem implant is inserted into the cement-filled neo-canal and down into normal medullary canal

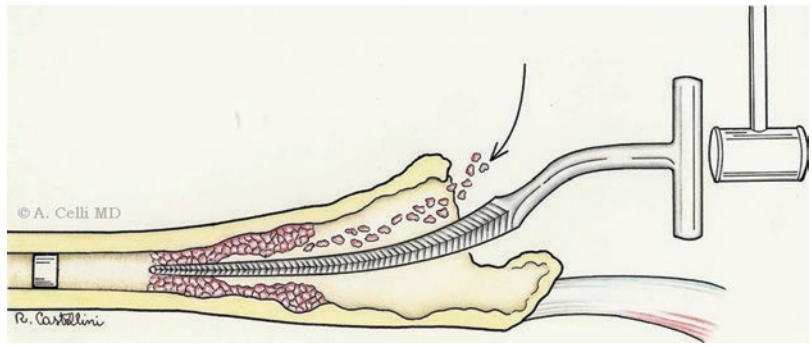

Fig. 14.18 Large size trial implant may be used instead of "tube-in-a-tube technique." The trial is placed into the canal through the osteolytic bone being sure the tip enters into the normal canal

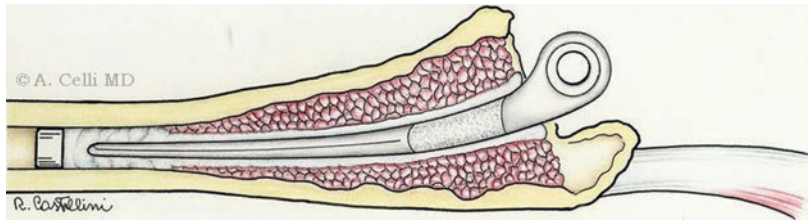

Fig. 14.19 The cancellous bone-chip allografts are impacted around the trial until the cortical expansion is filled. The trial is then removed, and the cement is injected using a narrow cement nozzle, and the component is implanted. Be careful to avoid that the allograft dislodge into the neo-canal and block the cement and implant insertion

14.10 Conclusion

- Aseptic loosening of TEA may result from several causes:
  - PE wear at the hinge with formation of black particulate debris (metal-on-metal contact), which gives rise to synovitis and osteolysis.
  - Humeral stem in varus/valgus or rotation malposition, which may alter implant function.
  - Ulnar stem rotational malposition, which may predispose to instability and wear at the hinge.
  - An excessively deep-seated ulnar stem, which involves coronoid impingement on the anterior flange of the humeral component during elbow flexion. The result is limited elbow flexion with proximal to distal pistoning of the ulnar component through the ulnar canal and ultimately loosening of the bone-cement interface. Coronoiplasty reduces the risk of pistoning.
  - An inadequate cementing technique, which produces an irregular cement-bone interface with insufficient stem fixation.
  - Patient non-compliance in relation to heavy manual labor or high-level recreational activities, which remains an absolute contraindication.
- Revision of TEA due to aseptic loosening is a technically demanding procedure.
  After careful clinical and radiological assessment to establish the mode of failure, the most common surgical revision procedures are:
  - Bushing replacement.
    The osteolysis often involves the humeral articular surface up to the olecranon fossa and the portion of the ulna around the olecranon process proximal to the stem.
  - Where fixed components are involved, controlled osteotomy with a trapezoidal window facilitates implant and cement removal, avoiding iatrogenic fracture or cortical perforation. The window graft is secured in place after reinsertion of the component.
  - Impaction grafting
    Restoration of the bone stock and of implant stability are critical for the success of revision surgery. Impaction grafting should be considered in patients with a significant metaphyseal bone defect confined within a thin cortical shell: Osteolysis causing cortical expansion (ballooning).
- Revision due to aseptic loosening is a demanding procedure with a higher rate of complications compared with primary arthroplasty. However, in the hands of an experienced surgeon, advanced implant design and improved cementing techniques provide good clinical outcomes and patient satisfaction.

Declaration of Conflict of Interest No potential conflicts of interest are related to this manuscript.

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15 Revision in Total Elbow Replacement with Bone Stock Loss: Surgical Technique and Expected Results

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Elbow arthroplasty has some unique characteristics compared to the other joints; in fact, the elbow is small in dimensions, and its stability is widely dependent on ligamentous integrity. Despite the continuous evolution of implants and surgical techniques, there is still a percentage of complications, such as loosening, infection, triceps weakness, and ulnar neuropathy. When revision surgery becomes necessary in presence of bone loss, bone augmentation techniques provide a reasonable outcome.

Mobilization of total elbow arthroplasties are fairly infrequent conditions that, especially in case of bone loss, lead the surgeon through a difficult decision-making process: the surgery is technically very demanding; the skin conditions are often complicated by previous scars, retractions, and atrophy; and the risk of infection is always high. There is necessity of multiple surgical equipments, grafts, and dedicated instruments. On the other side, procrastinating the surgery exposes the risk of further bone loss, worsening muscle atrophy and increasing the risk of fracture.

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It is essential to understand the mechanism of failure of a prosthetic implant, immediately distinguishing between failures due to an underlying infection and those due to an aseptic loosening, or a periprosthetic fracture. Aseptic loosening is the most frequent cause of failure [1, 2] with a variable incidence in different case series, based on the indication to surgery and the type of implant used (the more the prosthesis is constrained, the greater the probability of mobilizing), and reaches up to affect 15% of total elbow prostheses [3]. The aim of this chapter is to examine the failure of total elbow arthroplasty by aseptic loosening with bone deficiency that represents the major technical obstacle in aseptic loosening.

15.1 Clinical Examination and Preoperative Evaluation

The majority of patients requiring prosthetic revision are elderly, with a high incidence of associated general conditions. The symptoms of an aseptic loosening are often insidious and subtle because only the patient usually complains a non-defined pain. In more advanced stages, the bone loss increases, and instability is associated to pain, with the patient reporting difficulty in controlling the forearm and the hand during the rotation movements, so that the joint can assume the typical characteristics of the floating elbow. An accurate interview is mandatory, also to evaluate the presence of risk factors for infec-

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tion (such as previous infection, previous elbow surgery, presence of diseases that may cause secondary immunosuppression as diabetes mellitus, psoriatic arthritis, or severe rheumatoid arthritis). It is also important to know the patients' work and recreational activities, in order to support the possibility of mechanical failure.

During the physical examination, it is necessary to evaluate the skin conditions, the presence of redness and/or secretions, and the state of previous surgical scar. Subsequently, the angle of valgus and the active and passive ROM in flexion-extension and pronation-supination will be examined, along with the generation of pain and metallic sounds by the implant during movements. Finally, it is necessary to check the stability of the elbow and to evaluate the functionality and the previous anterior transposition of the ulnar nerve. A complete blood check is essential, evaluating full blood count, hemoglobin, erythrocyte sedimentation rate, and C-reactive protein. During the consult, the patient must be carefully informed of the difficulty of the procedure, which often is able to offer results that only partially meet the patient's expectations. The possible complications must be explained, including risks of nerve injuries, infection, early or late loosening of the implant, intraoperative and postoperative fractures, and so on.

15.2 Imaging and Preoperative Planning

Due to the high demanding feature of these procedures, it is essential to perform an accurate preoperative surgical planning. Plain anterior posterior and lateral radiographs are mandatory, which must include all the humeral and ulnar sides up to normal bone: it is important to observe the level of intramedullary cementation and any possible hardware, stress fracture, or bone alteration present close to the revision site. Radiographic studies of the opposite unaffected elbow should be used in preoperative planning to estimate the size of the required humeral or ulnar graft. A CT scan is often useful, in order to better visualize and understand the areas of bone deficiency and to plan the number and position of grafts and plates. Recently the dual-energy CT scan reported good results in visualization of bony structures in presence of metallic hardware, and it may improve the evaluation accuracy, if available [4].

Finally, a strongly specific procedure (when positive) in detecting bone infections is the white blood cell scintigraphy.

15.3 Treatment Options

In some selected cases, it can be decided to continue with conservative treatment with the use of a permanent splint. This decision is based on patient characteristics, risk factors, and local conditions at the elbow, when the risk of local and general major complications is consistent.

The classification we prefer to use to perform the preoperative planning is the one proposed by Stanley [5] in 2012. This classification is simple and useful for planning the kind of revision.

In this classification, bone loss is divided into three types (Fig. 15.1):

1. Type 1 – Minimal bone loss.
2. Type 2 – Intramedullary bone loss.
3. Type 3 – Structural cortical bone loss.

The surgical revision must be able to provide a bone augmentation to overcome the defect. There are three main types of grafts:

1. Cortical grafting.
2. Cancellous grafting.
3. Allograft prosthetic composite (APC).

The choice of the type of surgery should be guided by the size and location of loss of bone substance. In any case the use of a graft is mandatory in prosthetic revisions with loss of bone stock, mainly because the graft increases the bone stock, helps to bridge bone defects, and provides temporary structural support for implant stability.

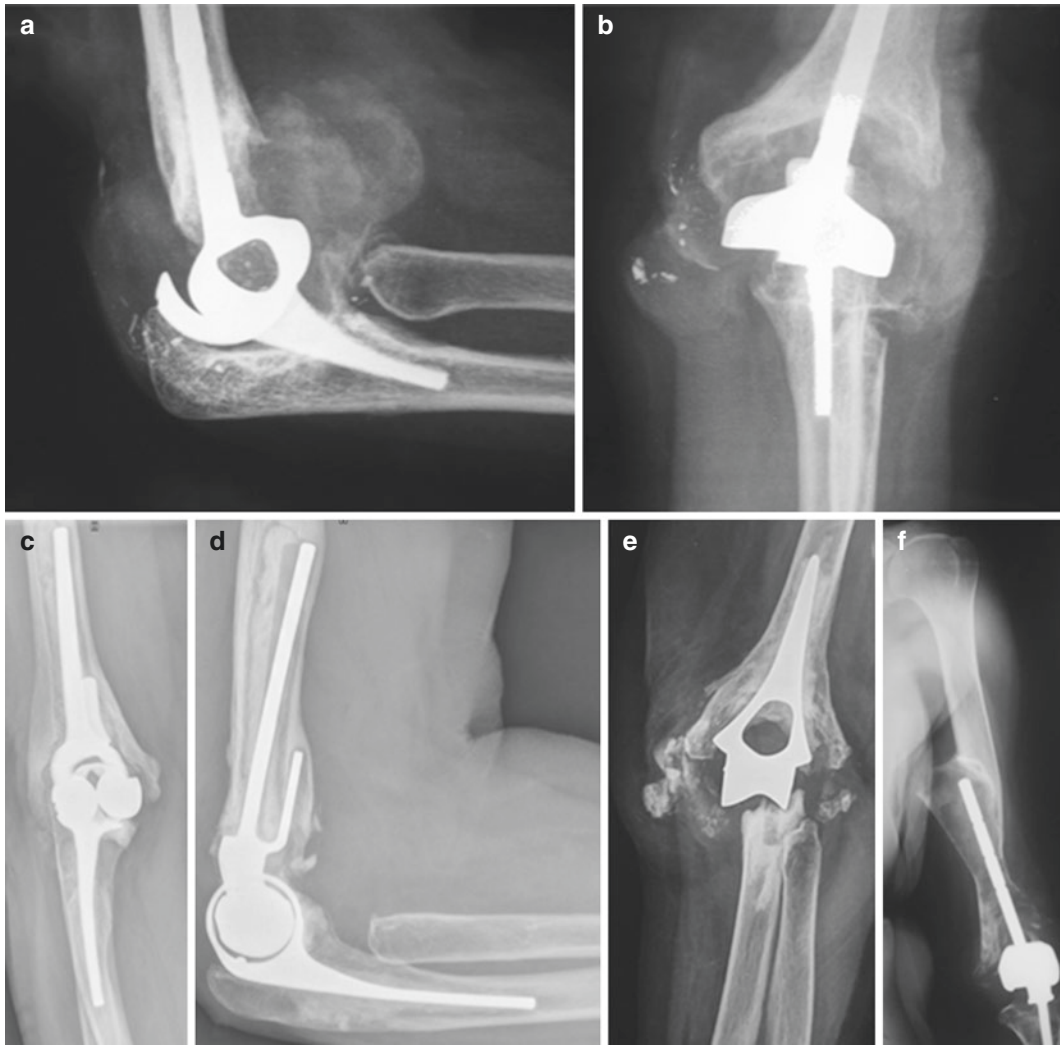

Fig. 15.1 (**a**, **b**) Type 1: minimal bone loss. (**c**, **d**) Type 2: Intramedullary bone loss. (**e**, **f**) Type 3: structural cortical bone loss (**e**, ulnar bone loss; **f**, humeral bone loss)

15.3.1 Type I

15.3.1.1 Minimal Bone Loss

Minimal bone loss (Fig. 15.1a, b) is more frequently seen in patients with a long follow-up, rather than in patients who recently underwent to an elbow replacement. In this type the bone loss affected the metaepiphyseal region, and it does not involve the prosthetic stem (Fig. 15.2). This type of bone loss can be related to the development of metallosis and to polyethylene usure which lead to the development of granulation tissue. If the bone loss is minimal, it is possible for the surgeon to use a standard prosthesis during the revision surgery, filling the bone loss with cement [6] (Fig. 15.3).

15.3.2 Type II

15.3.2.1 Intramedullary Bone Loss

In type II bone loss, the medullary periprosthetic bone is involved, with the cortical bone typically thinner but preserved (Fig. 15.1b, c). In this case

the surgeon should completely remove the prosthesis and the cement. The best option is the intramedullary removal of the cement, but if this cannot be easily achieved, the surgeon can perform a bony window, with the recommendation to cut it along the thicker side of the diaphysis. The length of the window is very important: it should comprise the endomedullary cap, and it should be at least 1/3 of the diaphyseal diameter, and, to ease a better bone contact during the repositioning of the removed cortical bone, an oblique osteotomy has to be preferred (Fig. 15.4a, b).

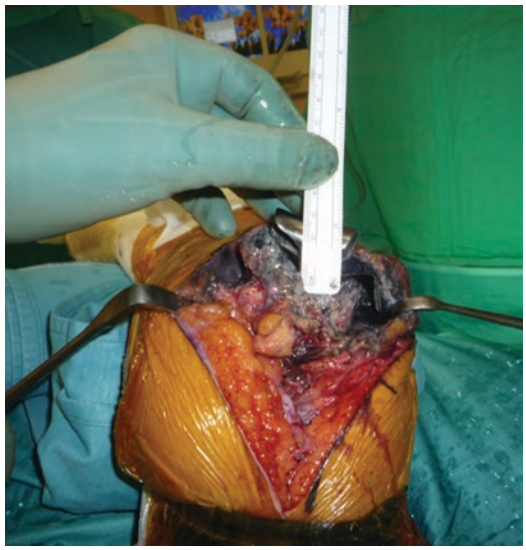

Fig. 15.2 Intraoperative measurement of the bone defect

15.3.3 Type III

15.3.3.1 Structural Cortical Bone Loss

Massive bone loss can involve the distal humerus, less frequently the proximal ulna or both the bones (Fig. 15.1e, f). In structural cortical bone loss, the revision surgery is based on the bone loss pattern: if the cortical walls are mostly preserved, the surgeon can simply fill the endomedullary space with bone chips and strengthen the cortical wall with a cortical graft. If the bone is not adequate or mostly absent, it is necessary to use the APC technique.

In the first technique, the cortical graft can be positioned both on the humeral and ulnar surfaces. The cortical graft has the aim of mechanical support, and, later on, it has an important role during the integration and the remodeling of the periprosthetic bone. The use of cancellous bone graft allows to fill the frequently associated intramedullary bone loss and to reduce the amount of cement needed.

The patient may be placed in supine decubitus, with the affected limb across the chest or in lateral decubitus. We generally prefer lateral decubitus because the humerus is more stable in

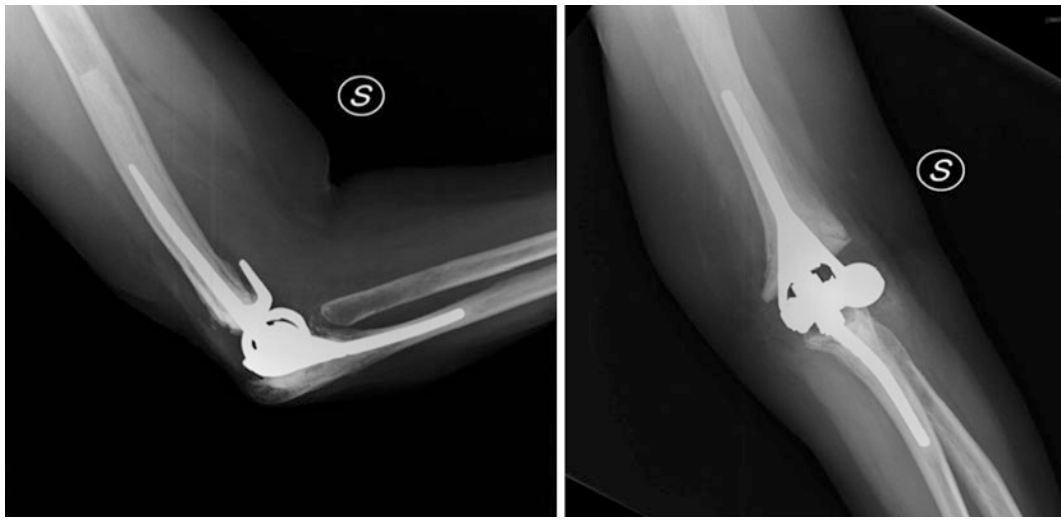

Fig. 15.3 Post-op X-rays of type 1 bone loss

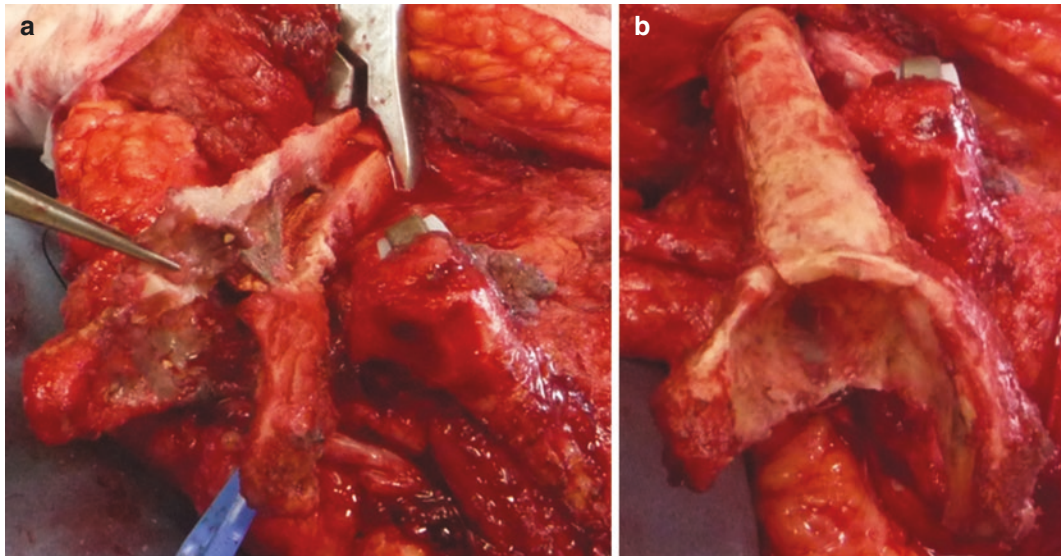

Fig. 15.4 Type 2 bone loss. (**a**) Bony window performed to remove the previous cement. The length of the window should comprise the endomedullary cap, and it should be at least 1/3 of the diaphyseal diameter. To ease a better bone contact during the closure of the window, a trapezoidal osteotomy has to be preferred. (**b**) Closure of the bone window, after the cement removal with the help of osteotomes and high-speed burr (take care to maintain as more bone stock as possible)

the arm holder. Once the sterile tourniquet is positioned, the skin incision is performed, usually reproducing a previous scar which, generally, is posterior. However, based on the necessities, it is also important to consider the potential benefit of using a new incision, and in case of relevant differences with low risk of skin sufferance, this path is to be preferred. When ulnar nerve is compressed, it must be released as first step, evaluating an anterior transposition, if not already performed. The surgical approach then depends on the surgeon's preference. In our unit, we prefer to use the TRAP approach [7] which consists in the isolation and detachment of the anconeus from ulna and the guide of this muscular flap to detach the triceps from the olecranon with a small bone fragment (Fig. 15.5). This approach allows the surgeon to keep the extension apparatus intact in all its soft tissue components, even if it detaches from its bone insertion.

Once the prosthesis has been reached, it is necessary to evaluate its mobilization and the presence of metallosis or polyethylene debris and carefully remove them. The quality of reliable

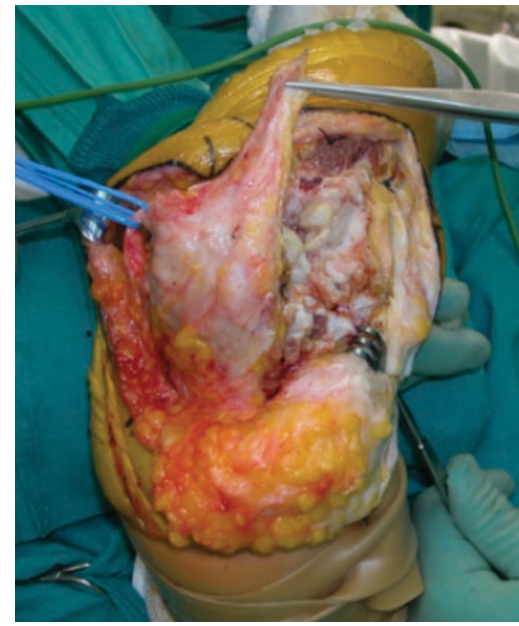

Fig. 15.5 TRAP approach described by S. W. O'Driscoll: the anconeus is isolated and detached from ulna and used as guide to detach the triceps from the olecranon with a small bone fragment. In this case we use a TRAP approach for an APC technique

bone tissue e is often poor with the majority of the local bone stock porotic and thinned, requiring special care when removing the prosthetic components. Periprosthetic intraoperative fractures must be carefully avoided, since they can lead to major difficulties and complications. Once the prosthesis has been disassembled, the mobilized prosthetic component (in most cases the humeral component) and the cement layer are removed with the help of osteotomes and high-speed burr, taking care in maintaining as more bone stock as possible. To help the component removal in case of valid fixation, a bone window (posterior to the humerus or on ulnar medial side) of trapezoidal shape is executed (Fig. 15.4). The bone stumps are regularized until viable bone tissue is reached.

From the bone window, it is possible to insert cancellous grafts to fill up any intramedullary bone loss and to perform a new cementation (Fig. 15.6) with a cement gun (generally with addition of vancomycin). At this point, we proceed to the preparation of the cortical graft. It is always preferable to use a graft from the same anatomical region, modeled to follow the native humeral or ulnar curvature [8, 9].

The graft is prepared using special cutting guides following the pathoanatomy of the bone loss.

The graft may be single or double (at the humeral level), if the patient's bone is extremely osteoporotic. In case of use of a single graft, this is to be positioned posteriorly; if double, a 180 ° configuration is preferred (front and rear) (Fig. 15.7a). In the ulna the graft is usually placed medially, to avoid impingement with the radius or, less frequently, posteriorly, in order to create

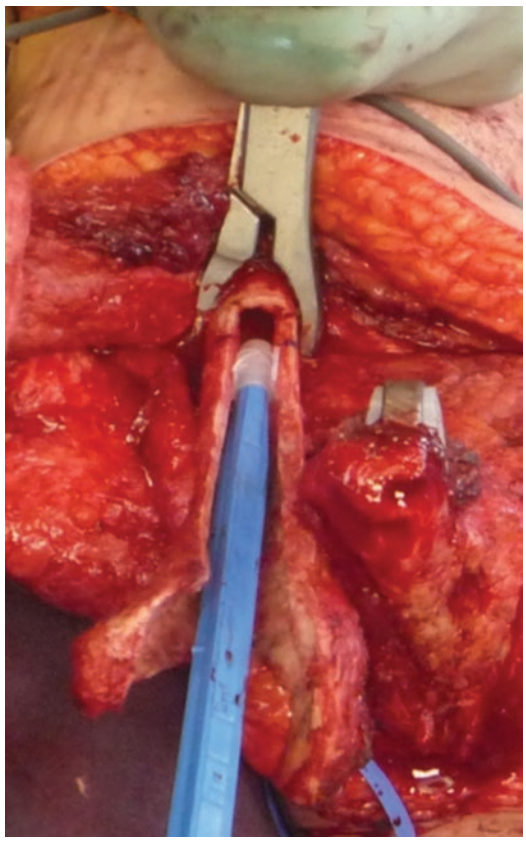

Fig. 15.6 This picture shows the cap insertion through the bone window, before filling the canal with the new cement

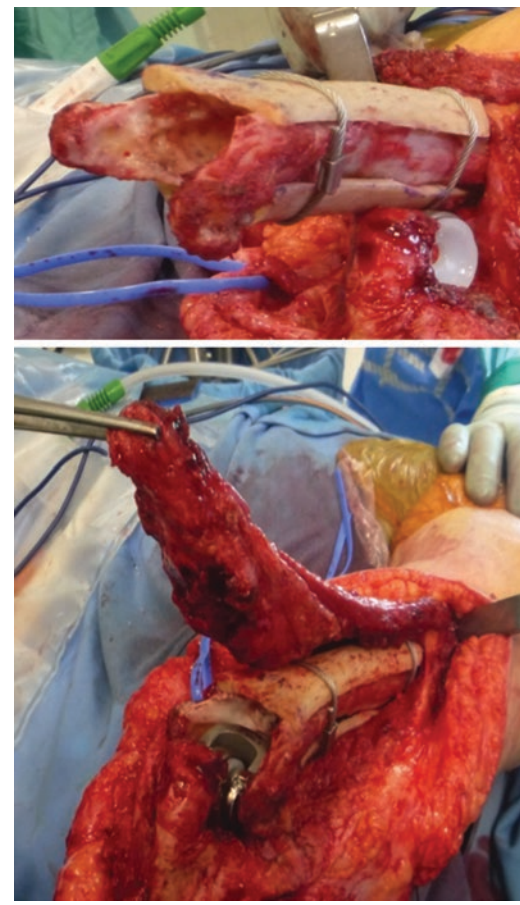

Fig. 15.7 The prosthetic components to be implanted should be the ones with the longest stem available, to ensure greater stability. In figure **a**, double cortical graft (front and rear) and graft fixation with metallic cerclages have been performed. Figure **b** shows the final implanted construct

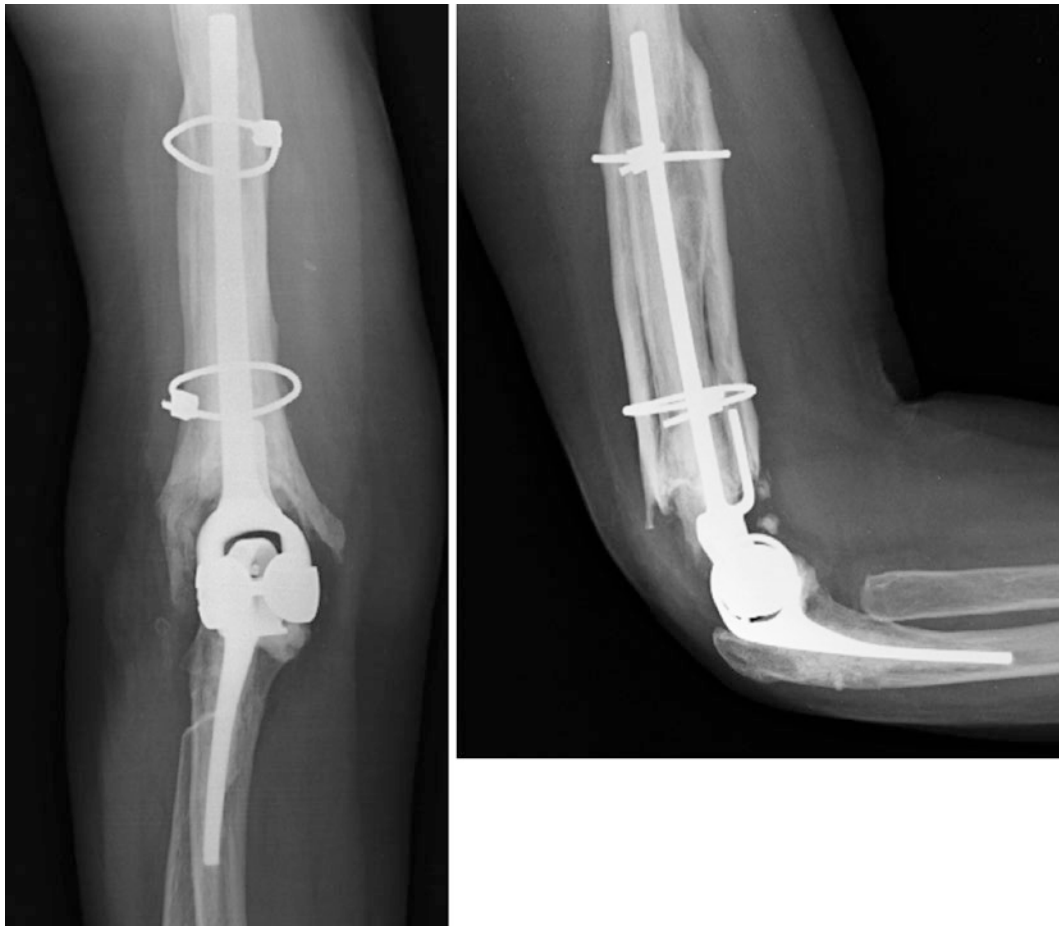

Fig. 15.8 X-rays of the case reported in Fig. 15.6 at 1 year of follow-up, showing a good allograft integration

support for the triceps tendon. In the event of a periprosthetic fracture, the graft must overcome the fracture line for the length of at least two cortical screws, to ensure the correct structural support. The prosthetic components to be implanted should be the ones with the longest stem available, to ensure greater stability. After closing the bone window and having positioned the implant trial, the graft is fixed with metal cerclages (Figs. 15.8 and 15.9). Furthermore, the cortical graft can also serve as a containing device for cancellous bone grafts, which can improve bone integration.

At this point the prosthesis is made integral with the graft, and it is possible to proceed with cementing and positioning of the final construct. Once the cement has polymerized, the two components (humeral and ulnar) are assembled.

A key point for a good implant functioning is the correct tension of soft tissues and extension apparatus (Fig. 15.7b) that might be difficult to achieve in case of bone loss, since there may be no landmark to be used. We usually take the length measure following the extensor apparatus: once the trial prosthesis is in situ, the elbow is reduced, and the extensor mechanism, if detached, is temporary place in situ. Then, with the elbow at 90° of flexion, the components are pulled out from the relative bones until the triceps is properly tightened: the length of the component fitted into the bone canal is marked, and the measures will be reported in the definitive components as limit to be inserted.

The use of allograft prosthetic composite (APC) should be considered as a valuable salvage option in selected patients with failed total elbow

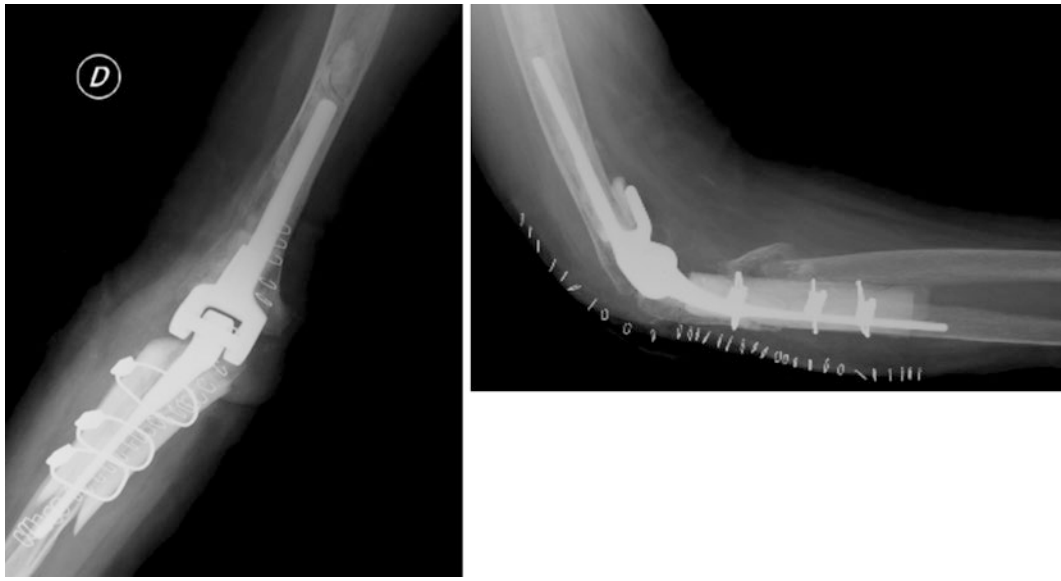

Fig. 15.9 In this case the bone loss involved mainly the proximal ulna. Surgery was performed with double cortical grafts and metallic cerclages

arthroplasty with massive bone loss, in which other graft types are not feasible. APC grafts are especially indicated for patients with major bone defects (4 cm or greater) [8] that entirely involve the olecranon, the ulna in its proximal third, or both [10]. The suspect of acute or subacute infective process should be considered as a major contraindication to the use of these grafts.

In the APC technique, graft size has to be very accurate, in order to perfectly fit the prosthetic components. In addition, prior to set the prosthetic components, it is mandatory to achieve the right graft rotation, as it has to perfectly match with the patient's bone. Then cement is used to fix the prosthesis in the allograft, and both this component will be united with the host bone (Fig. 15.10).

Finally, the use of a bridge plate fixed with screws to increase the stability of the entire construct is advised; alternatively or in addition, metal rims can be used, being careful not to break the host bone or the cortical graft [1] (Fig. 15.11).

15.4 Discussion and Conclusions

Elbow prosthesis revision, especially in case of bone loss, is very demanding. This is a salvage surgery which requires great attention of the surgeon in these important steps:

1. A septic failure has to be excluded, with the evaluation of blood exams and eventually with a scintigraphy and cultural exams.
2. It is very important to design a correct preoperative planning in order to choose the right surgical technique for each case and in order to plan the use of a graft.

If the remaining cortical is sufficient to cover the prosthesis and to avoid an implant loosening, the use of cortical strut grafts, associated with cancellous bone grafts, will be preferred. In case of a huge amount of cortical bone loss, we prefer an APC technique, always considering that elbow replacement surgery (and especially in case of

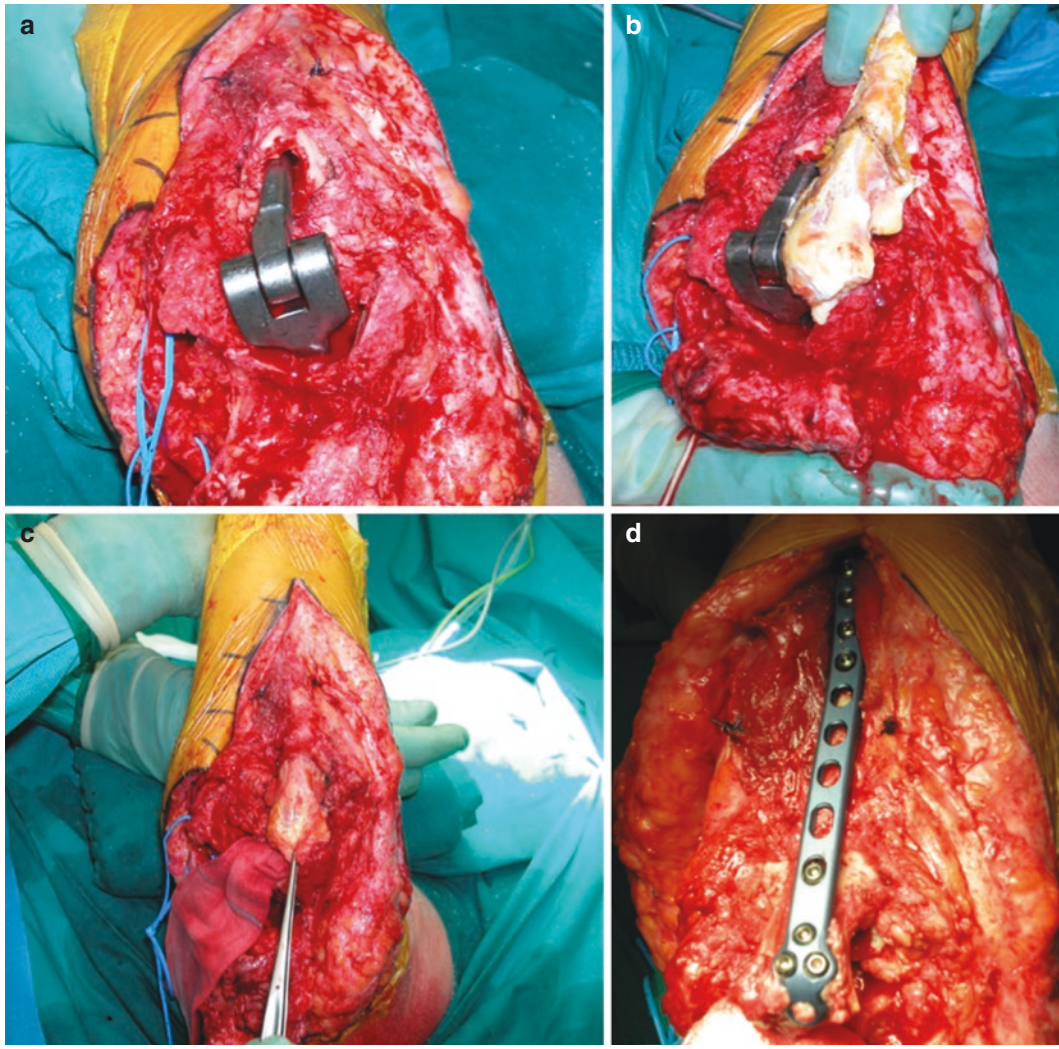

Fig. 15.10 APC technique. The optimal prosthetic position evidences a massive ulnar bone loss (**a**). In order to fill this gap, a proximal ulna bone graft is shaped as required (**b**). The prosthesis with the graft are positioned in the host bone (**c**) and fixed in situ with plate and screws (**d**)

revision) carries out high complication rate. Sanchez-Sotelo and other main authors in their experience in revision surgery report an incidence of 6 of 11 complications. The most frequently reported are periprosthetic fractures and cortical perforation during the removal maneuvers due to a lack of bone stock; these two complications together can reach up to 75% of the incidence rate and generally affect the ulnar component. Another fairly frequent complication is represented by nerve injuries (incidence ranging from 6% to 27% in different case series); the nerve most frequently affected is the ulnar nerve, which we always recommend to anteriorly transpose if not already

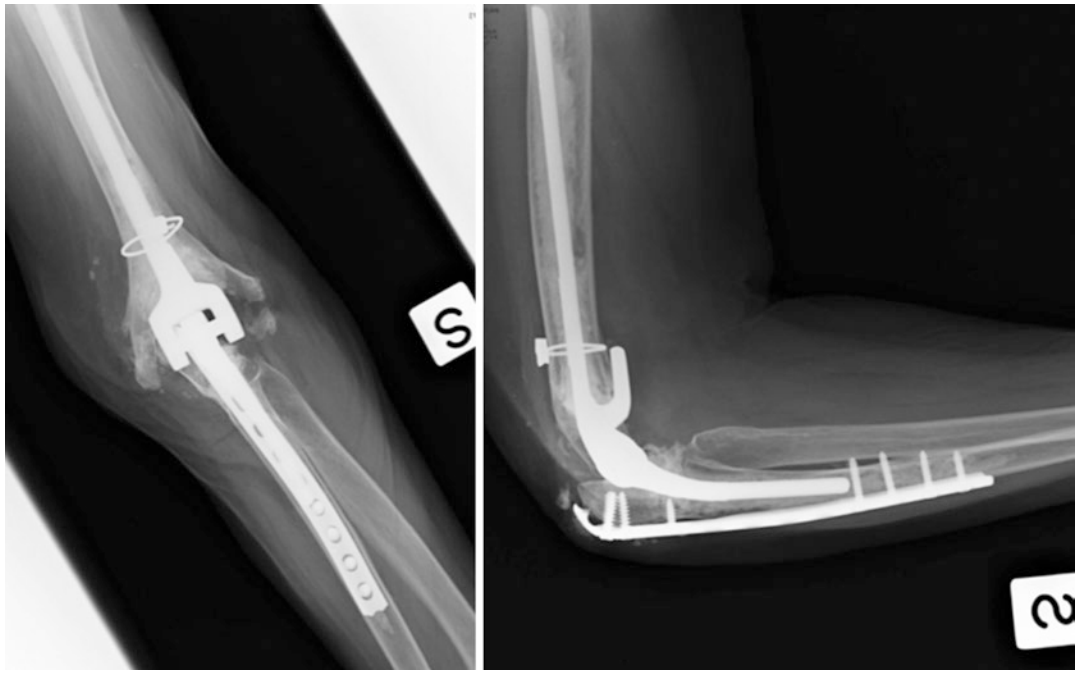

Fig. 15.11 One year Fu X-rays which show signs of good consolidations between the APC and the host bone

done, but median or radial nerve can also be affected. Radial nerve injuries are mostly reported as a result of unexpected cement leakage from accidental perforations of the cortical humeral or during cement removal, which is why we recommend to isolate and protect the radial nerve prior to implant removal. Other common complications are infections and skin problems due to previous surgical scars. Triceps insufficiency or its avulsion is reported in different cases from 4% to 9%, and the treatment can be both surgical or nonsurgical based on the functional requirements of the patient. Finally, the last complication that can occur is the aseptic mobilization of the implant.

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Resection Elbow Arthroplasty: Expected Clinical Results

16

Peter Constantine Zarkadas
and Gabriel Jonathan Tobias

16.1 Introduction

When compared with total hip [1] or knee arthroplasty [2], TEA has been identified as having a significantly higher incidence of postoperative infection [3]. Literature reports that despite great effort to reduce perioperative infection, up to 12% [3, 4] of TEA procedures are complicated by infection. Infection following TEA is concerning because management options are limited. Once a deep prosthetic infection is identified, treatment options include long-term antibiotic suppression, debridement and retention of prosthesis, and one- or two-stage revision with reimplantation, arthrodesis, resection, or in the extreme case amputation [3, 5]. The most common modality of treatment following a postoperative infection is a two-stage revision [6–9]. Reimplantation however puts the patient at risk for further surgical intervention and reinfection [3].

Studies out of Germany [10–12] and Italy [13] have previously described resection in a post-traumatic setting. Based on the positive early results in the post-traumatic setting, it was suggested that elbow resection may produce results superior to those of arthrodesis [10–13]. The indication for elbow resection as the definitive procedure includes medically frail patients, poor bone stalk following resection, patient choice, or refractory prosthetic infections resistant to all treatment options [9].

16.2 Organisms of Infection

The timing of infection can help provide information on guidance of management, as well as the likely causative organism of infection [14]. As seen with early (<3 months) infections, the most common organism encountered are those related to the surgery itself, namely, *Staphylococcus aureus* [15]. Other organisms associated with early-onset infections are gram-negative bacilli, anaerobic organisms, and infections that are of a mixed type [15].

Like early-onset infections, delayed-onset infections, or infections that occur between 3 and 12 months after surgery, are infections that usually arise during implantation of the prosthesis [5]. Because these infections are slow to progress, they are often associated with organisms such as coagulase-negative staphylococci or enterococci that are considered less virulent [5].

Late-onset infections are those that occur greater than 12 months after surgery and are the product of hematogenous seeding [5]. Typical organisms seen in late-onset infections are *Staphylococcus aureus*, beta-hemolytic streptococci, or enterobacteriaceae [5].

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Table 16.1 Summary of different microorganisms cultured during elbow resection. Staphylococcus species (54.9%) was the most common bacterial cultured. Long-term outcome of resection arthroplasty for the failed total elbow arthroplasty

Organism	Frequency ($N = 51$)	Percentage
Methicillin-sensitive *Staphylococcus aureus*	15	29.4
Methicillin-resistant *Staphylococcus aureus*	2	3.9
Methicillin-sensitive *Staphylococcus epidermidis*	9	17.6
Methicillin-resistant *Staphylococcus epidermidis*	2	3.9
Serratia marcescens	1	2
Clostridium difficile	1	2
Mycobacterium	1	2
Propionibacterium acnes	1	2
Pseudomonas aeruginosa	1	2
Multiorganism[a]	10	19.6
No bacteria cultured	8	15.7

[a]Multiorganism is defined as more than one bacterium cultured

Reproduced with permission from Zarkadas PC et al. J Bone Joint Surg Am. 2010 Nov 3;92(15):2576-82

In a study of ten resection arthroplasties for PJI, Rhee et al. [4] found that the majority (80%) of their population suffered from delayed-onset infections. Of the infections that organisms were grown from, the following were represented: *Pseudomonas aeruginosa*, methicillin-resistant *Staphylococcus aureus*, methicillin-sensitive *Staphylococcus aureus*, and coagulase-negative *Staphylococcus* [4]. A study by Yamaguchi et al. found S*taphylococcus* as the main infecting organism in a group of five patients who underwent elbow resection [9] (Table 16.1).

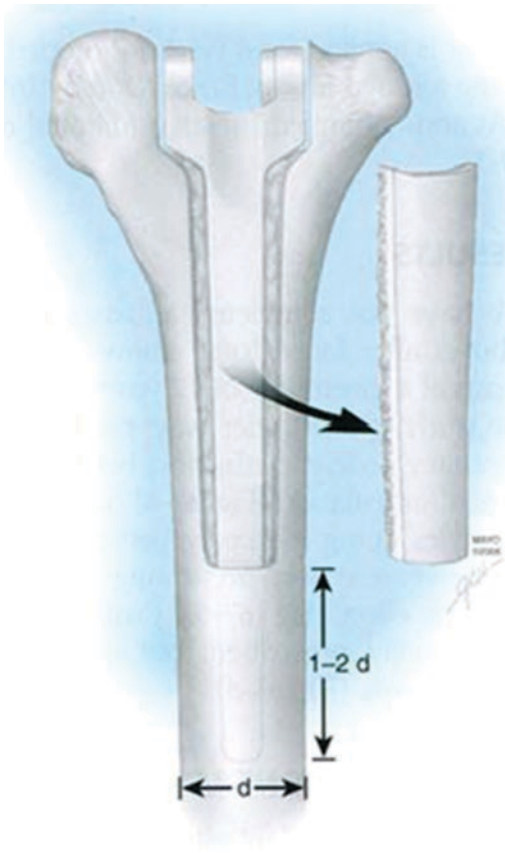
16.3 Surgical Procedure

The main goal of elbow resection is to eradicate the infection while preserving bone stalk and when possible maintaining structural bony integrity by which some elbow function is preserved. Gschwend highlighted the need to preserve the humeral condyles for stability of the elbow joint [10]. The surgical technique therefore necessitates that all infected material be removed, which includes the prosthesis, all cement, and all infected tissue (soft tissue and bone). Critical tissue including that required for neurovascular integrity and bony structure is maintained [3].

We recommend using the previous skin incision to expose the area, almost always through a posterior approach [3, 4]. Wound edges are excised where necessary to eradicate any necrotic or infected skin material. The joint is exposed, and deep cultures are taken from the infected area(s). The ulnar nerve is then identified and transposed when applicable. The ulnar nerve need not be dissected and transposed unless the patient has a symptomatic impairment or if the procedure cannot progress safely without its retraction [3]. The ulnar nerve is not uncommonly encased in scar and proximal identification within virgin tissue, and meticulous dissection is paramount. The triceps is then followed up from the point of origin to the medial and lateral aspects where it is elevated from the posterior aspect of the humerus. The triceps is typically elevated off the olecranon and split, or a VY tongue-type incision can be made within the tendon for later repair. Disengaging the ulnar from the humeral component will be determined in part by the prosthetic design and soft tissue tensioning. Occasionally it may be possible to remove the prosthetic components by dislocating the elbow without disruption of the triceps mechanism.

The type of arthroplasty implant may guide extraction and the amount of bone that must be removed from the shaft of the humerus. With the implant visible, a determination is made whether the implant has loosened or has remained stable. Loose implants are removed with comparative ease, with less risk of intraoperative fracture [3]. Implants that are secured require more care and attention.

For well-fixed cemented humeral stems, the preferred technique uses the creation of a posterior humeral window (as shown in Fig. 16.1) [3]. The ideal window is trapezoid in shape. A progressively wider resection toward the distal end of the humerus functions to maintain the strength of the medial and lateral condyles. To reduce damage to the bone and decrease the chances of subsequent infection, a high-speed burr and flexible reamers are used to remove implant cement. Care must be taken during this step in order to limit the



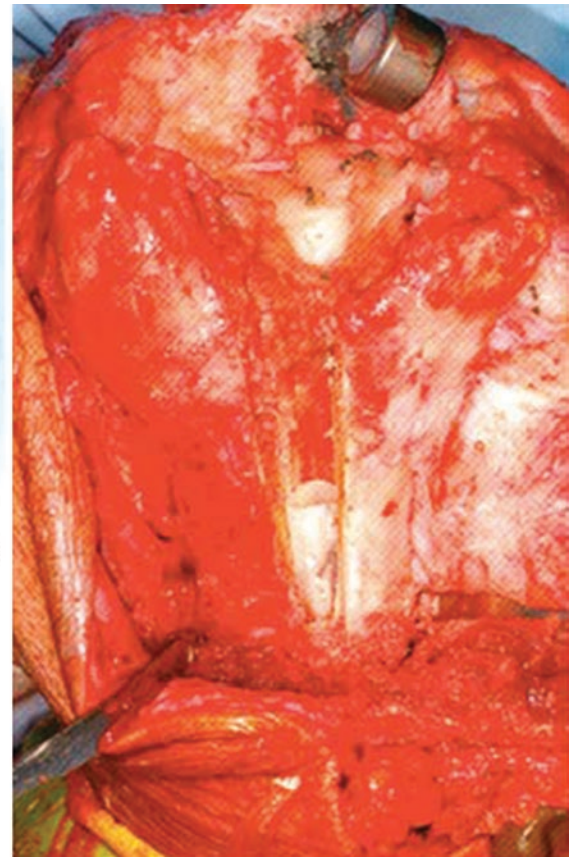


Fig. 16.1 Resection of a well-fixed total elbow replacement is performed by first removing a trapezoid shaped bone window from the posterior aspect of the humerus. The length of this bone window should be at least two diameters of the distal extent of the prosthesis. The posterior window is later secured with a number five monofilament absorbable suture (Reprinted with permission from Morrey BF, Sanchez Sotelo J. Nonimplantation salvage of severe elbow dysfunction. In: Morrey BF, Sanchez Sotelo J. editors. The elbow and its disorder, Philadelphia: Saunders/Elsevier; 2009, p. 912. Used with permission of the Mayo Foundation for Medical Education and Research.)

possibility of intraoperative fracture to the humeral condyles. If deemed a high risk of fracture, Rhee et al. [4] used cerclage wires to stabilize the site. With the implant and all remaining bone cement removed, the ulna and humerus are stabilized with one another. Where needed, a soft tissue release is performed to balance the distal humerus and proximal portion of the ulna. For further stabilization of the area, heavy sutures can be placed through the bone. If intraoperative fractures were sustained to the condyles, Kirschner wires or heavy sutures can be utilized as an adjunct for stability. Care is taken to protect neurovascular structures as a closure is performed. Rhee et al. used a Hemovac closed wound drainage system with two drains in the joint space to aid with healing [4].

Upon completion of the surgery, the elbow is placed in a cast at 90° for 6 weeks. The goal of this postoperative method is to ensure mature scar formation, allowing for adequate stability of the distal end of the humerus and the proximal end of the ulna. Some individuals require additional bracing postoperatively.

16.4 Outcomes

After resection arthroplasty of the elbow, the MEPS significantly increases [3, 4]. In a study of 10 elbows that underwent resection arthroplasty for infection, the mean MEPS increased from 50.0 preoperatively to 73.5 points postoperatively

(mean follow-up of 52.4 months) [4]. Based on the MEPS system, six elbows scored as good, three as fair, and poor in one [4]. A study that included 51 elbows at short-term follow-up and 30 at long-term follow-up demonstrated similar improvements in the MEPS, with an average preoperative score of 37, improving to an early postoperative value of 59 points [3]. At long-term follow-up, a mean MEPS of 60 was achieved in 29 patients [3]. The two scores did not significantly differ between the short- and long-term follow-up [3]. Using the MEPS, it was found that 5 elbows were graded as stable, 9 elbows were moderately unstable, and 16 elbows were rated as grossly unstable or flail at long-term follow-up [3]. In the long-term follow-up group of the Zarkadas et al. study [3], 8 elbows were rated as good, 11 were fair, and 11 were poor under the MEPS.

DASH scores in the Rhee et al. [4] study improved from a baseline mean score of 46.5 to a 53.0 points at the last postoperative follow-up visit [4]. The final follow-up visit in the Zarkadas et al. [3] in 29 patients produced an average score of 71 points [3]. Twenty-one of the 51 individuals self-reported that they believed bracing improved function in the Zarkadas study [3].

16.5 Complications

Infection requiring surgical intervention was found in one of ten elbows in the Rhee et al. study [4]. The infection required two surgeries consisting of irrigation, debridement, and antibiotics [4]. There were no other complications such as issues with wound v, intraoperative or postoperative fractures, or permanent nerve injury reported in the study [4].

In the Zarkadas et al. study of 51 elbows, 24 (47%) required surgery to control infection after the resection, 12 (24%) had what was described as wound-healing problems, 18 (35%) sustained intraoperative fractures, and 9 (18%) of patients demonstrated transient or permanent nerve injury [3]. In one patient, amputation was performed after an iatrogenic vascular injury occurred [3]. The mean number of reoperations after resection due to complications was 2.7 [3].

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17 Change in Quality of Life and Cost/Utility Analysis After Elbow Arthroplasty

Barbara Melis

17.1 Introduction

In the treatment of primary or secondary elbow arthropathy, the development of artificial joint replacement has become the most important therapy option in the prevention of permanent disability. Severe elbow arthropathy occurs most commonly in case of rheumatoid arthritis or other degenerative conditions and following intra-articular fractures. It can greatly affect an individual's health, quality of life, and working. Loss of elbow motion is disabling, and normal elbow function is required for positioning the hand in space, which is crucial in the performance of activities of daily living (ADL).

Total elbow arthroplasty (TEA) has the potential to improve pain, function, and quality of life for many patients with articular destruction; however, despite the fairly good functional results and elbow scores, the survival and complication rates are still not as favorable as those following arthroplasties in other joints.

In a systematic review, Welsink et al. [1] reported that 70% of 9379 TEAs were performed for rheumatoid arthritis, the complication rates ranged from 11% to 38%, and the weighted mean survival rate for the linked and unlinked prostheses was 85.5% at 7.8 years and 74% at 12.3 years, respectively. Primary osteoarthritis is a less common indication for TEA; Schoch et al. [2] showed that TEA represents a reliable surgical option for pain relief in patients with primary osteoarthritis but not for restoration of extension; complications and mechanical failure were observed in 39% and 17% of cases, respectively.

As reported by Zhou et al. [3], TEA is a relatively uncommon surgery with only 3146 TEA performed over a 5-year period in comparison to higher volume arthroplasty such as total knee arthroplasty which is performed at a rate of 700,000 annually in the United States. Recent trends in the United States indicate an increase in the number of TEA procedures performed per year with a tendency toward performing more procedures for trauma than for inflammatory arthritis: Day et al. [4] reported a 248% increase of the number of primary TEA from 1993 to 2007 which equates to a 6.4% annual procedure volume growth rate. Gay et al. [5], using New York State Department of Health database, found a 44% increase in the number of total elbow arthroplasties performed per year. In 1994, Kraay et al. [6] reported 80% of total elbow arthroplasties in their series were performed secondary to rheumatoid arthritis. In contrast to the above studies, Gay et al. [5] showed a decreasing trend in the number of rheumatoid arthritis patients, but this decrease in number was offset by a 132% increase in the number of total elbow arthroplasty procedures performed for trauma or elbow fracture diagnosis.

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The rising number of elbow arthroplasty procedures has the potential to place a financial strain on the healthcare system. In terms of quality of life and cost/utility ratio, the efficacy of treatment has been rarely investigated. Obtaining and understanding this information is important in an era of increasing cost-conscious delivery of healthcare.

17.2 Change in Quality of Life and Cost/Utility Analysis

Giannicola et al. [7] examined the improvement in quality of life achieved after 33 elbow arthroplasty procedures performed for stiffness in Italy between 2007 and 2010, and they verified the cost/utility ratio of this surgery. The authors observed a significant improvement between pre- and postoperative scores and range of motion; satisfactory results were reported in 91% of the patients. A quality-adjusted life year was calculated to evaluate the cost/utility ratio of surgery. Seventy percent of the patients obtained an improvement in quality of life postoperatively. Linear regression analysis showed that the preoperative quality of life score and the improvement of pain score were the only two variables that significantly affected quality of life. Elbow arthroplasty showed a satisfactory cost/utility ratio; cost/utility ratio ranged between 670 and 817 Euro/quality-adjusted life year.

Angst et al. [8] studied 79 patients who underwent TEA for rheumatoid arthritis and post-traumatic arthritis. Significant functional limitation was also present evidenced by the low scores on the function scales and subscales. However, this limitation did not substantially affect overall health perception and quality of life. To adequately perform ADL, certain functional abilities are required. Elbow flexion was 120° or more in 96% of arthroplasty joints, a necessary condition to reach the mouth using the hand. The patients were highly satisfied with the result of their arthroplasty. Overall, 44% of the patients felt that their preoperative expectations about the arthroplasty were met completely; only 8% of the patients were somewhat dissatisfied. 82% of the patients felt themselves better than before the arthroplasty, 5% unchanged, and 13% worse. Eighty-seven percent of the patients declared that they would choose total elbow joint replacement again, if they found themselves in similar circumstances to those that prevailed preoperatively. The patients reported low pain levels and good elbow joint stability and satisfaction.

Zhou et al. [3] evaluated hospital length of stay (LOS), hospital direct cost, in-hospital mortality, complications, and 30-day readmission rates in 3146 adult patients who underwent a total elbow arthroplasty for rheumatoid arthritis or post-traumatic arthritis in the United States. The mean LOS was 4.2 ± 5 days, and the mean total direct cost for the hospital was 16.300 ± 4000 US dollars per case. The overall complication rate was 3.1% and included mortality <1%, DVT (0.8%), reoperation (0.5%), and infection (0.4%). The 30-day readmission rate was 4.4%. The authors concluded that TEA is a relatively uncommon surgery in comparison to other arthroplasties but is associated with low inpatient and 30-day perioperative complication rate. The 30-day readmission rate and overall hospital costs are comparable to the traditional total hip and knee arthroplasty surgeries.

17.3 Discussion

Giannicola et al. [7] indicated that elbow arthroplasty leads to significant improvement in quality of life, particularly in patients with low preoperative quality of life; pain reduction is the most important factor affecting quality of life improvement. Same, Angst et al. [8] reported low pain levels and good elbow joint stability and satisfaction after elbow arthroplasty; nevertheless, significant functional limitations were observed. Because pain is the most important factor affecting health perception and quality of life [7, 8], this result is not surprising and suggests that surgical treatment should be aimed not only at recovering elbow motion but also at relieving pain. An accurate evaluation of the different tissues involved in each patient (i.e., articular surface, bone, capsuloligamentous, and nervous

structures) is needed to be able to select the most appropriate surgical technique.

In the patients who had undergone elbow arthroplasty, general well-being, quality of life, and satisfaction with treatment are good on average. Some specific functions remain significantly impaired but appear not to play a decisive role in the performance of tasks of daily living and perception of quality of life in general. Clinical measures of elbow function do not necessarily reflect patient well-being, performance levels in ADL, and quality of life. This is important, because it suggests that a study relying only on functional measures would overlook the high self-perceived quality of life and satisfaction of the patients, which may be decisive in determining future utilization of healthcare resources.

As reported by Giannicola et al. [7], elbow arthroplasty for early treatment of elbow stiffness may be useful in reducing social and public health costs, in terms of sick days, absenteeism, disability pension, medical treatment, and physical therapy and in improving quality of life. Elbow arthroplasty shows a satisfactory cost/utility ratio, which may justify an increase in health spending in this area to reduce the social costs of lingering elbow stiffness. The 30-day readmission rate and overall hospital costs are comparable to the traditional total hip and knee arthroplasty surgeries [3]. Continued advances in this field are key to make this operation as reliable and lasting as hip or knee arthroplasty.

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Part III

Distal Humeral Hemiarthroplasty

18 Anatomical Considerations and Biomechanics in Distal Humeral Hemiarthroplasty: Are Custom-Made Implants Essential?

D. Polimanti, M. Scacchi, and G. Giannicola

18.1 Introduction

Distal humeral hemiarthroplasty has, over the last decade, become a treatment option for elbow joint disease that predominantly affects the distal humerus, including fractures, nonunions, and avascular necrosis [1]. The anatomy and the biomechanics of the elbow joint are complex and have not yet been fully characterized; a thorough understanding of both these aspects is, however, of paramount importance to anatomical implant design.

The main aim of this chapter is to describe the latest anatomical and biomechanical developments on this topic to provide a better understanding of the clinical usefulness and limitations of distal humeral hemiarthroplasty.

18.2 Anatomical Considerations

A detailed knowledge of the elbow anatomy and its variations is crucial for the prosthetic replacement of the distal humerus [2]. It is particularly important to be aware of the fact that the articular surface of the trochlea is angulated in relation to the medullary canal and epicondylar axes. Indeed, it is tilted approximately by 6° in valgus on the frontal plane, rotated inward by about 5° on the transverse plane, and rotated anteriorly by about 30° on the lateral plane [3] (see Fig. 3.5a–c, Chap. 3). Therefore, distal humerus joint replacement devices should be constructed in such a way as to allow replication of these angles.

When McDonald et al. [4] investigated variations in distal humerus angulation in relation to implant alignment in a CT scan study based on computer design software (Fig. 18.1), they reported that anatomical variations in varus-valgus angulation of the distal humerus significantly affect the alignment of the implant. The currently available distal humeral hemiarthroplasty (DHH) implant, in which the valgus angulation is fixed, cannot consequently be positioned without sacrificing the alignment of the flexion-extension axis. Moreover, owing to differences in varus-valgus angulation, the implant cannot sometimes be optimally aligned without perforating the periosteal cortex (see Fig. 3.8, Chap. 3). The authors of this study [4] believe that the accuracy of the implant placement may be improved by introducing greater modularity of the humeral components, with three valgus angulations of 0°, 4°, and 8°.

In a CT scan study, Brownhill et al. [5] determined the relationship between the medullary canal axis and the flexion-extension axis of the distal humerus on the sagittal plane (Fig. 18.2). They reported that the anterior offset varies significantly (range, 6.6–11.1 mm), is higher in males than

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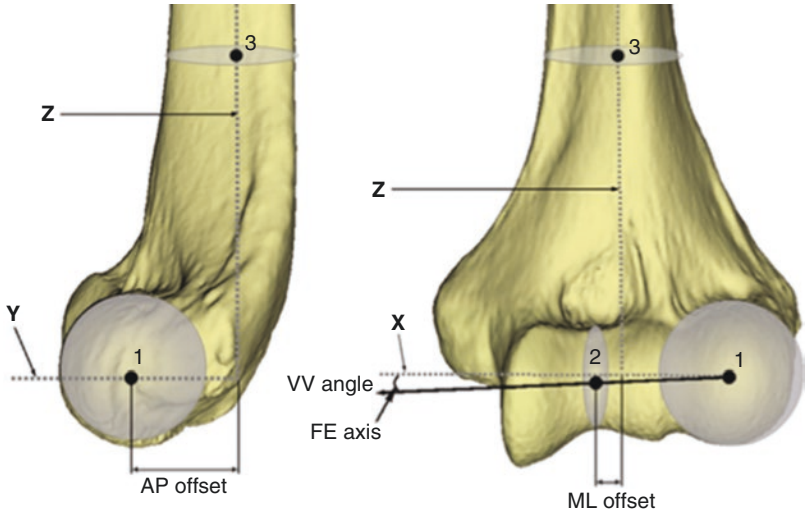

Fig. 18.1 A humeral coordinate system was defined according to the geometric centers of the capitellum (1), trochlea (2), and medullary canal (3). The flexion-extension (FE) axis was defined as a line intersecting the capitellum and trochlea. Varus-valgus (VV) angulation was defined as the angle of the FE axis relative to the *x*-axis on the coronal plane (*From: McDonald CP, Peters TM, Johnson JA, King GJ. Stem abutment affects alignment of the humeral component in computer-assisted elbow arthroplasty. Journal of Shoulder and Elbow Surgery. 2011;20(6):891–8)*

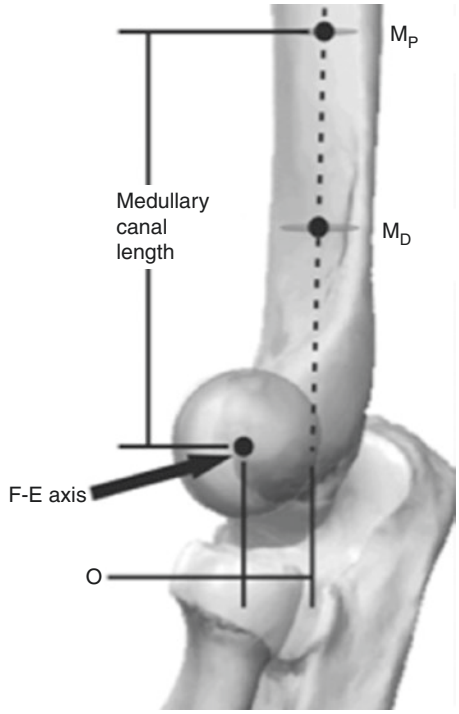

Fig. 18.2 O represents the offset between the flexion-extension axis and the medullary canal axis *(From: Brownhill JR, King GJ, Johnson JA. Morphologic analysis of the distal humerus with special interest in elbow implant sizing and alignment. Journal of Shoulder and Elbow Surgery. 2007;16(3))*

females, is directly proportional to the length of the medullary canal, and is not correlated with articular size. The authors of that study [5] suggested that the implant should be designed with a slight apex posterior curvature in the distal portion and a straighter proximal section in order to match the anteroposterior curvature of the distal third of the humerus (i.e., the anatomical bow) and to center the medullary canal more accurately.

A thorough knowledge of the anatomy of the articular surface, i.e., the capitulum humeri and trochlea, is also of paramount importance to the development of a DHH implant that mimics the native joint and the articular surface contact mechanism; indeed, an altered contact pattern results in premature wear of the ulnar and radial cartilages, which may in turn cause pain and functional impairment [6, 7]. A detailed description of the anatomy of the capitulum humeri and trochlea and their variations is provided in Chap. 3. Briefly, the anatomical findings that are relevant to the design of a DHH implant are (1) the capitulum humeri is not spherical but somewhat ellipsoid, with a greater radius of curvature in the medial-lateral direction [8, 9], and (2) the humeral trochlea may vary in shape (see Fig. 3.4, Chap. 3) and diameter depending on the osseous contour and

cartilage thickness [10–12]; therefore, the design of anatomical prosthetic devices should be based not only on different sizes of the humeral spool but also on different shapes of this component.

18.3 Biomechanical Considerations

Several studies have shown that the commercial DHH implant results in a significantly reduced joint contact area and greater contact stress if compared with the native joint [13–15]. In their cadaveric study, Lapner et al. [13] analyzed the effect of DHH implant size on elbow articular contact; the native articulation contact patterns were compared with optimal, oversized, and undersized implants (Latitude Anatomic Hemiarthroplasty, Tornier, Texas, USA) during passive elbow flexion-extension. The authors reported that the mean contact area of the native ulnohumeral joint with and without intact ligaments was significantly greater than that of optimal, oversized, and undersized implants (Fig. 18.3). The mean ulnohumeral and radiocapitellar contact area decreased on average by 44% and 4%, respectively, following placement of an optimally sized implant; furthermore, there was no significant effect of implant size on the contact area. The authors concluded that it is above all the shape, rather than the size, of the elbow implant that leads to altered contact patterns, adding that further research is required to develop a more anatomical distal humeral articular implant shape [13]. In an MRI study, Giannicola et al. [11] reported a marked variability in the shape of the trochlea, which may be less or more concave regardless of the size of the bone; in particular, the trochlear notch angle ranged from 124° to 156° (see Fig. 3.4, Chap. 3).

Willing et al. [14] also reported a reduction in elbow joint contact area in a cadaveric study performed with DHH prostheses manufactured on the basis of CT images of the distal humerus. In the native ulnohumeral joint, the contact area increases with elbow flexion. Although an increase in contact area with flexion was also observed in the DHH implant, if compared with the native ulnohumeral joint, the size of the contact area was 42% smaller (Fig. 18.4); the

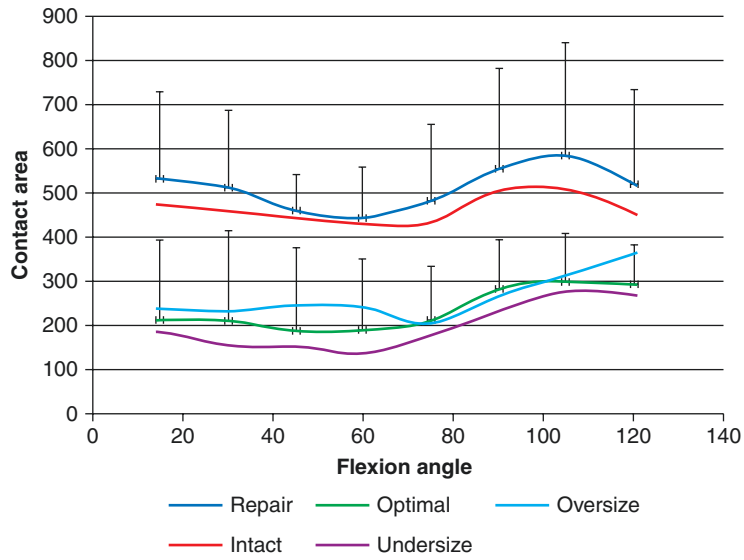

Fig. 18.3 Ulnohumeral contact area. Graph showing the mean ulnohumeral contact area at increasing flexion angles. Comparison of ligament intact, repaired, optimal, undersize, and oversize implants. Note: Higher contact area of the native (repair/intact) versus the implanted condition (significant difference) *(From: Lapner M, Willing R, Johnson JA, King GJ. The effect of distal humeral hemiarthroplasty on articular contact of the elbow. Clinical Biomechanics. 2014;29(5):537–44)*

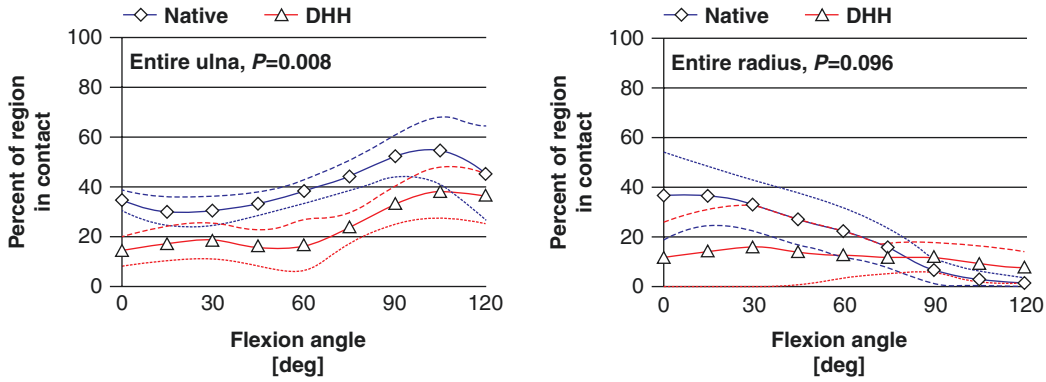

Fig. 18.4 Contact area versus flexion angle. Contact area at the ulna (left) and radius (right) as a function of flexion angle *(From: Willing R, Lapner M, King GJ, Johnson JA. In vitro assessment of the contact mechanics of reverse-engineered distal humeral hemiarthroplasty prostheses. Clinical Biomechanics. 2014;29(9):990–6)*

radiocapitellar contact area also decreased, though not significantly. Furthermore, the reductions in contact area were not uniform in the various subregions, thereby suggesting that the contact patterns were also altered. The authors [14] concluded that the main reason for the altered contact patterns is likely to have been that the custom-made prostheses considered in their study had been designed on the basis of the distal humeral osseous anatomy, without taking into account the effect of the cartilage thickness. This hypothesis is supported by a high-definition MRI study subsequently performed on 78 healthy elbows, in which Giannicola et al. [12] reported that the cartilage thickness is not uniform and modifies the morphology and diameter of the distal humeral articular surface. The lowest values of cartilage thickness were observed at the lateral and medial humeral edges, whereas the highest values were detected in the central articular zone. Cartilage thickness was also found to be independent of both the humeral bone size and other anthropometric characteristics.

In another study, Willing et al. [15] compared the contact patterns and cartilage stresses of the elbows before and after DHH performed using commercially available, bone reverse-engineered implants and cartilage reverse-engineered implants (Fig. 18.5). When the three different implant designs were compared, the cartilage reverse-engineered design yielded the largest contact areas and lowest contact stresses but was still unable to reproduce the contact mechanics of the native joint (Fig. 18.6). These findings are in keeping with a growing body of evidence indicating that reverse-engineered hemiarthroplasty implants do provide small improvements in contact mechanics when compared with commercially available designs but that further optimization of shape and material properties is required in order to faithfully reproduce native joint contact mechanics.

In a biomechanical study, Abhari et al. [16] studied the extent to which implant positioning affects ulnohumeral contact using patient-specific DHH implants. Reverse-engineered DHH implants were designed according to CT scans of their osseous geometry. The native ulnae were paired with the corresponding native humeri and custom-made DHH implants in a loading apparatus. The humeral component was placed at angles ranging from 5° varus to 5° valgus in 2.5° increments under a 100-N compressive load. Contact between the ulna and both the native distal humerus and the reverse-engineered DHH implant was measured at all the varus-valgus angles.

The mean contact area measured in the native articulation was significantly greater than that achieved using DHH implants in all the varus-valgus positions (Figs. 18.7 and 18.8). Furthermore, the contact pattern did change significantly in the DHH condition, particularly in the medial aspect of the joint. The authors [16] thus concluded that reverse-engineered prostheses not

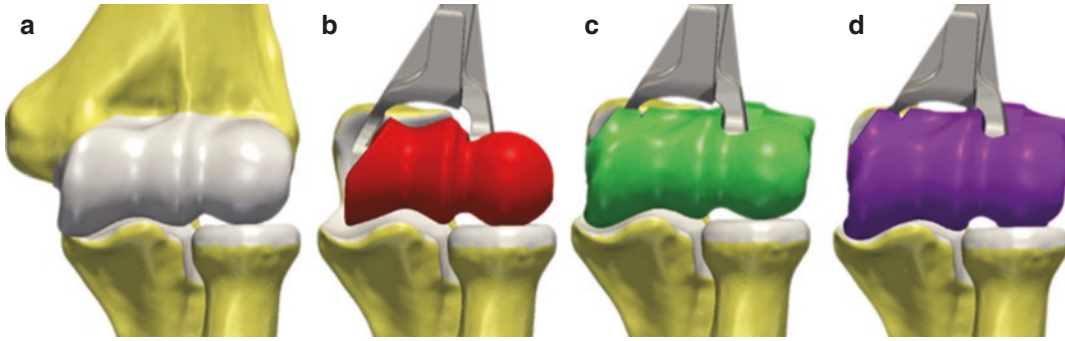

Fig. 18.5 The four contact configurations simulated. Native distal humerus (**a**), DHH commercially available implant (**b**), DHH bone reverse-engineered implant (**c**), DHH cartilage reverse-engineered implant (**d**) *(From: Willing R, King GJ, Johnson JA. Contact mechanics of reverse engineered distal humeral hemiarthroplasty implants. Journal of Biomechanics. 2015;48(15):4037–42)*

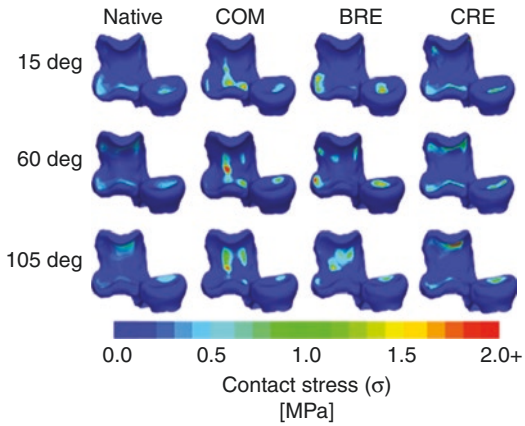

Fig. 18.6 Typical contact stress results for a single specimen. Contours describe the contact stresses across the contact surfaces of the ulna and radius at 15°, 60°, and 105° of flexion when articulating with the native distal humerus (native), the commercially available DHH design (COM), the bone reverse-engineered DHH design (BRE), and the cartilage reverse-engineered DHH design (CRE). Red fringe plot values denote contact stresses at or above 2 MPa; this upper limit was selected to allow a better visualization of the entire contact region *(From: Willing R, King GJ, Johnson JA. Contact mechanics of reverse engineered distal humeral hemiarthroplasty implants. Journal of Biomechanics. 2015;48(15):4037–42)*

only reduce the contact area between the joints but also alter the contact pattern. Although changes in the alignment of the prosthesis do not alter the overall contact area in native or DHH conditions, the use of DHH implants may alter the contact distribution patterns, particularly on the medial aspect of the joint. This edge loading may lead to increased cartilage wear resulting from changes in contact distribution in the joint. Implant positioning thus plays an important role in reproducing more native-like contact patterns and improving long-term clinical outcomes.

18.4 Conclusion

The DHH implant currently available clearly does not closely replicate the native anatomy; this limitation may result in greater cartilage wear, post-traumatic osteoarthritis, and unpredictable long-term clinical results. Custom-made implants provide a greater contact area and are generally associated with a lower degree of contact stress than the implants currently available on the market, which attempt to mimic the native anatomy but are simplified for commercial purposes. Anatomical implants should ideally be manufactured according to the anatomical variability and the effect of cartilage thickness on the shape and size of the distal humerus. Implant modularity should also be improved on the basis of these considerations, though this would very likely result in higher production costs. It may also be possible to improve commercial DHH prostheses by adopting other biomaterials with a Young's modulus closer to that of joint cartilage.

Clinical studies designed to compare commercial and custom-made implants are needed to understand whether improvements in the

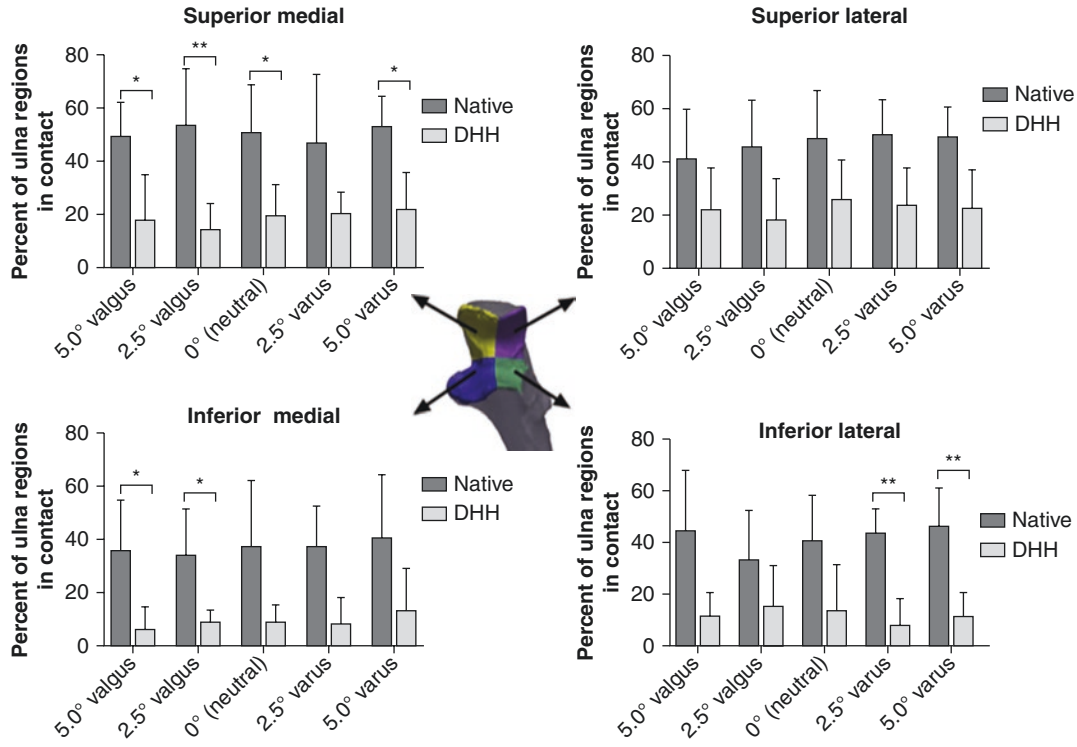

Fig. 18.7 Percent contact of ulna articular surface in different quadrants, as a function of implant varus-valgus angle *(From: Abhari RE, Willing R, King GJW, Johnson JA. An* In Vitro *Study of the Role of Implant Positioning on Ulnohumeral Articular Contact in Distal Humeral Hemiarthroplasty. J Hand Surg Am. 2017.42(8):602-609)*

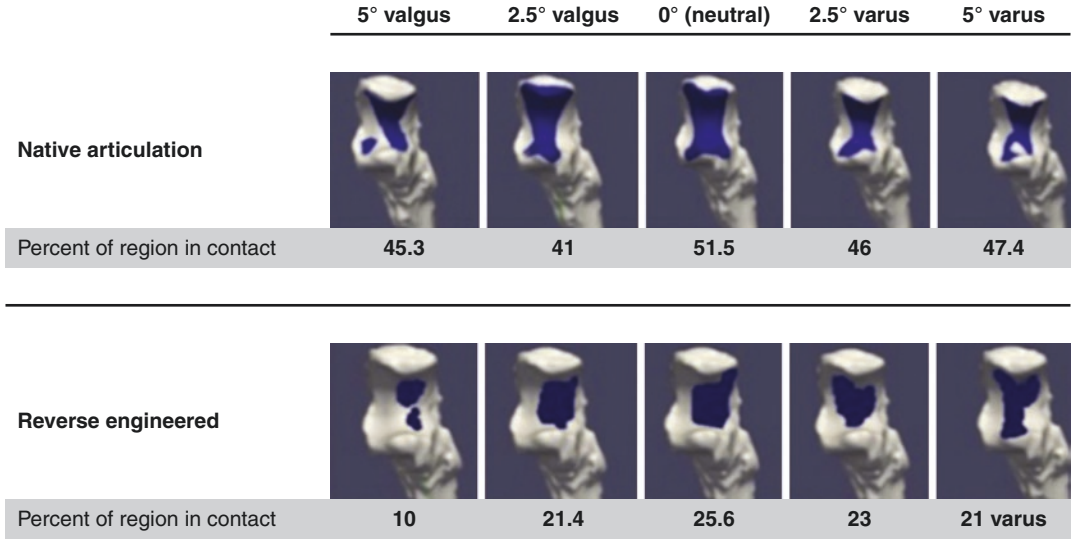

Fig. 18.8 Effect of implant varus-valgus positioning on contact pattern shift at the ulnar articulating surface *(From: Abhari RE, Willing R, King GJW, Johnson JA. An* In Vitro *Study of the Role of Implant Positioning on Ulnohumeral Articular Contact in Distal Humeral Hemiarthroplasty. J Hand Surg Am. 2017.42(8):602-609)*

anatomical design and biomaterials used to make such implants may lead to better clinical results in terms of function and pain.

Conflict of Interests The authors declare no commercial associations (e.g., consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) that might pose a conflict of interest in connection with the submitted manuscript.

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Distal Humeral Hemiarthroplasty: Indications and Expected Results

19

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19.1 Background

Mellen and Phalen [1] described the first report of a non-anatomic acrylic distal humeral hemiarthroplasty (DHH) implanted during the Second World War for salvage of high-energy injuries. Venable [2] and MacAusland [3] reported the first use of DHH in case of acute fractures of the elbow in the 1950s.

Since then, DHH has been frequently introduced for the treatment of irreparable fractures of distal humerus [4, 5]. In the 1970s, because of the advent and increasing popularity of total elbow arthroplasty (TEA) and the progresses in internal fixation (ORIF), DHH became less common in the management of complex elbow fractures.

The increasing development of the fourth generation implants, the potential limitations of TEA (wear debris [6], loosening [7], and limb weight restriction [8]), and the possibility of unenthusiastic clinical outcomes of ORIF in elderly people [9] increased the interest for DHH in the treatment of articular distal humerus fractures.

Three implants of DHH have currently published about their clinical outcomes: the non-anatomic Kudo (Biomet Ltd., Bridgend, UK), the anatomic Sorbie-Questor (Wright Medical Technology, Arlington, TNUSA), and the anatomic Latitude (Tornier, Montbonnot-Saint-Martin, France). This DHH has been performed in Europe, the UK, Australia, and the USA; however, in the USA these implants have just been used off-label, because of the lack of Food and Drug Administration approval [10].

This chapter will focus on the spectrum of the surgical indications (and contraindications) and the expected results of these third- and fourth-generation implants [11].

19.2 Methods

A comprehensive literature research was performed using PubMed. The keywords "distal," "humeral," and "hemiarthroplasty" were used to identify papers examining the topic of interest. The terms "indication" and "results" were added

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to the research in order to find articles that were specific to this chapter. Studies published from 2000 to 2017 were included in this chapter. The level of evidence of study titles and abstracts was reviewed to include high-quality literature (i.e., meta-analyses, systematic reviews, controlled trials). Papers published earlier than 2000 were considered if they contributed to the discussion on the historical progression and evolution of the surgical indications and clinical results.

19.3 Indications

Unreconstructable acute partial articular fractures of the distal humerus represent the primary surgical indication of DHH. The AO/OTA comprehensive classification of fractures [12] classifies partial articular distal humerus fractures as type B3, which are then further subclassified into capitellar, trochlear, and combined fractures.

ORIF is considered the gold standard for these fractures; however, it may not be suitable in elderly patients with comminution, severe osteopenia, and articular fragmentation or in case of pre-existing elbow deformity. Nonoperative treatment can be considered as an alternative treatment to ORIF in this setting but often implies loss of elbow motion and unsatisfactory clinical outcomes [13].

DHH presents a fascinating alternative treatment that resurfaces the irreparable trochlea and capitellum of the distal humerus in an active older patient, but it relies on the integrity or reconstruction of the primary and secondary elbow stabilizers: the medial and lateral columns with the collateral ligaments [14, 15]. The radial head and coronoid must be intact when considering the performance of DHH [16]. However, fixation of the radial head or olecranon with DHH is possible and has been described [17].

The theoretical advantages of DHH over TEA are the absence of polyethylene debris with the consequent osteolysis and the absence of weight restriction, especially in younger and active patients. However, no literature supports yet the use of DHH over TEA.

DHH has been emerging as an attractive option in case of chronic failure of internal fixation or nonoperative treatment (non-union or malunion) [18–20]. DHH has also been indicated for the management of rheumatoid arthritis (RA) of the elbow [21].

Absolute contraindications to DHH and TEA are contaminated open fractures or chronic infection of the elbow. DHH is also absolutely contraindicated in case of non-recuperable medial or lateral column bone stock, irreparable MCL or LCL, or fractures of the radial head or coronoid that cannot be rigidly fixed. Linked TEA should be considered in all these circumstances with bone or soft-tissue deficiency [22].

Relative contraindications to DHH comprise younger patients where every attempt should be made to perform internal fixation. Chondral damages or pre-existing osteoarthritis to the greater sigmoid notch or radial head are also relative contraindications for the risk of postoperative arthritic pain and limited range of motion. Fractures involving olecranon or radial head are also relative contraindications for the possibility of postoperative instability of the implant and accelerated chondral wear of the joint. In case of arthritis, hemiarthroplasty is not suggested because of the risk of pain caused by accelerated chondral wear and the possibile presence of joint instability due to alteration of the bony architecture or laxity of the collateral ligaments. In contrast literature reports satisfying results in patients with rheumatoid arthritis treated with humeral hemiarthroplasty [8].

19.4 Expected Results

Clinical results of DHH implants in patients with distal humeral fractures can be considered satisfactory. Good results depend on stability and ROM reached at the end of rehabilitation period. To ensure joint stability and reach, a good ROM is important to restore the native flexion-extension axis and repair collateral ligaments [10].

Dunn et al. [11] published a case series systematic review based on 17 primary articles regarding patients with fractured (13) and non-fractured (4) indication of DHH. The fractured patients represent the 87.2% of the literature;

72.7% were female with an average age of 62.2 years. In the non-fractured group, the 57.1% were male with an average age of 31.8 years, and the majority had a diagnosis of rheumatoid arthritis. Outcomes in the fractured group were good or excellent, at a mean follow-up of 42 months, in the 67.4% of patients. The flexion-extension ROM arc was 98°, and the prono-supination ROM arc was 160°. In the non-fractured group, good or excellent results, at a mean follow-up of 46 months, into 76.5% of patients. The flexion-extension ROM arc was 61°, and the prono-supination ROM arc was 116.5°. Complication rate was 27.6% and 50%; reoperation rate was 32.8% and 17.6% in the fractured and non-fractured group, respectively. The most common complications in the first group were hardware irritation (34.1%), neuropathy (16.5%), and laxity (16.5%); in the other group, stiffness (54.6%) was the most important complication.

Phadnis et al. [10] published a more recent review on DHH. In this review they analyzed 121 cases of DHH for distal humeral fractures with a mean follow-up of 37.5 months. The mean age of patients was 72.6 years. Functional outcome scores were reported with Mayo Elbow Performance Score (MEPS), and the reported MEPS was 87.6 with 61% of patients classified as excellent and 25% classified as good. Authors reported that patients with olecranon osteotomy had lower MEPS than other approaches. The mean ROM reached at the follow-up were 108° and 176°, respectively, for flexion-extension and prono-supination arc. Surgical complications were 18%, and the most represented was the ulnar nerve irritation, while re-operations were 28% with the metalwork removal used to fix the olecranon osteotomy.

19.5 Conclusions

Future research should be focused on randomized trials comparing distal humeral hemiarthroplasty with total arthroplasty or internal fixation in case of distal humeral fractures. Moreover subgroup analysis evaluating age, sex, and type of fracture would be necessary.

Conflict of Interests All the authors and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this manuscript.

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Distal Humerus Hemiarthroplasty: Surgical Technique

20

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20.1 Introduction

Distal humerus hemiarthroplasty (DHH) is a recent therapeutic option for the treatment of some acute unreconstructable humeral fractures, for the salvage of sequelae related to non-operative management or failed internal humeral fixation as well as in other rare pathological conditions [1–10]. Currently, the indications for DHH are somewhat limited, as explained in the previous chapter, because some anatomical and biomechanical conditions are mandatory if DHH is to be performed correctly. Several implants have been used for DHH, such as the humeral components of the unlinked total elbow arthroplasty (TEA), including Kudo [11], the Sorbie-Questor device, and, most recently, the Latitude system. However, as both the Kudo and the Sorbie-Questor prostheses are no longer available on the market, the Latitude is the only implant that is currently available.

The Latitude is a TEA flanged convertible modular system that allows a linked or unlinked TEA or a DHH to be performed. In the latter, the humeral component is composed of three modular parts: the stem, an anatomic spool, and a cannulated pin, which is used to attach the spool to the stem. The pin cannulation allows suture fixation of the collateral ligaments and condyles through the implant to provide joint stability, thereby avoiding the use of supplementary hardware. Should the need for revision to TEA arise, the DHH can be converted to an unlinked or linked TEA without extraction of the humeral component. Since the indications and the expected results associated with the DHH were described in detail in the previous chapter, the aim of this chapter is to describe the surgical technique.

20.2 Preoperative Planning

A radiographic assessment of the elbow should be based on standard anterior-posterior and lateral view X-rays and a CT scan with 2D and 3D reconstruction. Specific phantoms are available for the preoperative planning. The contralateral anteroposterior X-ray may be used to outline the profile of the distal humeral implant on the anatomical articular surface so as to be able to select the most suitable size of the components. Once the profile of the corresponding prosthesis has been drawn, it is necessary to verify its relationship with the coronoid or radial head. The axis of the radial neck should be aligned with the center of the capitellum, and the trochlea should be congruent with the greater sigmoid notch.

In case of distal humerus fractures, CT helps to clarify whether the fracture is reconstructable. The 2D sagittal plane scans and 3D

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reconstruction with radius and ulna subtraction are the most useful images in the author's experience (Fig. 20.1). In uncertain cases, the surgeon should ensure that the hardware required to perform osteosynthesis, DHH, and TEA is available in the operating room in order to be able to convert ORIF into partial or total arthroplasty in unreconstructable cases. However, whenever possible, the decision to perform a DHH should be made preoperatively so as to avoid longer operating times and a higher risk of infection.

In case of previous failed osteosynthesis, a detailed list of the hardware implanted before is needed to allow the surgeon to remove the hardware more easily; the previous operative report may also be useful in order to understand what surgical approach was adopted and, above all, the position of the ulnar nerve.

As mentioned in the previous chapter, there are some anatomical prerequisites when a DHH is planned: the main osseous and soft tissue stabilizers of the elbow (i.e., the greater sigmoid notch, the collateral ligaments, and the radial head) should be intact or at least reparable because elbow stability is mandatory to be able to perform a DHH; in addition, both the medial and lateral columns should be either intact or reconstructable to guarantee an adequate soft tissue reinsertion and healing [12].

20.3 Surgical Technique

The patient may be positioned in a supine, lateral decubitus, or prone position, according to the surgeon's preference. An arm support can be used in the lateral and prone positions, bearing in mind

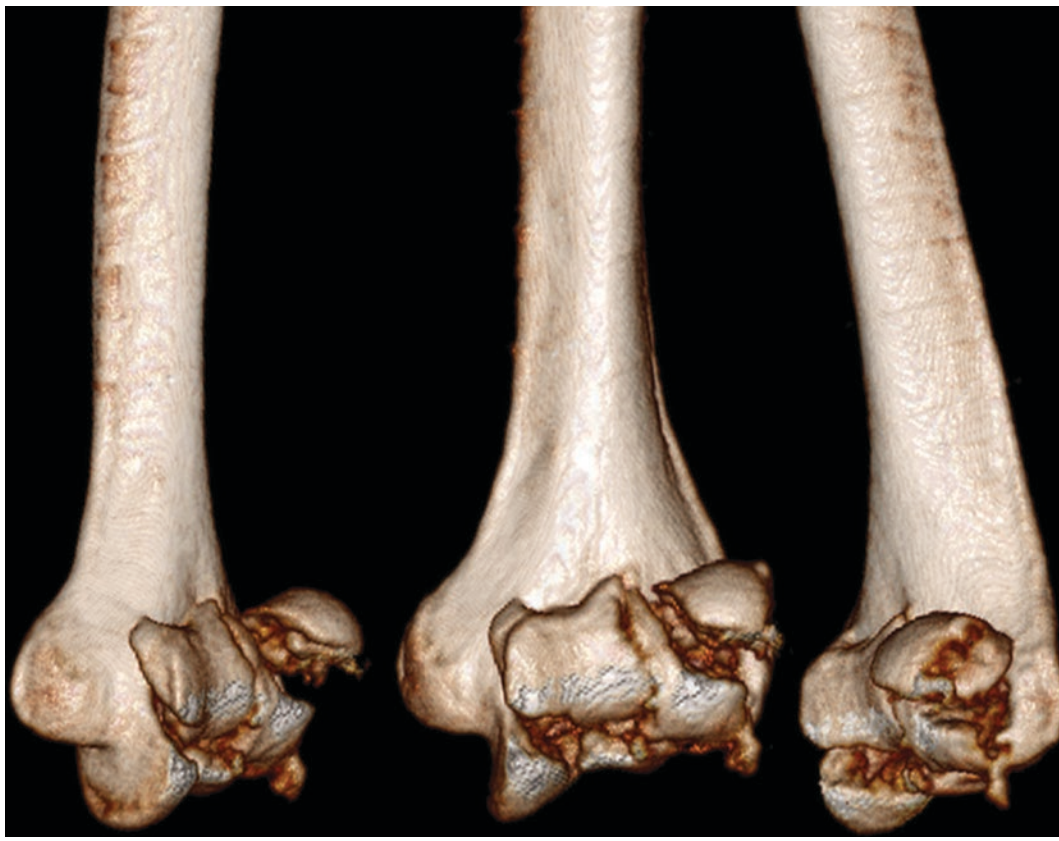

Fig. 20.1 3D CT scan reconstructions show a comminuted unreconstructable humeral shear fracture in a 68-year-old woman who underwent surgery for DHH. The following figures refer to this clinical case

that a complete range of motion of the elbow is required during the procedure. A sterile tourniquet inflated to 250 mmHg can also be used, though the author prefers to use a silicone ring (HemaClear®—MED & CARE—Gdynia, Poland) as the latter provides an adequate degree of ischemia and, at the same time, the emptying of the limb; furthermore, the reduced size of the silicone ring allows the surgical incision to be extended proximally if required. A posterior skin incision of approximately 20 cm is performed, and full-thickness medial and lateral subcutaneous flaps are lifted (Fig. 20.2a). The ulnar nerve needs to be identified, and a large neurolysis is required to transpose the nerve anteriorly and subcutaneously both during and at the end of surgery (Fig. 20.2b).

The surgical exposure should be chosen according to the type of pathology and surgical procedure planned. We believe that the triceps-on approach [13] should be performed in all cases of acute fractures so as to initially expose the distal humerus. Indeed, if there is any doubt regarding the osteosynthesis of the fracture, an intraoperative decision may be made without violating the olecranon with this type of exposure. If the surgeon is not familiar with the Alonso-Llames procedure, triceps splitting or reflecting approaches are recommended [14]. The author's preference is the triceps-on approach in which the triceps insertion is maintained. It allows an early unrestricted range of motion and avoids any issues with subcutaneous hardware and triceps failures. In addition to the classical triceps-on approach, Phadnis et al. [15] described a modified procedure for DHH consisting of a sliver of medial triceps tendon from the olecranon with at least 75% of the lateral tendon remaining fully attached, including the entire part of the tendon on the dorsal aspect of the olecranon. They found that both the approaches they described afforded an adequate degree of exposure and allowed safe implantation of the prosthesis in the distal humerus, reporting that all their patients had MRC grade 5 triceps power at follow-up.

Another approach described for DHH is the olecranon osteotomy [16–19], which affords good visualization of the distal humeral articular surface but requires fixation with further hardware. In addition, given that ulna wear is a concern after DHH, violating the olecranon with an osteotomy may exacerbate this problem [20]. Lastly, if there is any instability upon trialling the DHH, then conversion to TEA may be compromised by the osteotomy. On the other hand, the olecranon osteotomy allows to avoid the violation of the soft tissue constraints of the elbow and the ligamentous reconstruction in cases with

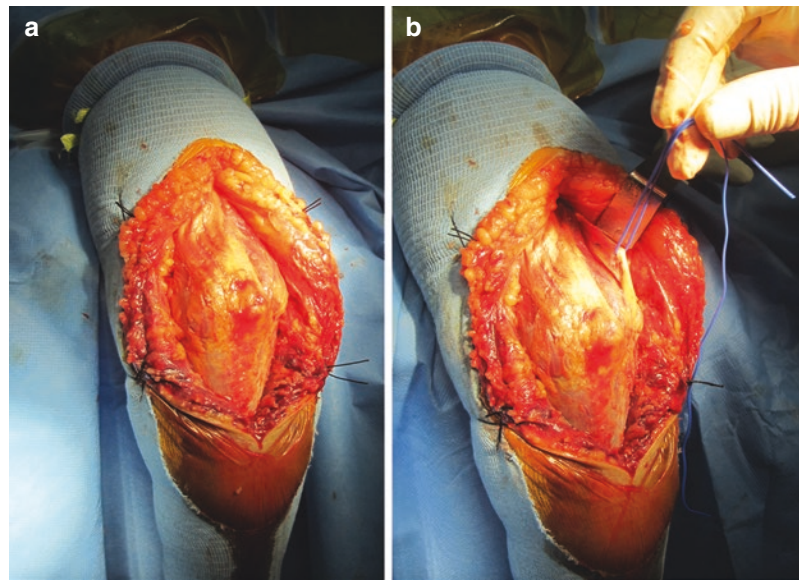

Fig. 20.2 A posterior skin incision of about 20 cm on the elbow was developed with the patient positioned in prone decubitus. Full-thickness medial and lateral subcutaneous flaps are lifted. A monouse silicone ring is visible in the upper extremity of the limb (**a**). The ulnar nerve is identified and mobilized (**b**)

intact collateral ligaments. These considerations suggest that the surgeon should adopt the most adequate surgical approach according to the pathoanatomical conditions of each patient.

A wide release of the lateral septum and the triceps muscle from the posterior aspect of the humerus are mandatory to mobilize the ulna and radius medially; this approach allows the distal humerus to be adequately exposed and thus avoid radial nerve injuries. A posterior capsulectomy is then performed. Several authors prefer to detach both the medial and lateral soft tissue constraints of the elbow; the collateral ligaments are elevated off the humeral insertions subperiosteally by means of a sharp dissection, thereby allowing dislocation of the elbow. In the medial compartment, the MCL and flexor-pronator muscles should be detached together from the humeral medial epicondyle. In the lateral compartment, a Kocher approach is performed, and the LCL complex, including the epicondyle muscles, is elevated subperiosteally in a way resembling that used for the medial side (Fig. 20.3a–c). It is worth preparing the Krackow sutures for the ligaments and epicondyle muscles at this point of surgery because the soft tissue footprint is more evident as soon as those structures are detached and the level of accuracy that can be achieved when this procedure is performed at the end of surgery after removal of the tourniquet is lower.

The author prefers to detach the LCL and common extensor origin on their own and leave the medial compartment intact in cases in which it is preserved. Despite being reduced, the working window remains sufficient, and the postoperative stability is preserved to a greater extent. This approach is particularly useful in acute unreconstructable humeral shear fractures and their sequelae when the medial trochlea and MCL are not involved. It should, however, be borne in mind that in some cases, the bone ligament insertions may be involved in the fracture pattern and leave the ligament attached to a bone fragment, thereby facilitating the exposure of the joint and reinsertion at the end of procedure. The anterior capsule is then released, and the forearm is dislocated medially. After exposure of the distal humerus, any fracture fragments are removed. In post-traumatic cases, any previous ORIF hardware is also removed in this phase.

With the humeral articular surface exposed, the appropriate sizing of the implant spool is assessed by comparing the native capitellum and trochlea with the trial anatomical devices

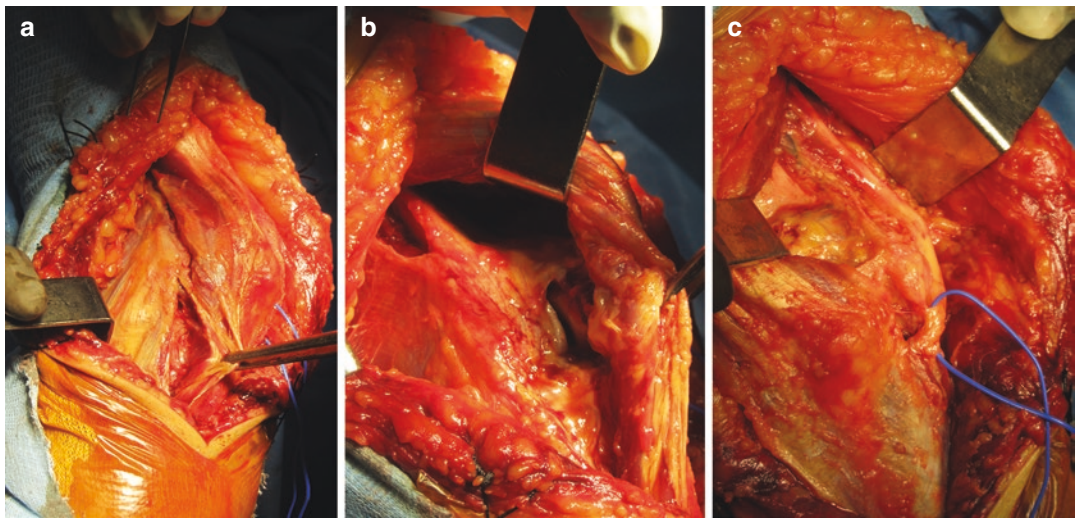

Fig. 20.3 The Kocher approach is performed in the lateral compartment (**a**). A wide release of the lateral septum and the triceps muscle from the posterior aspect of the humerus is performed (**b**). The release of the triceps and posterior capsulectomy are performed in the medial compartment to guarantee a better visualization of the articular surface (**c**)

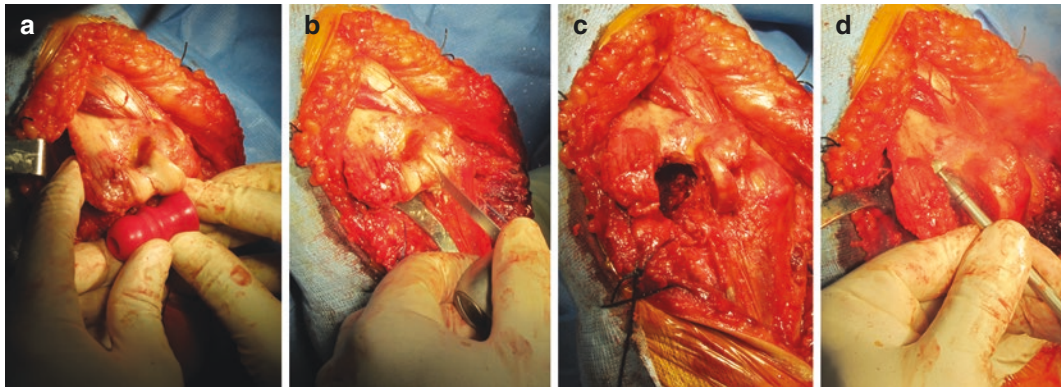

Fig. 20.4 The appropriate sizing of the implant spool is assessed by comparing the native capitellum and trochlea with the trial anatomical spool (**a**). Subsequently, the removal of the central portion of the trochlea is performed using an oscillating saw (**b**, **c**). The entry point of the medullary canal is then identified and opened with a high-speed burr (**d**)

(Fig. 20.4a). The aim of this comparison is to find a size that ensures the implant spool fits the native trochlear notch perfectly and aligns with the fovea of the radial head. There are different schools of thought as to whether the smaller or larger size should be chosen in cases in which the optimal choice falls between two sizes. While some authors recommends that the smaller size be chosen [21], Desai et al. [22] showed, in a biomechanical study they performed, that joint congruency is lower in an undersized distal humeral hemiarthroplasty implant than in an optimally sized or oversized implant. Indeed, they advocate that the larger implant should be favored when a surgeon has to decide between two implants' sizes. A larger implant is, in fact, likely to more accurately recreate the normal elbow kinematics, enhance the degree of congruency of the native ulna, and thus presumably reduce cartilage wear on the native ulna.

Once the choice of the spool size has been made, it is possible to proceed by removing the central portion of the trochlea to enter the diaphyseal canal, which is located in the proximal region of the olecranon fossa. The first step requires an oscillating saw (Fig. 20.4b), whereas the second step requires a high-speed burr (Fig. 20.4d). The flexion-extension axis needs to be identified at this point. The flexion-extension axis usually runs along a virtual line that extends from the origin of the LCL of the lateral epicondyle (the center of the capitellum) to the origin of the MCL on the medial epicondyle (just anterior and inferior to the medial epicondyle). The axis can be identified by free hand using a *k*-wire passed through the two epicondyles at the origin of the ligamentous insertion if the column is preserved. However, for greater accuracy, it is possible to use a dedicated flexion-extension axis drill guide for pin positioning.

Humeral broaches are used to shape the medullary canal according to the selected implant size. A cutting guide is used to complete the epiphyseal humeral cut using an oscillating saw. The trochlear cut guide can be attached to the broach. The guide should slide until it touches the bone; a drill is then used to make two holes in the guide, and stabilization pins are inserted into each hole to secure it. To ensure that the mediolateral and rotational orientation are correct, the distal cut on the trochlear cut guide should extend over the capitellum. It is essential that the cutting guide be positioned correctly because if it is placed too proximally, it may result in a very thin medial column that is susceptible to fracture (Fig. 20.5a–c). An oscillating saw is then used to cut along the outside edges of the trochlear cut guide. Five cuts are required: the bottom middle cut, the lateral and medial cuts, the distal capitellum cut, and, lastly, the anterior cut. Before the

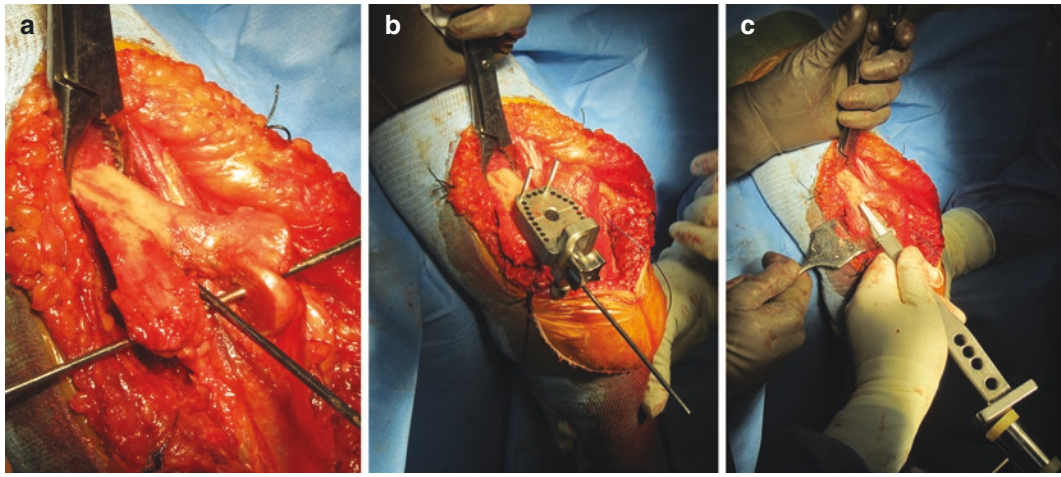

Fig. 20.5 The flexion-extension axis is identified by using a *k*-wire passed through the two epicondyles at the origin of the ligamentous insertion if the columns are preserved (**a**). A cutting guide is available to complete the epiphyseal humeral cuts (**b**). Humeral broaches are used to shape the medullary canal according to the selected implant size (**c**). In the new kit, these two last steps are reversed

cuts are made, drawing the direction of the flexion-extension axis directly on the bone using a surgical marker may subsequently prove useful when the trial stem is inserted to remove any causes of altered positioning. The contact between the trial component and the cutting surfaces is then assessed; if the correct contact has not been achieved, a burr is used to improve the shaping of the cuts and achieve the optimum orientation of the implant. The anatomical trial spool is then positioned (Fig. 20.6a) and the joint reduced (Fig. 20.6b), and the relationship between the prosthesis and the articular surface of the ulna and radius is examined; an intraoperative check with fluoroscopy is advisable at this point.

In case of distal humerus fracture, the correct humeral height may be judged in different ways: one is by referencing against the patients' native olecranon fossa, the proximal part of which is usually recognizable even in multi-fragmentary fractures; another is by approximating the fractured condyles to the supracondylar ridges with the trial stem in situ while ensuring that the epicondyles are aligned with the implant's epicondylar axis. When the columns are intact, the alignment between the humeral ligament insertions and the implant rotation axis confirms the correct positioning; an evaluation of the correct lengthening and tension of collateral ligaments related to the prosthesis rotational axis support the correct position of the implant in such cases. Rotation of the implant is instead assessed by referencing against the flat posterior cortex of the humerus, proximal to the olecranon fossa, as described in Chap. 6. To achieve the greatest accuracy when restoring the flexion-extension axis, the implant should not run parallel to the posterior humeral cortex line but be internally rotated (mean 14°) [20, 23].

The trial component is then removed, and the medullary canal is prepared for cementation. It is important to irrigate the canal abundantly and subsequently dry it. A cement stopper is inserted, and a cement gun is used to inject an antibiotic-loaded, low-viscosity cement (Fig. 20.7a). The definitive components are then positioned using all the landmarks that allow the components to be correctly oriented in line with the flexion-extension axis, and any excess cement is carefully removed (Fig. 20.7b). It is always advisable to insert a bone graft between the humeral shaft and the anterior flange of the humeral component to enhance the stability of the definitive device. If

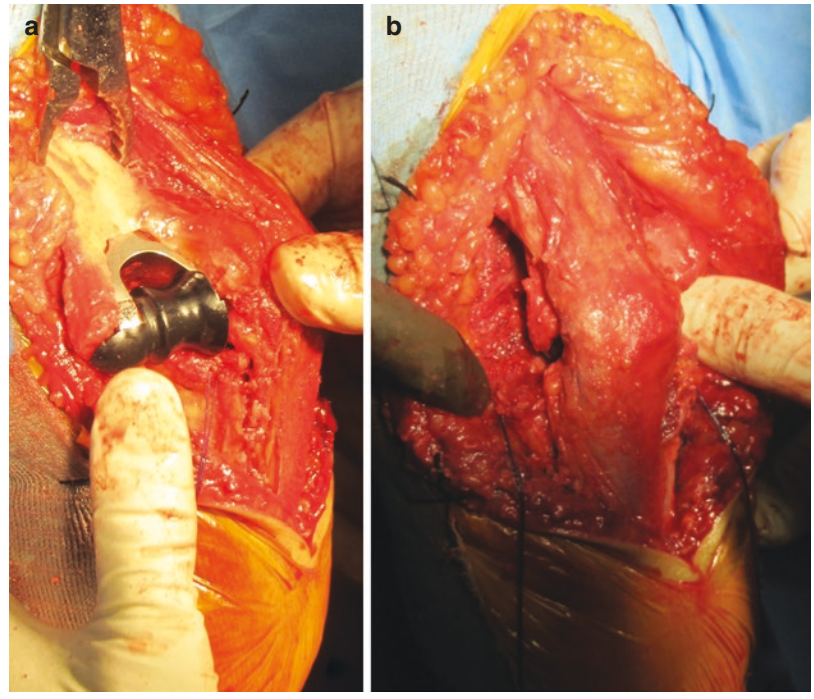

Fig. 20.6 The trial implant is positioned (**a**) and the joint reduced (**b**) to assess the joint congruency and motion

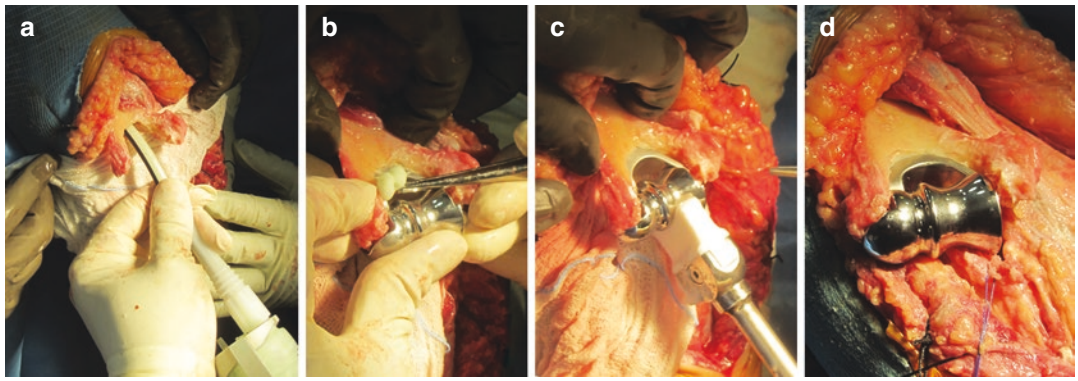

Fig. 20.7 A cement gun is used to perform cementation of the humeral medullary canal (**a**). The excess cement is then accurately removed (**b**), the implant pressed into its seating until the cement hardens (**c**). The final implant positioned (**d**)

fragments of the resected trochlea cannot be used for this purpose, it may be necessary to take autologous bone grafts from the patient's iliac crest through an additional cutaneous incision on the hip.

Ligamentous reconstruction needs to be performed once the cement has hardened. If the ligaments remain attached to the fragments, which is known to occur in distal humerus fractures, the fragments may be fixed by means of threaded *k*-wires, screws, cerclages, or plates. Phadnis et al. described a suture repair technique aimed at the reconstruction of fractured condyles with ligaments attached (Fig. 20.8) [20]. Once drill holes have been made in the medial and lateral condylar fragments, a fiber wire is passed through the cannulated pin of the prosthesis and into the pre-made drill holes of the condyles and then

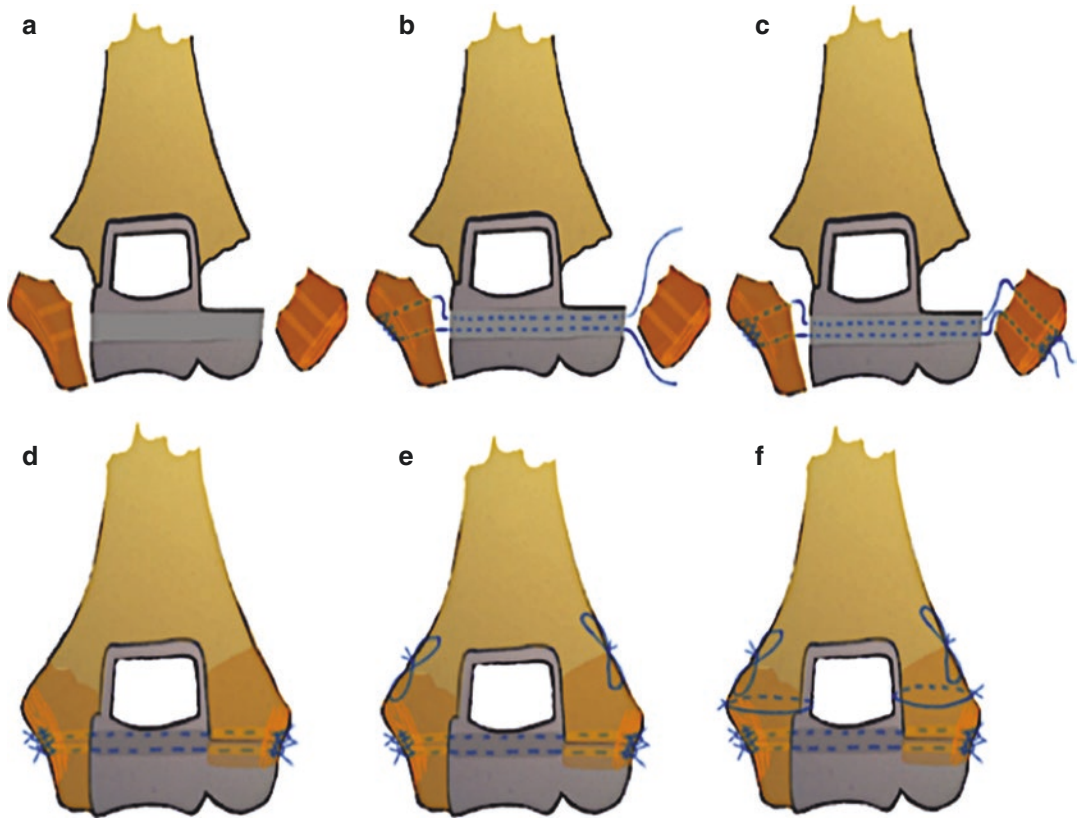

Fig. 20.8 Reconstruction of fractured condyles. (**a**) Drill holes are made in the medial and lateral condylar fragments (**b** and **c**). The #2 FiberWire is passed through the cannulation in the spool and premade drill holes and is then whipstitched into the collateral ligaments. (**d**) Condyles are reduced to the implant and humeral columns and tied firmly to each other through the cannulated spool (**e** and **f**). Condyles are further secured with tension band sutures through drill holes and cerclage sutures to the implant (From Phadnis J, Banerjee S, Watts AC, Little N, Hearnden A, Patel VR. Elbow hemiarthroplasty using a "triceps-on" approach for the management of acute distal humeral fractures. J Shoulder Elbow Surg. 2015 Aug;24(8):1178-86. doi: https://doi.org/10.1016/j.jse.2015.04.010. Reprinted with permission)

whipstitched into collateral ligaments. The condyles are reduced to the implant and humeral columns before being tied firmly to each other through the cannulated spool. The condyles are further secured with tension band sutures by means of drill holes and cerclage sutures to the implant. A classic transosseous reinsertion can be performed if the column is intact. Suture anchors can also be used. We usually perform ligament/tendon reinsertion with a Krackow suture using nonabsorbable wire passed through the cannulated pin and firmly secured to soft tissues of the contralateral side, ensuring that contact between the ligament and its bone footprint is achieved (Fig. 20.9). Every effort should be made to perform column reconstruction in DHH to guarantee contact between the ligaments and the bone and thus favor healing. As described above, the common extensor and flexor tendons are reinserted at the same time as the ligamentous reinsertion in a single layer.

The tourniquet is then released, and a careful hemostasis is performed. Subcutaneous anterior transposition is performed at the end of surgery to avoid any conflict with the prosthetic components and to adequately detain the nerve. This procedure also allows easier access to the prosthetic components in the event of a future revi-

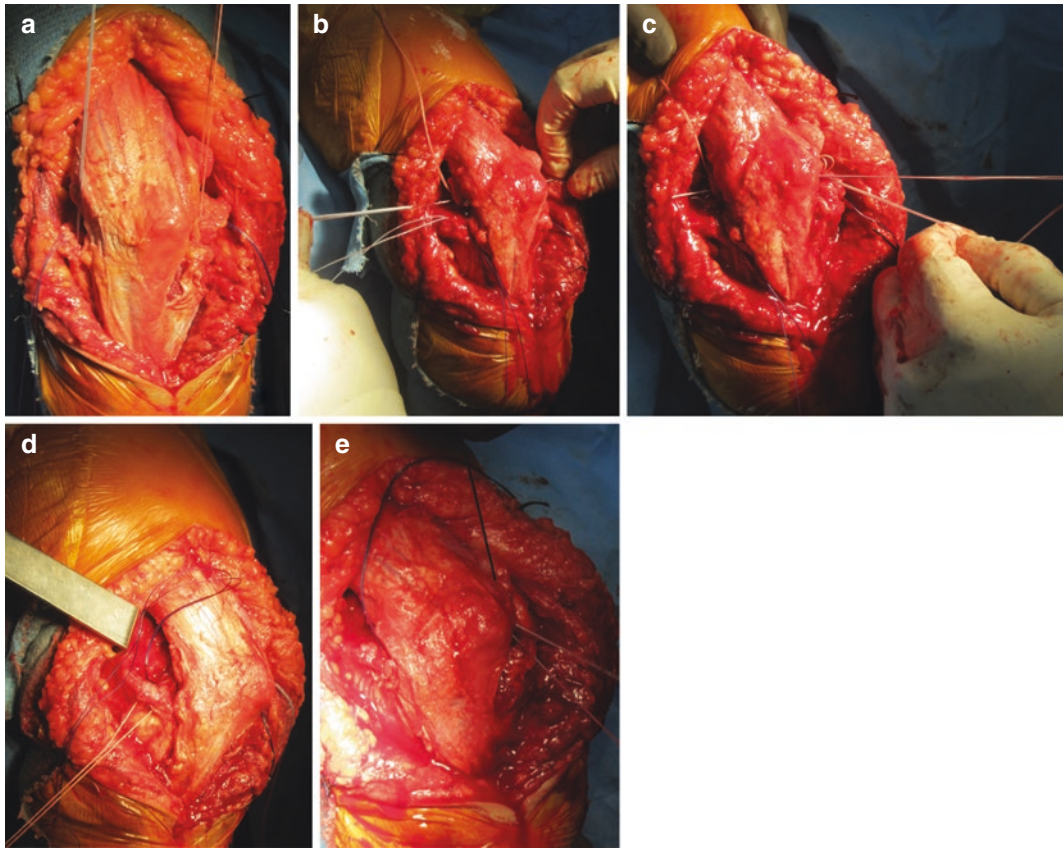

Fig. 20.9 After joint reduction, the LCL and MCL complexes are prepared with locked nonabsorbable suture wires (**a**). Each suture is passed through the cannulated pin (**b**, **c**) and firmly secured to soft tissues on the contralateral side (**d**, **e**), ensuring that contact between the ligament and its bone footprint is achieved

sion. Before closure, a functional and radiographic assessment of the DHH is performed. Two subcutaneous drainages are applied, and the elbow is immobilized in a compression bandaging for the next 24–48 h. The arm is rested in elevation, and continuous cryotherapy is administered.

Passive mobilization is allowed following drainage removal, with the ROM varying according to the type of access used (preserved olecranon or osteosynthesized) and above all to the quality of the ligamentous reconstruction. Some authors suggest that ROM recovery should start as soon as possible, soft tissue permitting. In particular, Heijink et al. [24] recommended that passive range of motion start on the first postoperative day and that active range of motion be resumed after 6 weeks, both under the supervision of a physical therapist. Phadnis et al. [20] recommend that patients limit heavy or repetitive activities to minimize the joint reaction force, particularly for the first 6 weeks, when the condyles and collateral ligaments are still healing. Other authors are more prudent as regards the rehabilitation program and suggest that patients should start on gentle range of motion exercises (active-assisted) at 2 weeks postoperatively, with gentle strengthening at 6 weeks [25]. No weight-bearing restrictions should be placed on the patients once strengthening has been completed. Other authors instead do not advocate any specific rehabilitation protocol, suggesting that the patients should start on their own using formal therapy only as needed. If motion does not approach expectations

based on surgery, bracing should be considered at 2–3 months [26].

As regards the specific protocol-based surgical approaches other than the triceps-on approach, when patients undergo an olecranon osteotomy and subsequent osteosynthesis, they may commence active exercise at 4 or 6 weeks, while union of the osteotomy is still progressing [12]. When a Bryan-Morrey approach is adopted, Burkhart et al. [27] recommend anterior upper arm splinting in full extension postoperatively and allow active flexion for the first 6 weeks and active extension thereafter.

Some authors recommend the use of a continuous passive motion (CPM) [12] machine. We disagree with the use of this type of rehabilitation device, particularly when it is self-managed by the patient in a domestic environment, as we believe that CPM may lead to instability by placing excessive stress on the ligament reconstruction. The author's preference is physical therapy administered once/twice per day with the assistance of a skilled elbow therapist. Exercises should be performed in a supine overhead position with the shoulder flexed at 90°, a position controlled by holding the wrist with the healthy hand, in the first 6–7 weeks postoperatively. Gentle active and active-assisted elbow flexion and extension to full range are performed as tolerated [28]. During flexion/extension mobilization, the forearm should be held in pronation, supination, or a neutral position depending on the involvement of the LCL, the MCL, or both ligaments, respectively. Gentle active assisted supination and pronation may also be performed in the supine position, with the shoulder in 90° of forward flexion. Patients should be carefully instructed, both before and after the DHH procedure, with regard to how to behave postoperatively in order to ensure that the implant lasts as long as possible: repetitive elbow heavy activities should be avoided, as should straining of the elbow with heavy loads.

Conflict of Interests The authors declare no commercial associations (e.g., consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) that might pose a conflict of interest in connection with the submitted manuscript.

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21 Complication Management in Distal Humerus Hemiarthroplasty

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21.1 Introduction

Distal humerus hemiarthroplasty (DHH) was designed to overcome the disadvantages of ORIF and TEA. ORIF may lead to early loss of reduction in severely comminuted and/or osteoporotic fractures. TEA may lead to early loosening necessitating revision, especially in the high-demand patient. The weight-bearing restriction of 3–5 kg may be suitable for some rheumatoid and lower demand patients but is too limiting for most patients with primary and posttraumatic arthritis, as these are younger and have greater physical demands.

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In trauma, AO type C3 fractures are the most common indication for arthroplasty. In the elderly patient, TEA has proved an accepted treatment option, but complication rates are still higher than in other joints. As the ulnar component has the highest risk for loosening, the rationale of DHH is to avoid the use of the ulnar component. By eliminating the proximal ulna component, the risk of ulnar component loosening and PMMA wear is eliminated. In addition, DHH may reduce the operating time which is beneficial for the elderly multimorbid patient. In the hip the hemiarthroplasty (HHA) concept has a defined value in the treatment algorithm of proximal femur fractures of the elderly multimorbid patient. While HHA verifiably reduces OR time and complications as it simplifies surgery compared to total hip arthroplasty (THA), DHH is more difficult than semiconstrained TEA, and it is questionable whether the theoretical advantages will prevail clinically.

DHH can only be performed in isolation in low fractures with intact epicondyles. In most cases additional measures to reconstruction of the epicondyles to ensure ligamentous stability are required, making this surgery rather complex and prone to complications. Osseous and ligamentous integrity or reconstruction is a necessary precondition for successful DHH as it is a form of unlinked arthroplasty. In addition, cartilage wear of the radial head and sigmoid notch is likely to occur over time, and stiffness can be a serious concern to the patient.

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21.2 Instability

DHH is associated with a risk of instability that can be derived from poor soft tissue balance, inadequate opposing bone, or inadequate ligament reconstruction.

It is important to correctly reconstruct the flexion/extension axis. Overlengthening will impede reconstruction of the ligaments/epicondyles and reduce the flexion arc due to increased triceps working length. Underlengthening might lead to instability due to inadequate soft tissue tension in triceps, biceps, and brachialis.

Most commonly in trauma cases, the lateral and/or medial epicondyle is involved in the fracture pattern. As the collateral ligaments arise from the epicondyles, reconstruction is a necessary part of DHH. Repair of the collateral ligaments through the humeral spool is routinely performed, but there is concern regarding the potential of the ligament to heal to metal. Therefore, refixation should always be performed including the bony fragments that carry the ligament. These fragments should be repaired as anatomically as possible to the supracondylar humeral shaft. Stability can be enhanced by additional sutures through the humeral spool. DHH without restoration of the medial and lateral column will most probably lead to an unstable joint with a poor clinical outcome (Fig. 21.1). Insufficient repair of the epicondyles/ligaments will lead to instability (Figs. 21.2, 21.3, and 21.4). Furthermore, the radial head and coronoid process need to be intact or reconstructable to provide a stable opposing joint surface for the DHH articulation.

Achieving stability in these patients is challenging. Heijink et al. reported three cases of valgus instability after DHH in a cohort of six patients. One of those showed persistent subluxation and was unsatisfied with the result [1]. This 55-year-old female was treated with DHH 10 months after ORIF of a C3 fracture of the distal humerus because of severe avascular necrosis of the capitellum. This patient refused further surgery. The authors noted that the patients with instability had a LCL release to enable hemi implantation. As the other three patients of this series, in whom an olecranon osteotomy was used, did not suffer instability, the authors recommended to avoid ligament releasing approaches.

Nestorson et al. reported one case of instability that was treated with LCL reconstruction in a cohort of 42 patients [2]. However, no detailed information is provided regarding LCL-reconstruction technique with implanted DHH nor the influence of LCL reconstruction on the outcome. All cases in this series were acute fractures approached by a partial detachment of the triceps, so no iatrogenic detachment of the ligaments was performed. In most acute fractures, the ligament release has already been done by the fracture by detaching the condyles from the shaft of the humerus. Meticulous refixation of the epicondyles and ligaments had to be performed after DHH implantation. Nevertheless, the authors had one case of loosening, in which they found non-union of both epicondyles. The authors concluded that instability due to the non-union – similar to the case described in Fig. 21.1 – might have contributed to early loosening as they did not find other reasons.

Hohman et al. performed careful repair of the ligaments and epicondyles and stated that they conducted a "conservative" rehabilitation to avoid instability [3]. No case of instability occurred in their cohort of seven patients. Nevertheless, they were concerned about elbow stiffness in the follow-up, and the authors assumed that stiffness might mask instability to a certain degree.

The "easiest" and safest solution for instability of a DHH is conversion to a semiconstrained TEA. There are only two TEA systems available that can be used as an anatomic hemiarthroplasty, the Latitude system and the Sorbie-Questor. The latter only allows conversion to an unlinked TEA which will most probably be insufficient in case of an unstable DHH. The Latitude elbow system which is used most widely for DHH is a modular system that allows conversion to a semiconstrained linked TEA – without removal of the humeral stem. The anatomic DHH spool is replaced with the TEA spool. The ulnar component and – if applicable – the radial head component are implanted. The TEA should be linked

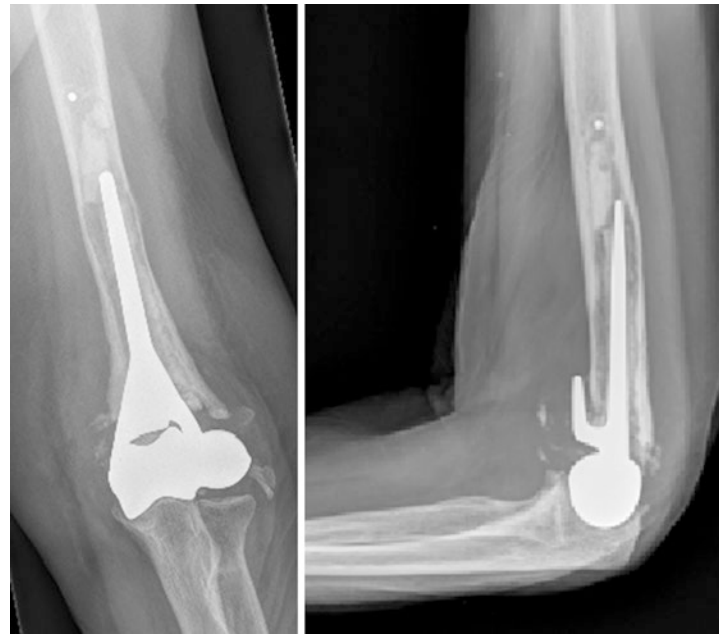

Fig. 21.1 Implantation of a hemi in another hospital in case of AO C3 distal humerus fracture in a 81 years old female patient. Epicondyles were not reconstructed. The elbow was grossly unstable. Radiographic evaluation showed early loosening at 1 year post-op. Increased radiohumeral distance can be observed in the a.p. view as a sign for lateral instability. Gross instability might have contributed to early loosening. Two stage revision to TEA was performed

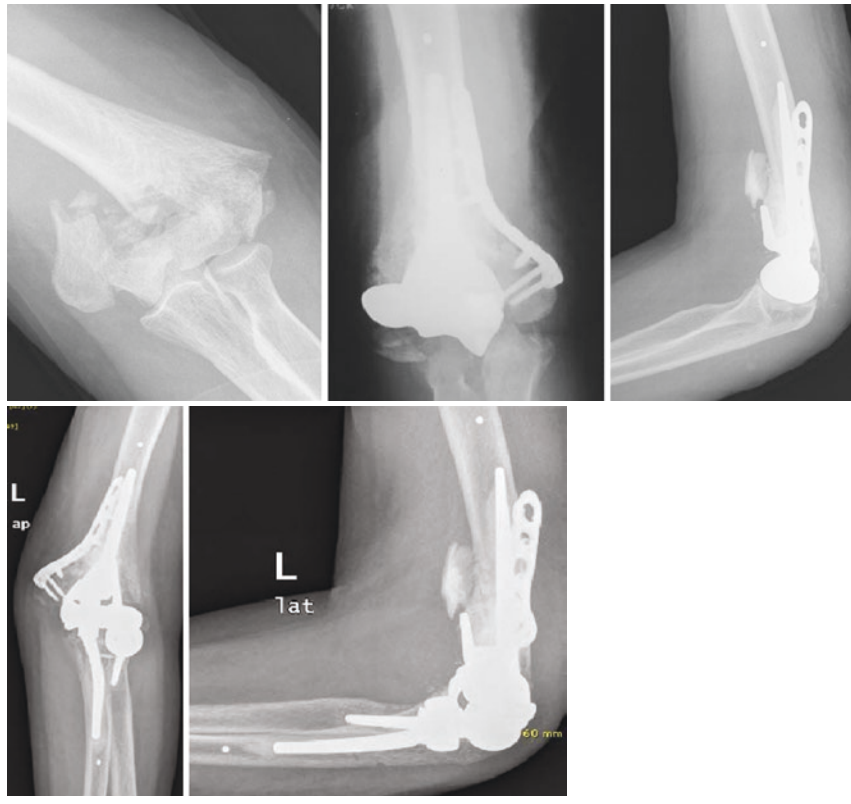

Fig. 21.2 Implantation of a hemi in another hospital in case of AO C3 distal humerus fracture in 60 years old female patient. Plate reconstruction of the ulnar epicondyle. No or unstable reconstruction of the lateral epicondyle led to elbow dislocation immediately post-op. Conversion to TEA without removal of the well fixed humeral shaft was performed

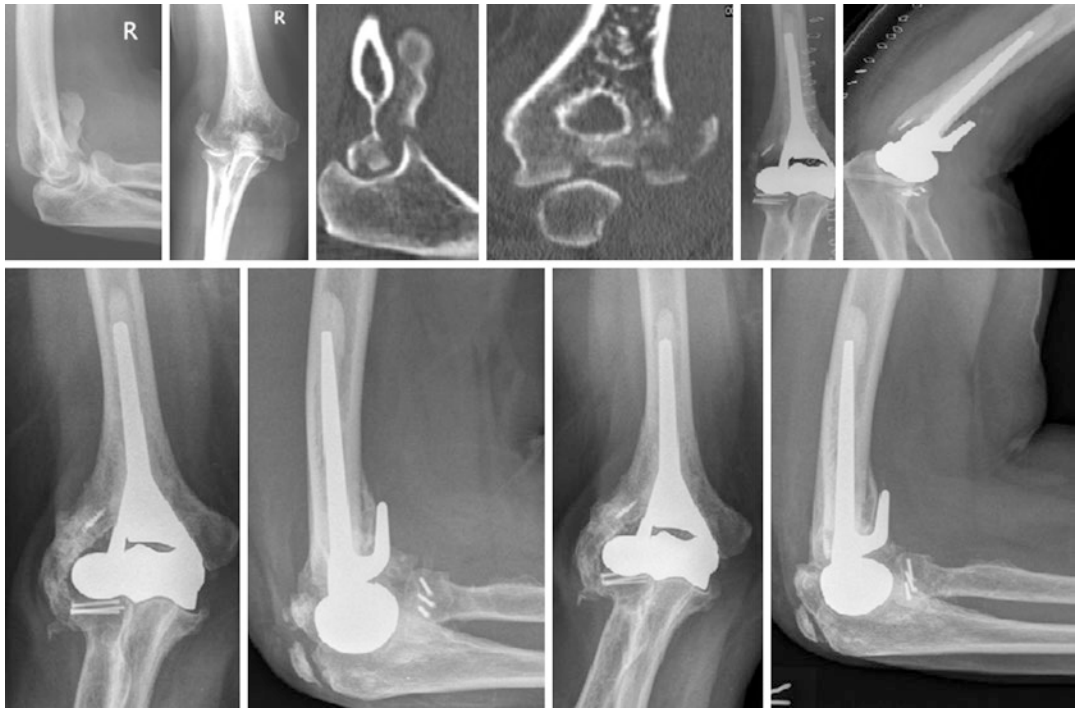

Fig. 21.3 In a 65 years old female patient with an AO B3 distal huemral fracture and Mason type III radial head fracture DHH was performed combined with LUCL-refixation with a suture anchor and screw osteosynthesis of the radial head. The X-rays in the control after 19 months revealed developement of an ossification of the LCL. As the lateral epoicondyle could not be reconstructed anatomically the soft tissues were repaired to the remaining stump of the epicondyle and the LCL was addditionally repaired through the humeral spool. The HO should be regarded as sign for lateral instability. As the patient did not suffer from instability, one must assume that the stiffness might mask the instability. As the patient had an reasonable functional result (extension deficit 30, Flexion 100°, Pronation 80°, Supination 80°, MEPS: good.) without pain, revision was not needed. After 4.2 years X-rays and clinical result did not show any significant changes

with an ulna cap after revision for an unstable DHH (Fig. 21.2). In our experience conversion works well with the Latitude system [4, 5]. Especially in the elderly low-demand patient, the threshold to convert DHH to semiconstrained TEA should be low.

In the younger high-demand patient, efforts to preserve the DHH may be justifiable. However, no valid data exist, and we do not have our own experience with ligament reconstruction for unstable DHH. There is only one case mentioned by Nestorson et al., but no details on surgical technique or outcome are reported. The difficulty may be to achieve healing of the graft which is only possible with a sufficient bone stock of the corresponding epicondyle. Alternatively and/or additionally, augmentation with an internal brace which could be placed through the cannulated screw connecting the spool and the prosthesis shaft. In case of a young high-demand patient, in whom the surgeon absolutely wants to avoid a TEA, these options must be honestly discussed with the patient, with all their potential risks, as the outcome is unpredictable.

21.3 Non-union of Reconstructed Epicondyles

In C3 fractures reconstruction of the epicondyles is often necessary in order to achieve sufficient ligamentous stability. Different methods have been reported: *K*-wires, screws, plates, and transosseous/transprosthetic sutures. As the bony

contact area is low, union is critical. Nestorson et al. described two non-unions in 42 patients—one of the medial and one of the lateral epicondyle [2]. It is not known how many epicondyles were reconstructed in this cohort. Neither the mode of stabilization nor the influence on the outcome is reported. But the authors did not list the non-union as a problematic complication which leads to the assumption that they were asymptomatic.

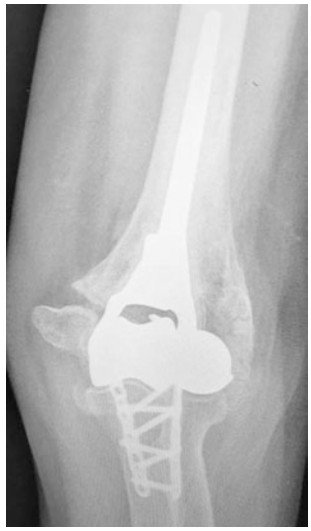

Fig. 21.4 Asymptomatic non union of the medial condyle in a 65 female after transosseous/transprosthetic suture refixation. No instability resulted from this non-union

We have observed two patients with epicondyle non-unions (Figs. 21.4 and 21.5). Both cases are asymptomatic. Therefore, there has been no indication for revision so far. In the current literature, no report of revision surgery for symptomatic epicondyle non-union in DHH can be found.

The treatment options for symptomatic non-union are revision osteosynthesis with cancellous bone grafting or resection, but this does not seem reasonable as this may lead to instability. Therefore, if revision osteosynthesis is not possible or reasonable, conversion to a linked TEA must be considered as a symptomatic non-union is likely to be associated with marked instability. This assumption is supported by Nestorson et al. who described bilateral epicondyle non-union as a possible factor promoting early loosening due to instability and our case described in Fig. 21.1.

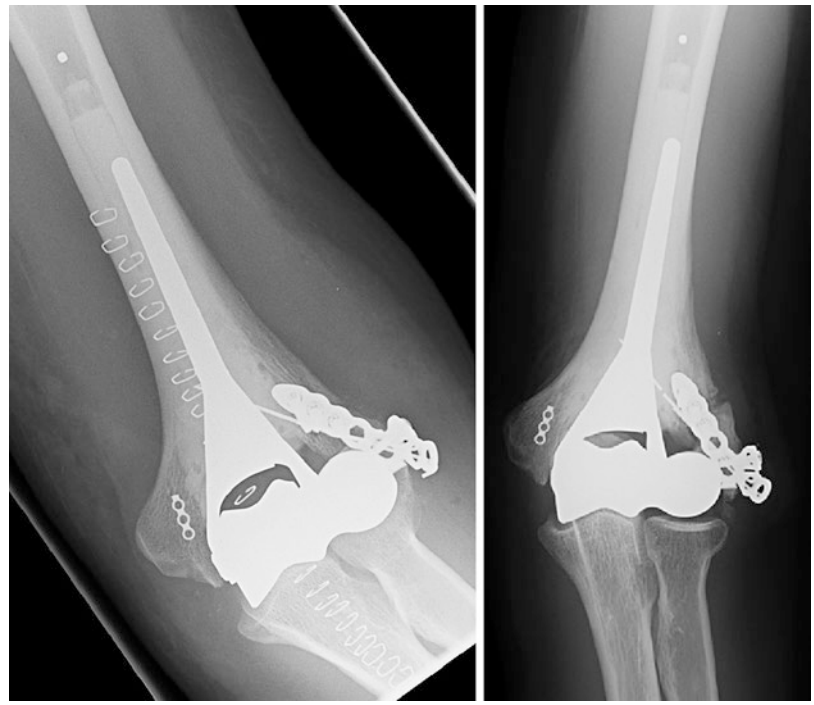

Fig. 21.5 Asymptomatic lateral epicondyle non-union in a 49 years who received a hemi because of a comminuted capitellar and troclear troch shear fracture

21.4 Prominent Hardware After Olecranon Osteotomy or ORIF of Epicondyles

Prominent hardware has been reported in most DHH papers. Hohmann et al. reported on three hardware removals in eight patients: *K*-wires used for lateral column reconstruction, one suture button device, and one not specified device used for olecranon osteotomy fixation [3]. Schultzel et al. reported one hardware removal of a not specified prominent olecranon fixation device in ten patients with an olecranon osteotomy for DHH [6]. Smith and Hughes had to perform hardware removal in 10 of 26 patients: 7× tension band, 1 homerun screw, 1 compression screw, and 1 plate used for olecranon osteotomy refixation [7]. Parsons et al. removed the tension band wires used for olecranon osteotomy refixation in three of eight patients [8].

Therefore, it must be concluded that an olecranon osteotomy approach is associated with a higher rate of implant removal compared to olecranon sparing approaches. The advantage of ligament sparing must be weighed against the need for additional surgery—especially in the elderly patient.

21.5 Wear

Wear of the proximal forearm cartilage is only a matter of time as in every hemiarthroplasty. Joint incongruencies due to imperfect mimicry of the native distal humeral anatomy as well as the articulation of metal against cartilage are the most important factors contributing to wear even in a perfectly implanted DHH.

Burkhart et al. reported wear in 1 of 10 [5], Parsons in 1 of 8 [8], Smith and Hughes in 13 of 16 [7], and Hohmann in 7 of 7 patients [3]. Phadnis et al. reported ulnar wear in 10 of 16 and radial wear in 3 of 16 patients [9]. Adolfsson and Nestorson reported progressive wear in three out of five patients [10, 11]. The prosthesis used in this case series was a Kudo humeral component which is non-anatomic. The authors therefore concluded that the Kudo should not be used as hemi. In a later series—now using the Latitude system—Nestorson et al. reported that the rate of wear was "markedly reduced" to only 5 of 42 patients [2]. Minor wear has been reported not to affect clinical outcome. Smith and Hughes reported 2 cases of complete cartilage wear and 6 of 16 cases with bony wear that were associated with inferior results [7]. This high rate of wear may be associated with the olecranon osteotomy approach used by the authors.

Basic research supports the thesis that optimal fit of a hemi reduces contact pressures. Lappner et al. concluded from their cadaveric study that shape differences of DHH compared with the native anatomy might be responsible for cartilage wear due to altered contact patterns [12]. Desai et al. showed that perfect or oversized spool sizing leads to better joint congruency and kinematics than an undersized spool [13]. Willing et al. showed in a finite element modelling that cartilage reversed engineered DHH implants provide the best contact mechanics compared to bone reversed engineered and commercially available implants [14, 15]. As the distal humeral surface was exactly reproduced, the decreased contact area was attributed to the increased stiffness of the metal implants compared to the softer cartilage. Therefore, the authors concluded that the use of materials with cartilage-like properties might be more important than custom-made implants.

Instability can be another factor promoting cartilage wear. The only case with wear in the cohort of Heijink et al. was the one with subluxation [1]. In a systematic review by Phadnis et al., olecranon osteotomy was presumed to promote wear as the olecranon cartilage might be harmed or contact pressures altered as a result of osteotomy and the functional results seem inferior compared to olecranon sparing approaches [16].

Asymptomatic wear does not need to be treated but should be observed. The only therapeutic option for symptomatic wear is conversion to TEA (Figs. 21.6 and 21.7). If the joint is stable, unlinked TEA can be considered.

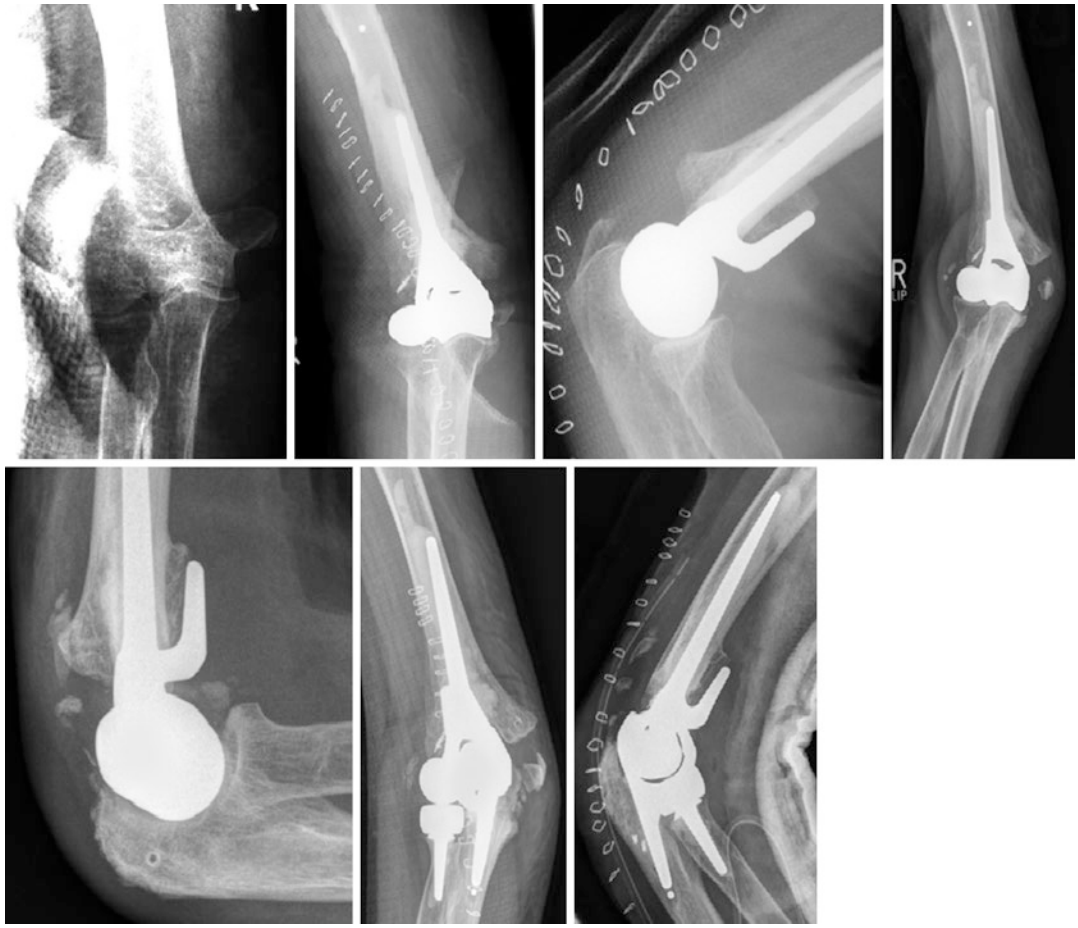

Fig. 21.6 A 70 years old female patient suffered a B3/C3 distal humerus fracture due to a fall from her bicycle. After 5 months she had a good result (MEPS 80, DASH 17, no pain) with full range of motion except a 5° extension deficit. After 13 months she complained increasing pain (MEPS 60, DASH 30, increasing pain, good function). X-rays revealed cartilage wear of the proximal forearm. Conversion to linked TEA was performed without removal of the well fixed humeral stem

21.6 Stiffness

Stiffness is a common problem in DHH. While the elderly low-demand patient may cope with stiffness, younger high-demand patients may not be satisfied with their result depending on the degree of stiffness and individual demands. Most common reason for stiffness is arthrofibrosis. Open release may be a good option according to the common therapeutic strategies of the stiff elbow. As the skills in arthroscopic release of the stiff elbow advance, this may be an option in the hands of the advanced elbow arthroscopist. However, there is little data for either option. Only Smith and Hughes mentioned open release in one patient, but no details on technique or outcome were published [7].

Another reason for stiffness may be overlengthening, by placement of a humeral component too far distally. This can raise several issues, instability due to inadequate ligament reconstruction as discussed above, overly tight soft tissues that may not respond that well to surgical release alone, and increased pressure on the proximal forearm cartilage with the risk of early wear. Therefore, revision arthroplasty should be a consideration in this situation. No data concerning this problem have been published so far.

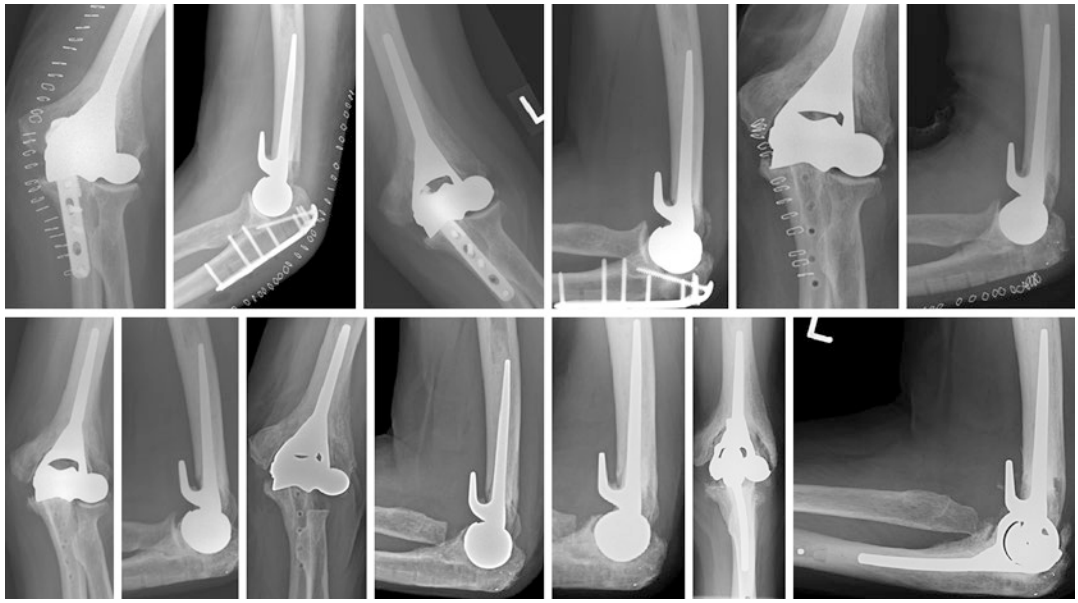

Fig. 21.7 A 61 years old patient with Implantation of a Hemi due to rheumatoid arthritis. The ulnar plate had to removed. A radial head resection was performed as he complained of lateral sided pain 3 years later. However, this did not relieve his pain sufficiently. Ulnar wear progressed. One year later conversion to TEA had to be performed. 8 years later he is doing well

Instability can also be a reason for stiffness and should always be considered when planning revision surgery. Surgical release might unmask instability and therefore change or even worsen patient complaints.

21.7 Conclusion

DHH is a complex operation, potentially much more difficult than TEA, and is prone to complications. In 2012 Dunn et al. identified a 32% reoperation rate (37 of 116 elbows) for fracture indications and 18% (3 of 17 elbows) for non-fracture indications [17]. There were 85 complications among the 116 trauma patients. Most common problems were hardware irritation (34%), ulnar nerve problems (16%), "laxity" (16%), intra- or postoperative fracture (9%), pain (7%), stiffness (6%), HO (2%), osteoarthritis (2%), loosening (2%), PLRI (1%), and wound breakdown (1%).

Prevention of complications is of utmost importance. Instability must be avoided by stable reconstruction of the epicondyles carrying the collateral ligaments and common extensor and flexor origins. Implantation of DHH in correct height is not only crucial for anatomic refixation of the epicondyles but triceps and brachialis tension, too, which is another factor providing stability. In acute cases the osteoligamentous release sustained at the time of the fracture allows a triceps-sparing approach. Olecranon osteotomy can be avoided in most cases minimizing the risk of reoperation for hardware removal. Furthermore, olecranon osteotomy might be a factor promoting ulnohumeral wear especially if it does perfectly depart in the bare area of the ulna or if it is not reduced perfectly.

In contrast to hip hemiarthroplasty, DHH must therefore be considered an expert operation and should be performed in elbow centers only. Surgeons must be aware of the possible complications. The indication must be outlined carefully and should not be extended excessively.

As conversion to TEA is the solution to many problems, a modular implant that allows conversion to unlinked or linked TEA should be used.

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Part IV

Radial Head and Radiocapitellar Arthroplasty

22 Indications for Radial Head Arthroplasty and Classification of Current Implants

Giovanni Merolla, Antonio Padolino, Paolo Paladini, and Giuseppe Porcellini

22.1 Introduction

Controversy still exist over the indications for fixation versus radial head replacement for displaced and comminuted radial head fractures. Although the excision of the radial head has been historically indicated in unreconstructable comminuted fractures, it can induce pain, instability, proximal migration of the radius, decreased strength, and osteoarthritis [1–3]. These unsatisfactory clinical outcomes are related to the critical role of the radial head in force transmission and stability of the elbow [4, 5]; the lack of these stabilizing effects are even more relevant in presence of associated ligaments or other bony injuries [4–6]. There is a substantial agreement in the literature that restoration of radiocapitellar contact, through the fixation or replacement of the radial head, is an essential point in the radial head fractures treatment [7–9]. On the other hand, capitellum wear due to the use of implant arthroplasty remains a concern [10–12]. Radial head arthroplasty is a modern surgical option when faced with a complex fracture and associated elbow ligament injuries.

22.2 Indications for Radial Head Arthroplasty

Radial head arthroplasty is indicated in patients with complex pattern of radial head fractures. The Mason classifications of radial head fractures include nondisplaced fractures (type I), displaced partial head fractures (type II), and displaced fractures involving the entire radial head (type III) [13]. A modification of this original classification was then performed by Johnston [14] who added a fourth type including a displaced radial head fracture with associated elbow dislocation and by Broberg-Morrey [15] who defined the amount of radial head fracture displacement as follows:

- Type I: <2 mm.
- Type II: ≥2 mm and involvement ≥30% of the joint surface.
- Type III: comminuted.
- Type IV: any type with elbow dislocation.

Finally, Hotchkiss in 1997 [16] modified Mason classification with respect to mechanical block to motion to guide the operative treatment. Interestingly, Ring in 2008 [17] showed the poor

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reliability of aforementioned radiographic classifications to assess elbow instability and emphasized the poor results of internal fixation in the presence of more than three fragments and associated dislocation, with bone and ligament injuries. On the basis of these assumptions, radial head arthroplasty is indicated in the following conditions:

1. Acute comminuted fractures in which a stable fixation is precluded; in this condition, fractures with three or more fragments or severe comminution are also included [17].
2. Complex elbow injuries, with bone fractures and ligament tears that involve greater than 30% of the articular rim of the radial head, which cannot be reconstructed [11].
3. Instability of the elbow after radial head excision [16].
4. Persistent pain and instability following radial head primary resections, malunions, or after complex elbow fracture dislocations involving the radial head [12, 18].
5. Suspected Essex-Lopresti lesions [7, 18].
6. Associated terrible triad injuries [7].
7. Unreconstructable radial head fractures with concomitant medial collateral ligament injury, interosseous membrane injury, or elbow dislocation [19, 20].

22.3 Contraindications and Current Trend

Radial head implant should be avoided in the presence of concurrent locally or remote infection. We also consider at high risk the use of radial head arthroplasty in fractures that extend beyond the bicipital tuberosity due to the mismatch of the rotational axis of the implant and the capitellum. In these conditions, cemented long-stem bipolar prostheses may minimize the effects of this mismatch, even though it remains at high risk of failure.

Overall, several controlled trials have shown the superiority of radial head replacement compared to internal fixation in terms of postoperative complications and outcome scores for Mason type III and IV fractures [21–23]. These findings have likely contributed to the increase in utilization of radial head arthroplasty compared to the internal fixation and non-operative management for radial head and neck fractures. The shorter operative time with radial head replacement and improvement of radial head implant technology may have contributed to these trends.

22.4 Models of Radial Head Arthroplasty

Prosthetic models for replacement of the radial head can be divided in silicone prostheses, unipolar or bipolar, monoblock or modular, anatomical or non-anatomical, and cemented or press-fit [24, 25].

Silicone implants were used in the past after radial head resection. These prostheses are now rarely implanted because of high rates of loosening, fracture, and silicone synovitis [26] (Fig. 22.1).

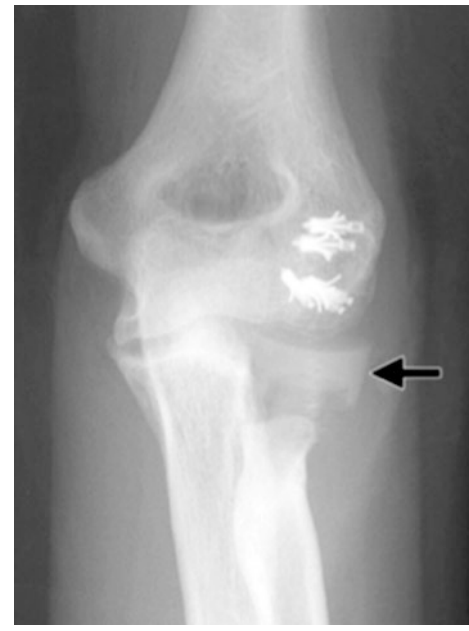

Fig. 22.1 Silicone radial head implant

Fig. 22.2 Unipolar monoblock (Swanson Titanium Radial Head-Wright Medical Technology)

The compressibility of silicone makes it unable to restore the biomechanics of the elbow [27].

Unipolar monoblock prostheses consist of a radial head that doesn't move separately from the radial neck. The unipolar stem could be fixed as press-fit or cemented way. These implants are becoming obsolete because of the absence of modularity. These prostheses don't allow to restore the anatomy and the radial head kinematic (Fig. 22.2). Different studies underline the importance of an accurate reproduction of the size and orientation of the radial head to restore the complex articular movements of the elbow [25, 28].

Unipolar modular prostheses, the evolution of monoblock, have gained better results (Fig. 22.3). The problem of these implants is the "incongruity" that can cause local pain for degenerative changes of the capitulum humeri [25, 29].

The difficulties of unipolar implants are to reproduce the height, diameters, medial offset, and cervicocephalic angle of the native radial head.

Bipolar modular prostheses have a design that allows semiconstrained articulation of the radial head with the fixed metal stem. They may rotate 10°–15° in all planes. This design could reduce stress at the implant-bone interface and increase the contact area of the capitellar joint [30] (Fig. 22.4).

Judet [31] introduced a floating head bipolar prosthesis with a longer stem that allows 35° of motion in any direction.

Bipolarity permits an "automatic" positioning of the radial head with respect to the neck and the opposite articular surfaces. However, this may be associated with reduced articular stability and possible tribologic drawbacks related to wear of the polyethylene positioned between the stem and the radial head [25].

This increased motion is greater potential for osteolysis, particle disease, and osteoarthrosis at the radiocapitellar joint space. A resurfacing of the capitulum humeri could solve the last problem [26].

Anatomical modular prostheses could restore the right radial length and give the "congruity" of the humeral-radial articulation (Fig. 22.5). The uncemented stem could be smooth or rough. The smooth one has endomedullary movements (loose-fit) that permit a better congruence of the radial head with the humeral condyle during pronation-supination and extension-flexion. The rough stem could be covered by osteoconductive biomaterials that facilitate the primary press-fit and osteointegration [25].

22.5 Overview

The indication for radial head arthroplasty is for Mason type III and IV fractures.

The goal of all kind of implants should be the restoration of joint stability, preservation of range of motion, and maintenance of radial length in patients with complex radial head fractures [32].

In literature the quality of evidence is poor for different reasons: small number of patients of the series, heterogeneus injury pattern of fracture, etc.

Fig. 22.3 Unipolar modular radial head arthroplasty (EvolveTM PROLINE—Wright)

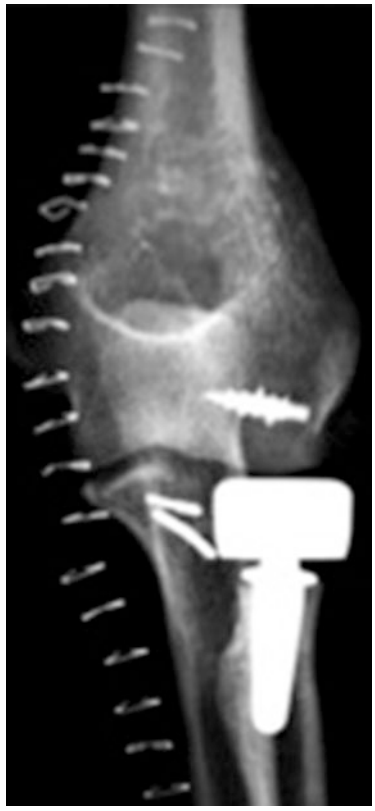

Fig. 22.4 Bipolar modular radial head arthroplasty (CRF-Tornier)

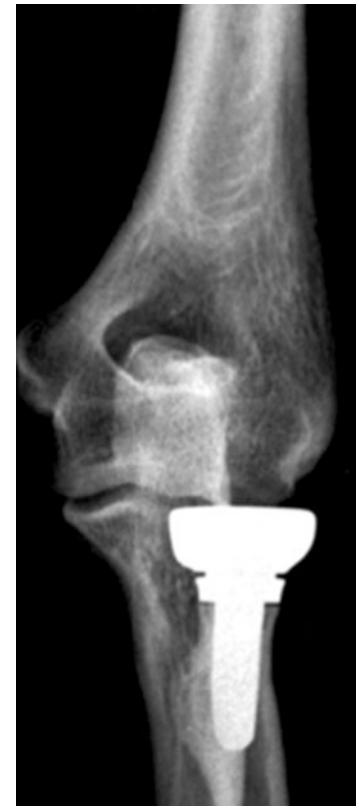

Fig. 22.5 Anatomical modular radial head arthroplasty (Acumed)

Outcomes of each implants, rate of success, and complications will be illustrated in the following chapters.

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23 Non-anatomical Monopolar Uncemented Radial Head Arthroplasty: Surgical Technique and Expected Outcomes

Davide Blonna and Marco Lamalfa

Non-anatomical monopolar uncemented radial head arthroplasty (NA-RHA) is one of the most commonly performed radial head arthroplasties and is one of the first radial head replacements with a well-documented long-term follow-up [1–3]. Despite the most recent interest in alternative anatomical or bipolar models, NA-RHA remains a valid implant that could be still considered the gold standard.

The benefits of NA-RHA include a simple technique of implantation, simple instrumentation and solid scientific background. These designs behave as a spacer and are based on the concept that a real anatomical replacement of the radial head is not achievable due to the extreme anatomical variability. The main disadvantages are that most design requires a press-fit insertion in the radial shaft, a condition not always possible to achieve considering either poor bone quality or the limited modularity of the stem sizes. Some designs have overcome these potential limitations and utilize a spacer concept with a smooth stem. The smooth stem can move slightly (loose fit) in the proximal radius improving radial head tracking thus reducing abnormal kinematics and problems with articular wear and pain.

Another limit of NA-RHA is that they generally require a good alignment between radial shaft and capitulum of the humerus. This condition is not always satisfied in cases of "Monteggia-like" fracture dislocation of the elbow or in long-standing deformities affecting the proximal forearm. In such cases a bipolar radial head implant might be preferred since these designs provide a theoretical improvement in tracking.

Indications are similar to other radial head implants and include acute treatment of (1) radial head fractures, especially in cases of comminution of the radial head associated with a valgus instability due to concomitant MCL tear, (2) radial head fractures associated with coronoid fracture and LCL tear (terrible triad pattern of injury, Fig. 23.1), (3) "Monteggia-like fractures" with a good alignment between radial shaft and capitulum of the humerus, and (4) Essex-Lopresti pattern of injury. In radial head fracture cases, ORIF should always be considered as the first treatment choice. The decision between ORIF and radial head replacement is not straightforward in some cases, and this topic is outside the scope of this chapter. Briefly, it is the authors' experience to recommend radial head replacement in cases of comminution and impaction of the 1/3 anterior part of the radial head especially if some degree of instability is intraoperatively documented. The age of the patients is not usually a limiting factor.

In chronic cases the use of these implants is related to the necessity to improve elbow stability against valgus instability, posterolateral instability or axial instability. It is worth emphasizing here that these patterns of instability can be found isolated or in combination in the same patient.

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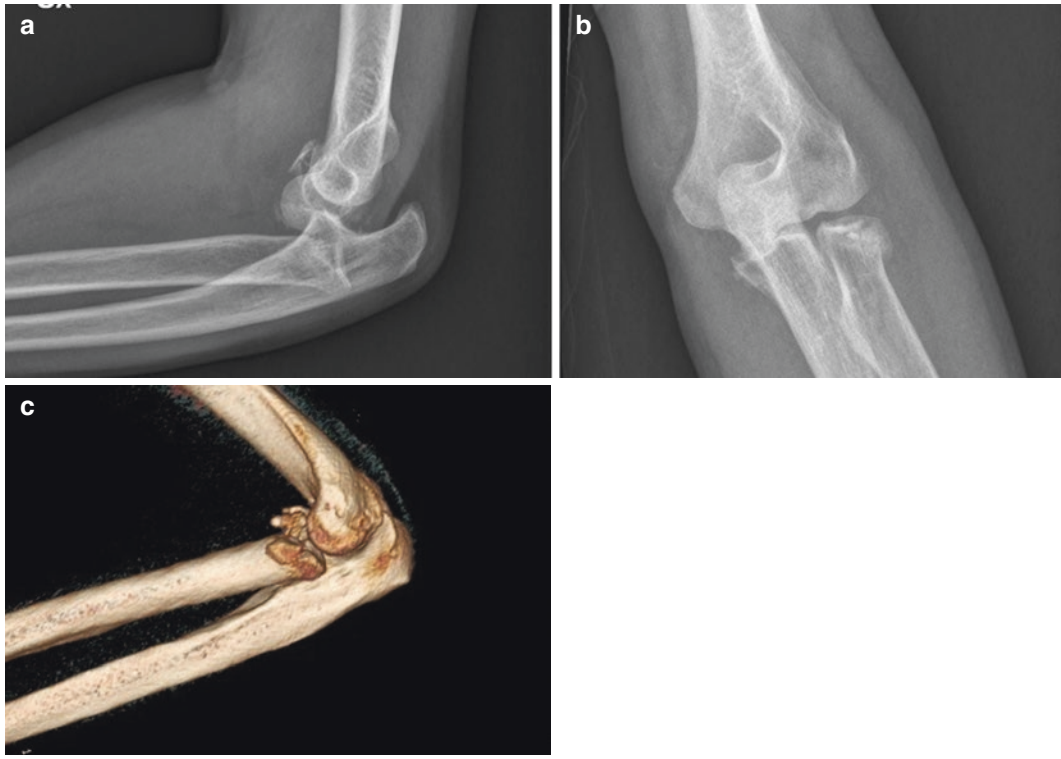

Fig. 23.1 (**a**–**c**) The X-ray and 3D-CT scan show a terrible triad pattern of fracture dislocation of the elbow. The 3D CT scan demonstrates that the radial head is comminuted

23.1 Surgical Technique

A correct surgical technique is mandatory to obtain good long-term outcomes. The fact that the technique and instrumentation are simple should not lead the surgeon to believe that a meticulous technique and appropriate learning curve is not necessary.

- *Patient positioning*: Radial head implantation can be performed with the patients in various positions. We suggest leaving the patient in the supine position, with the arm draped over the chest. This position allows for an easy intraoperative fluoroscopic check and does not preclude other concomitant surgical steps to treat the coronoid, proximal ulna or soft tissues.
- *Surgical approach*: The most common surgical approach to the lateral elbow is the Kocher approach that uses the interval between anconeus and *extensor carpi ulnaris* (the so-called Kocher interval) to easily reach the lateral ligament complex and, underneath, the radial head (Fig. 23.2).

The Kocher approach has the advantage that can be easily extended either proximal to the humerus or distal to the radial shaft without too much fear of neurovascular structures. Moreover, it allows a good visualization of both the anterior and posterior aspect of the radial head, particularly of the area of the lesser sigmoid notch. The correct visualization of this area is one of the important surgical steps necessary to avoid overstuffing of the radial head implant. The main disadvantage of the Kocher approach is that the Kocher interval lays at the same level of the ulnar lateral collateral ligament of the elbow, and the incision of the LCL complex at the level of the Kocher interval might predispose the patient to recurrent posterolateral instability (Fig. 23.2).

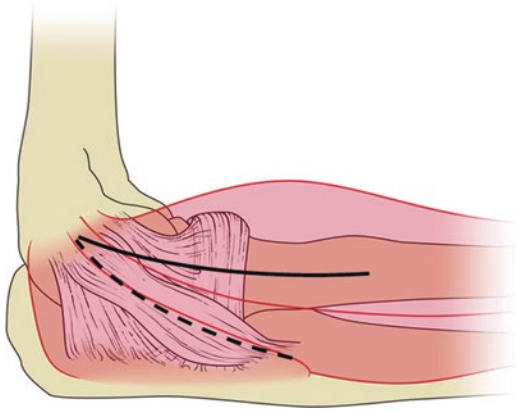

Fig. 23.2 Relationship between Kocher interval (dashed line), Kaplan approach (solid line) and the lateral collateral ligament complex

A safer way to avoid recurrent posterolateral instability is to excise the capsule and LCL complex more anteriorly than what the Kocher interval would suggest. Moreover, a careful repair of LCL complex is recommended after radial head implantation, along with some protection against varus stress for 3–4 weeks after surgery.

An attractive option is to use a more anterior approach, in all cases at risk of recurrent instability. The Kaplan approach is a surgical approach slightly anterior to the Kocher approach that entirely preserves the LCL complex (Fig. 23.2) without adversely affecting on the visualization of the radial head. It must be said however that by using the Kaplan approach a direct visualization of the lesser sigmoid notch is more difficult. Another limitation of the Kaplan approach is the risk of PIN damage in cases of distal extension of the approach—a condition, however, that is rarely encountered.

Exposure: A good visualization of the proximal radius without aggressive soft tissue detachment is the key to obtaining good outcomes and avoiding complications. A few steps can permit the surgeon to achieve good visualization of the proximal radius:

– Detachment of the common extensor tendon unit 2 cm proximal and slightly anterior to the lateral epicondyle with partial release of the anterior capsule. This proximal exposure increases the visualization of radial head, without affecting the LCL complex. This step is usually not necessary in cases of severe elbow instability due to the detachment of the common extensor tendon and LCL as a result of trauma (Fig. 23.3).
– Incision of the annular ligament and exposure of the radial neck. An extensive surgical exposure of the radial head diaphysis is not necessary. Once the neck of the radius is visualized, two Hohmann retractors are positioned in both aspects of the radial neck, and, by pulling laterally, the proximal radius is easily disengaged from the capitulum of the humerus permitting good visualization (Fig. 23.3). If scar tissue or heterotopic ossifications are present around the radial neck, careful identification of the PIN is recommended before placing the Hohmann retractor anteriorly, to avoid iatrogenic damage to the nerve.

Preparation of the diaphysis: This step is one of the most difficult and prone to mistakes that, although initially appearing minor, can have profound consequences on the longevity of the implant. If the radial head is still attached to the radial neck, an osteotomy is required. The osteotomy should be planned carefully according to the design of the implant and the known thickness of the radial head implant. All commercially available systems involve broaching the radial canal for proper stem fit. Some systems provide angled broaches that allow the preparation of the radial canal without requiring manoeuvres to lateralize the proximal radius. Proper canal preparation is important to obtain a good press fit of the definitive implant. A perfect press fit is however not always easy to achieve. The limiting factors are essentially poor cancellous bone in the proximal radius and the limited modularity of the stems that forces the surgeon to compromise between excessive press fit (with the risk of iatrogenic fracture) and loose fit. A loose fit is an appealing option with some designs of NA-RHA but is a concept that should not be generalized to all the NA-RHA.

How to avoid overstuffing: Several methods have been proposed to avoid overstuffing of the

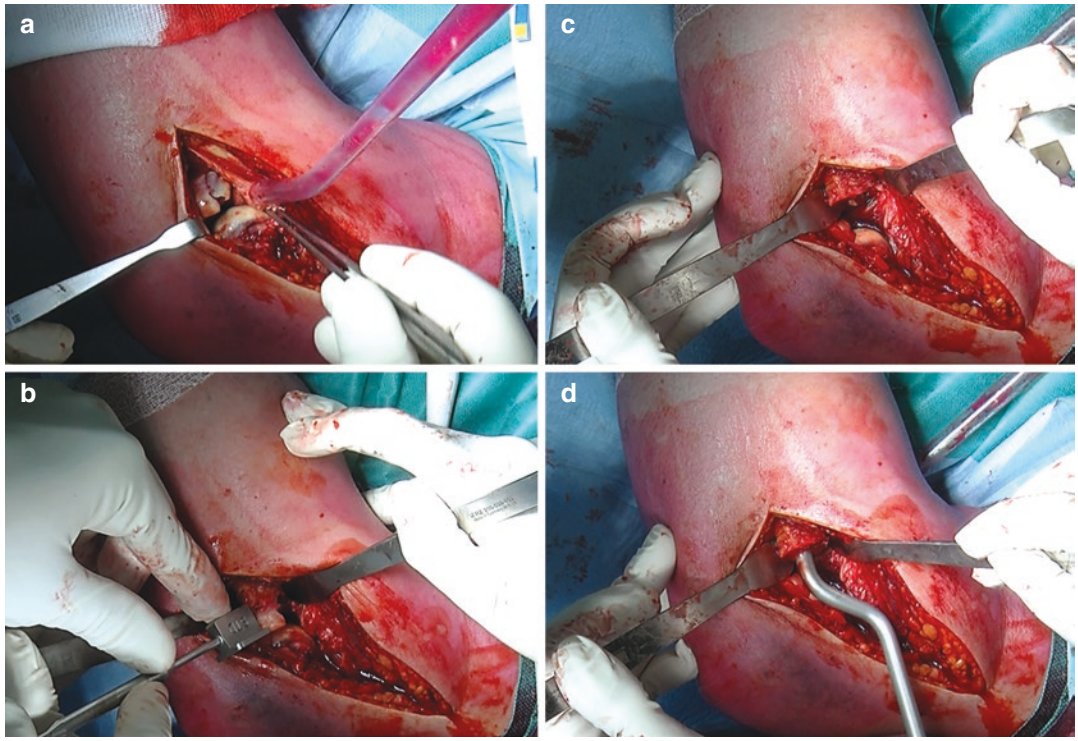

Fig. 23.3 (**a**) The Kaplan approach to the lateral elbow provides good visualization of the comminuted radial head. (**b**) A specific tool is used to define the line of neck osteotomy. (**c**) Two retractors are placed around the proximal radius to laterally displace the proximal shaft. (**d**) Broaching of the radial canal for proper stem fit (when required)

radial head implant, a common complication encounter after radial head replacement. None of the methods described have proven to be free of error. It is the authors' suggestion to integrate different tips and tricks to avoid overstuffing instead of following a single technique.

Our integrated method to avoid overstuffing is based on:

- Accurate exposure of the lateral elbow, regardless of the type of surgical approach. The exposure should aim for good visualization of the lesser sigmoid notch (Fig. 23.4).
- During the implantation of the trial, position the forearm without any varus stress. The trochlea and ulna (greater sigmoid notch) should match perfectly. Some pressure by the surgeon from distal to proximal can be helpful to guarantee a perfect matching and exclude any opening of the lateral side of the elbow due to concomitant varus stress. A lateral opening could erroneously lead the surgeon to fill the gap with a radial head component that is too long causing overstuffing.
- Intraoperative check with fluoroscopy. We suggest checking under fluoroscopy the correct position of the radial head implant especially during—but not limited to—the learning curve.

LCL complex repair: A solid repair/tensioning of the LCL complex and extensor tendon unit is mandatory in all post-traumatic cases (Figs. 23.5 and 23.6). We suggest using a 5.5 mm metallic anchor, screwed in the area of the LCL origin and loaded with three non-resorbable sutures. Three mattress sutures are positioned in

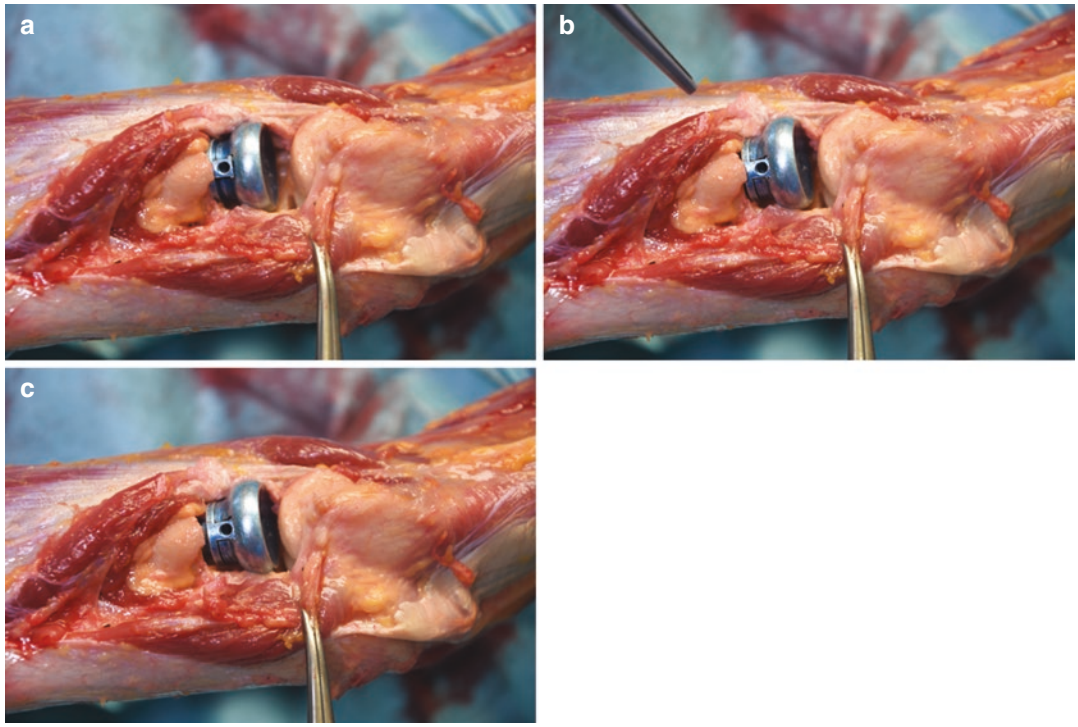

Fig. 23.4 These figures in a cadaver highlight the relationship between radial head and lesser sigmoid notch. (**a**) The radial head is 3 mm below the proximal margin of the lesser sigmoid notch; this is acceptable but, the long-term consequences on ulno-humeral joint are unknown. (**b**) The radial head is 1 mm below the proximal margin of the lesser sigmoid notch; this is the ideal setting. (**c**) The radial head is proximal to the lesser sigmoid notch; this should be avoided (overstuffing of the radial head)

the following order: (1) posterolateral, to imbricate the U-LCL and anconeus; (2) distal, to repair the annular ligament and to close the Kocher/Kaplan approach; and (3) in proximity of the anchor to repair/re-tension the common extensor tendon unit.

Postoperative care: The type and duration of the postoperative protocol are strictly dependent by variables other than the type of implant used. Any residual instability should be carefully identified after surgery, with the patient still under anaesthesia, to customize the postoperative care to that specific elbow. If skin healing is not considered at risk, in most of our patients, we allow unrestricted range of motion immediately after surgery. This is permitted by the integration of a Kaplan approach and secure repair/tensioning of the LCL complex.

23.2 Expected Results

Good to excellent outcomes have been reported after non-anatomical monopolar uncemented radial head arthroplasty. In 2001 Harrington et al. reported one of the first long-term follow-up studies of 20 patients affected by radial head fracture and elbow instability, showing favourable outcomes at an average of 12 years of follow-up [2].

Grewal et al. in the 2006 reported one of the first well-documented cohort of 26 patients affected by comminuted radial head fractures treated with a modular metallic radial head arthroplasty [1]. Twenty-two had an associated elbow dislocation, and 13 of them also had an associated fracture of the coronoid process. At 2 years follow-up, no implant required revision.

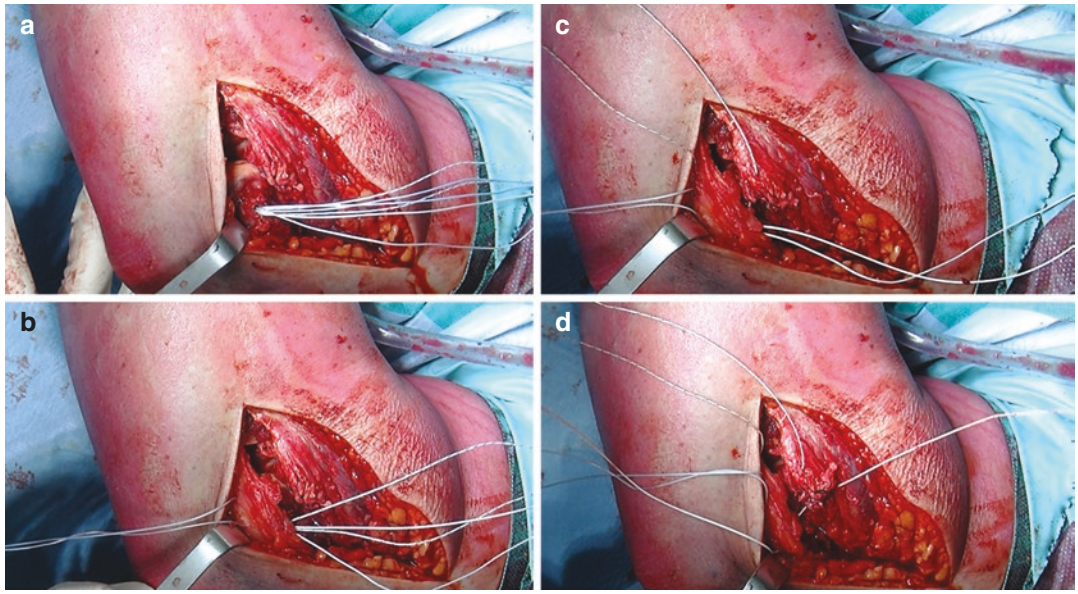

Fig. 23.5 Repair/re-tensioning of LCL complex. (**a**) A 5.5 mm metallic anchor is screwed in the lateral epicondyle. (**b**) The first mattress suture is placed inferiorly and distally embracing both the LCL in the deep layer and the anconeus in the superficial layer. (**c**) A second mattress suture is used to close the annular ligament and the Kaplan approach. (**d**) A third suture is used to reattach the extensor tendon unit to the epicondyle

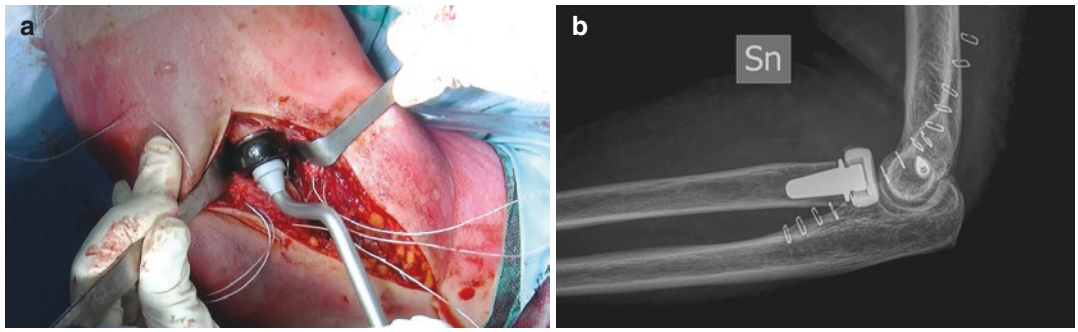

Fig. 23.6 (**a**) Implantation of the final non-anatomical press-fit redial head. In this case a pyrocarbon implant was preferred due to the young age of the patient. (**b**) Postoperative X-ray

More recently the same group reported the outcomes of 55 patients with an average of 8-year follow-up, including a longer follow-up of the same cohort of patients already published in 2006. Although 45% had stem lucencies, no patient required implant removal or revision [3].

Consistent good outcomes have also been reported from researchers not involved in the design of the radial head implant. Moghaddam et al. reported good outcomes at an average of 41 months in 75 patients [4]. Fifty-eight patients (77%) had periprosthetic radiolucency with no clinical consequences according to evaluated scores; 26 patients had moderate or severe periarticular ossification and scored substantially worse. Four patients required revisional surgery due to loosening of the prosthesis and chronic pain.

Similar rate of radiolucency was recently reported in a study of 32 patients at an average of

almost 9 years of follow-up. Periprosthetic radiolucency was noted in 21 patients (66%). The difference in functional outcomes was not significant between patients with and without radiolucency [5].

Few attempts were made trying to compare non-anatomical monopolar uncemented radial head arthroplasty versus other designs. Rodriguez-Quintana et al. compared two groups of 14 patients at an average age of 2 years of follow-up that underwent a radial head replacement using NA-RHA (with a loose fit stem) or anatomical uncemented press-fit implant [6]. Bone formation at the proximal radius under the implant occurred more in NA-RHA. Five anatomical press-fit stems had radiolucent lines at 2-year follow-up. Two were removed because of symptomatic loosening. The authors concluded that symptomatic aseptic loosening in anatomic implants is common. Bone formation at the proximal radial neck was observed more with smooth-stemmed implants.

23.3 Conclusions

Non-anatomical monopolar uncemented radial head replacement should be still considered the gold standard in unfixable radial head fractures. With a proper learning curve, good medium- to long-term follow-up should be expected. A common complication seems to be the radiolucency around the stem that, however, does not correlate with clinical symptoms.

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24 Anatomical Monopolar Press-Fit Radial Head Arthroplasty: Surgical Technique and Expected Outcomes

A. Marinelli and D. R. Shukla

24.1 Introduction

In the setting of a radial head fracture, fixation is preferred whenever possible, although resection can be still considered a potential option. However, recently there has been a growing international consensus that favors the use of a radial head replacement in patients with an unfixable radial head fracture, especially if there is associated complex elbow instability.

However, because radial head replacement can lead to stiffness, degenerative arthritis, and capitellar erosion, it is important to reproduce the mechanical function of the native radial head, to stabilize the elbow, and to neutralize the shear forces passing through the elbow. To replicate the physiologic radiocapitellar tracking, three different prosthetic strategies have been developed:

1. *Loose-fit stem RHP*. The stem is cylindrical and smooth with a polished coat; it is intentionally inserted undersized, so that the stem is allowed some degree of freedom inside the canal, and is meant to act more as a spacer. The loose fit, during the elbow movements, helps to accommodate the inevitable incongruences among the prosthesis and the capitellum and the lesser sigmoid notch, with a mechanism of self-centering similar to a bipolar prosthesis.
2. *Bipolar RHP*. The bipolar prostheses have an articulation between the stem and the radial head, allowing some tilting of the dish. Bipolar prostheses, secondary to the ability to self-align to the capitellum and to the proximal ulna, can adapt the tracking, even if not perfectly seated. Theoretical disadvantages using this type of prosthesis are the possible wear debris formation and an inferior mechanical stabilization in severe elbow instabilities [1].
3. *Anatomic RHP*. The anatomic RHPs have been developed to replicate as closely as possible the radial head anatomy, reproducing the physiologic radiocapitellar kinematics and biomechanics.

The first two RHP models are described in other chapters of the book.

24.2 Anatomic RHP Device Characteristics

The anatomic RHPs are designed to approximate the patient's native radial head, which is complex and not uniform. It is not circular, but rather elliptical [2–4]. The articulating dish is located eccentrically with respect to the neck, creating a cam effect between the radius and ulna at the proximal

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radioulnar joint, a feature that is essential for forearm rotation. However, the majority of currently available radial head implants are axisymmetric (or circular) in shape. Currently, there is only one anatomically shaped implant commercially available for use (Anatomical Radial Head System, Acumed, Hillsboro, OR, USA). Because patients' radial head shapes are not identical, the implant system is modular and includes 290 head and stem combinations including anatomically shaped radial heads and standard and long stems.

Radial head: Five left and five right anatomically shaped radial heads are provided, each with different diameters (20, 22, 24, 26, 28 mm), to accommodate various patient sizes. The heads are made of highly polished cobalt chrome to maximize the articular sliding and to minimize collar soft tissue irritation. The radial heads have an elliptic anatomical shape, with a 1 mm laterally offset dish from the center of the radial head. In the first-generation system, the dish depth was 2 mm among all implant head diameters. In the second-generation system, the dish depth increases with head diameter, to improve the radiocapitellar tracking and stability [5]. There is also 4° of tilt relative to the canal axis in two planes: anterior/posterior and medial/lateral. The medial part of the head is angled and smooth to improve contact with the radial notch of the ulna. The contoured lateral surface improves the interface with the annular ligament during pronation and supination movements. The head height is 10 mm for all of the head diameters, and adjustments in head height (i.e., implant length) can be achieved using different collar heights.

Stem: Twenty standard and 16 long stems are provided. They are made from titanium alloy with a grit-blasted surface to promote bony ongrowth. The stems are designed to press fit into the neck canal and have a tapered shape with two different lengths, standard and long. The standard stems are 25 mm long, and there are 20 standard stem options: 5 different stem diameters in 1 mm increments (6, 7, 8, 9 and 10 mm) each having 4 collar height options (0, 2, 4, and 8 mm) to provide proper restoration of the overall length of the radius. The standard stems can replace 9–17 mm of head and neck resection, and they are fully grit-blasted. In cases of very distal fractures or in the setting of a revision case, the long stems can replace from 19 to 28 mm. The long stems are available in four diameters in 2 mm increments (6, 8, 10, and 12 mm) and have four length options (50, 55, 60, 65 mm). The long stems are partially grit-blasted proximally to promote only a proximal bony ongrowth. With both standard and long stems, a Morse taper ensures a secure fit between the collar and the head.

It is essential that anatomic RHPs are positioned and fixed in the correct location in order to ensure proper joint alignment and to optimize radiocapitellar contact [6]. To make the surgical technique more reproducible, the instrumentation includes several assistive devices:

- A collar height gauge to determine the proper collar height determination (Fig. 24.1).
- Collar reamers are used to create a flat neck surface for the stem collar, to facilitate the accurate placement of the stem.
- Progressive size broaches for canal preparation. Specific progressive reamers have been recently added, as some advantages have been demonstrated [7].
- Color-coded trial heads and stems allow intraoperative evaluation for the definitive choice of the implant size.

24.3 Surgical Technique

The patient is placed in the supine position on the operating table. A non-sterile tourniquet is commonly used.

1. *Exposure*. *Superficial layer*: The skin incision is usually lateral, though replacement can be performed through a posterior skin incision if there are associated injuries such as an olecranon fracture, an anteromedial coronoid fracture, or an MCL injury that will be surgically addressed. In the latter two scenarios, it is possible, based on surgeon preference, to perform a combined (lateral and medial) approach rather than to address the injuries through a single posterior incision. *Deep layer:* There

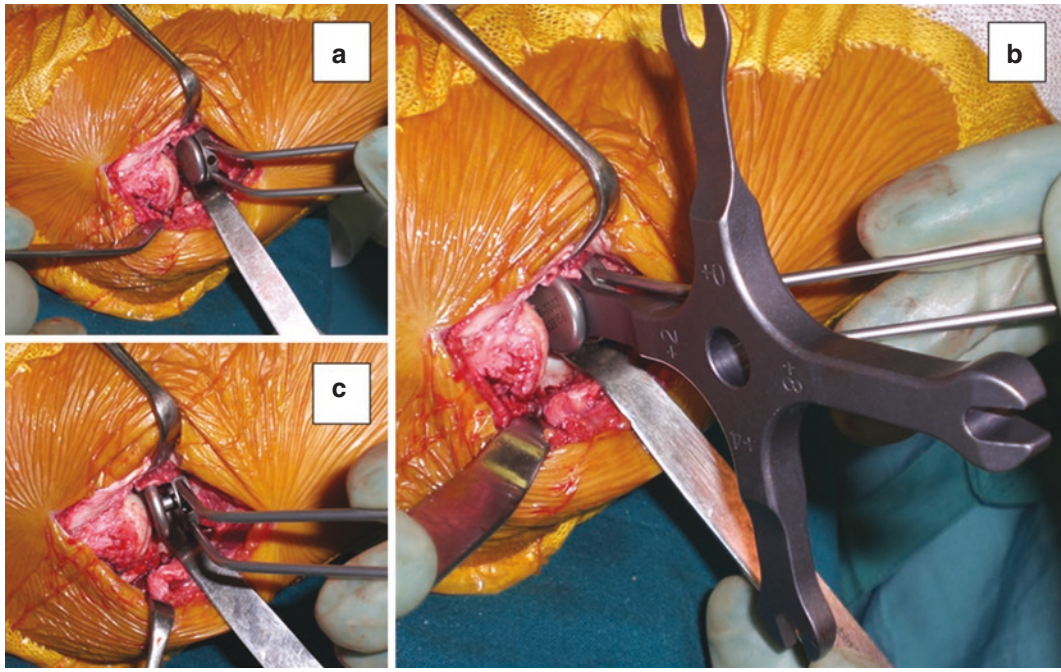

Fig. 24.1 (**a**) The sizing gauge is placed in the radial canal. (**b**) With the ulno-humeral joint reduced, a sequentially increased thickness of the "shape of a cross" collar height gauge is inserted, until the device contacts both the radius and capitellum. (**c**) The measurement corresponds to proper collar height for accurate restoration of radial length

are two suggested surgical approaches through which one can perform a radial head replacement, the transtendon approach and the Kocher approach, depending on the condition of the lateral collateral ligament. Based on the preoperative imaging and examination obtained in operative room under anesthesia, the integrity of the LCL is evaluated. If the LCL is not injured, our preference is to utilize the transtendon approach, splitting the common extensor tendon: this approach permits a good exposure of the proximal radius, facilitating the stem preparation and the implantation phase. More anterior approaches, like the Kaplan approach, which is between the common extensor and extensor carpi radialis brevis and longus, pose a greater risk to the posterior interosseous nerve (PIN) from possible intraoperative injury: it is a good exposure to perform radial head fixation, but we do not recommend it if replacement is anticipated. If the LCL is ruptured or if any injury is suspected, a Kocher approach is performed. This approach lies between the anconeus and the extensor carpi ulnaris and follows the lateral ulnar collateral ligament long its course from the condyle to the ulnar insertion, remaining just anterior to the ligament's course. For this reason, this approach permits an optimal exposure for its evaluation and treatment. In many circumstances, following the skin incision and subcutaneous tissue dissection, a radial head fragment, usually of conspicuous size, can be easily visualized, as the common extensor muscles tendon, capsule, and lateral collateral ligament have avulsed from the lateral epicondyle. In such circumstances, the surgeon can exploit the exposure through the injured tissues created at the time of injury. In other cases, injury to the lateral complex proceeds from the inside out (i.e., deep to superficial), leaving the extensor origin intact, while the capsule containing the LUCL (lateral ulnar collateral ligament) fibers is avulsed deep to the extensor tendon. In both situations, the Kocher approach, that lies directly superficial

to the LUCL, is the preferred approach to address the lateral ligament complex. In either approach (transtendon or Kocher), if the joint capsule and the annular ligament are intact, they are then incised in order to expose the radial head and remove the intra-articular hematoma. The anterior capsule and the origins of the extensors are elevated off the anterior aspect of the distal humerus.

2. *Fragment removal*: If the fracture is not amenable to fixation, all of the bony fragments are removed, and, if it is present, the residual part of the radial neck is resected using a microsagittal saw. The cut should be perpendicular to the shaft, without leaving a significant neck defect. However, it has recently demonstrated that the presence of a radial head fracture line extending to the neck, distally to the radial neck cut, does not reduce the stability of the implant [8]. Following resection of the head and neck, valgus and longitudinal stability are tested. After confirming the necessity of replacing the RH, all of the removed bony fragments are put together on the back table to recreate the native shape, if possible. This is also useful to confirm that all of the fragments have been excised, as well as to evaluate the size of the implant.
3. *Stem preparation*: By placing a Hohmann retractor over the posterior part of the radial neck, it is possible to deliver the proximal radius anterolaterally, facilitating the reaming and insertion of the prosthesis. If the LCL is torn, a varus and supinating stress maneuver allows for an even better exposure. The surgeon must note that applying a Hohmann retractor anteriorly can damage the posterior interosseous nerve (PIN), and for this reason, it is usually discouraged. Reamers are gently used in sequentially larger diameters, removing the cancellous bone, until cortical bone contact is achieved. Then, the specific collar reamer (also called "neck planer") is used to create a flat surface with at least 60% of contact with the trial radial head. To obtain the best fit, the maximum diameter reamer that the canal can accommodate is chosen. Biomechanical studies have shown that the best press fit, which is important for stem osteointegration and implant longevity, is achieved by maximizing the stem size in the radial canal [9, 10]. With the forearm in neutral position, the lateral aspect of the radial neck, that is in line with Lister's tubercle, is marked with the cautery.
4. *Radial head sizing*: The next step is the trial component insertion, during which particular attention should be given to determine the correct sizing of the radial head. In fact, it has been reported that radial lengthening or shortening of as little as 2.5 mm can affect the ulno-humeral kinematics and radiocapitellar pressures [11]. Radiocapitellar "overstuffing" can lead to early radiocapitellar wear and arthrosis and can restrict elbow motion; undersizing the implant length may result in residual valgus instability and not allow the radial head to appropriately load-share, thereby increasing contact forces at the ulno-humeral joint. To ensure proper implant size, possible five steps can be followed [12].
   (a) Recreate the shape of the fractured radial head on the back table, and compare it with the specific measurement devices provided in the instrumentation set (Fig. 24.2a).
   (b) Directly compare the native radial head with the prosthetic component trial, and, when in between head diameters, choose the smaller one (Fig. 24.2b).
   (c) With the ulno-humeral joint reduced, a sequentially taller height gauge is inserted, until the device simultaneously contacts the radius and capitellum (Fig. 24.1).
   (d) After having implanted the trial components, use the lesser sigmoid notch and not the humero-radial space as your landmark for the correct implant height [13]: the proximal edge of the prosthesis should not be more than 1 mm proximal to the proximal edge of the lesser sigmoid notch. The relationship between sigmoid notch and the radial head is not influenced by the position of the arm.
   (e) Intraoperative fluoroscopy is useful to confirm the correct diameter size and the stem alignment. However, recent studies have discussed the accuracy of one's

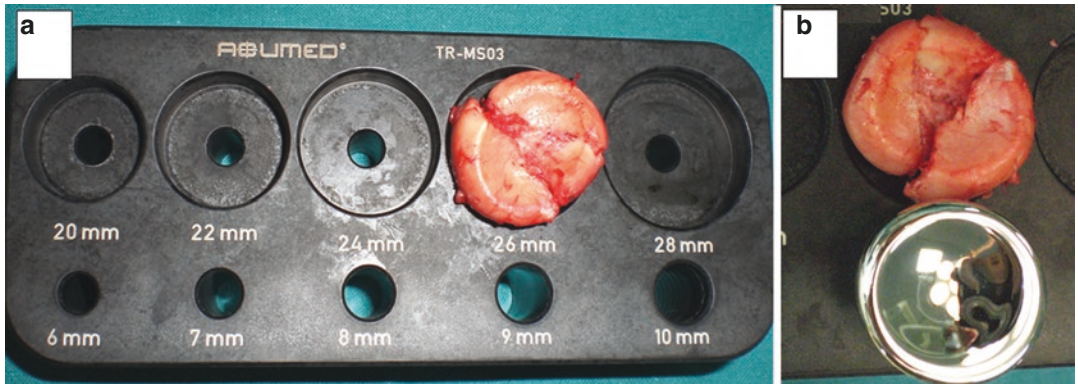

Fig. 24.2 It is possible to determine the radial head diameter by placing the resected head into the sizing pockets on the impactor base (**a**) and by directly comparing the resected head with the radial head trial (**b**)

ability to evaluate the radial head size with an anteroposterior radiograph of the ulno-humeral joint [14–16].

Alternatively, one can obtain radiographs of the uninjured, contralateral elbow obtained in the same positions of flexion-extension and pronation-supination [17]. On an AP fluoroscopic image, widening of the lateral ulno-humeral joint can sometimes be an anatomical variant [14] and therefore is not a reliable indicator of radiocapitellar joint overstuffing. Instead, any loss of the normal parallelism of the opposing joint surfaces of the medial ulno-humeral joint is highly suggestive of implant overlenghtening, even if this incongruity becomes radiographically apparent only when the overlenghtening of the radius is equal or superior to 6 mm [16].

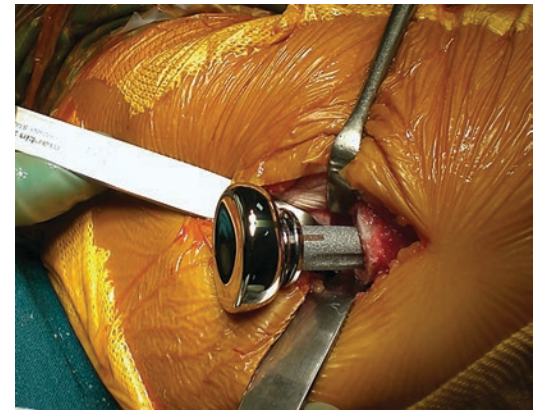

Fig. 24.3 Laser marks on the head and stem of the prosthesis are aligned with the lateral aspect of the radius when the forearm is in neutral rotation to ensure proper implant orientation during insertion. Lister's tubercle may also be used as a landmark for laser mark orientation

5. *RHP trial insertion*: The appropriate trial head is secured to the appropriate trial stem, aligning the laser mark on both components. The trial prosthesis is inserted, and the alignment between the laser mark on the prosthesis and the cautery sign, previously performed on the radial collar, allows for proper orientation during insertion. The collar of the prosthesis is then impacted flush with the resected stem: for a correct seating, at least two-thirds of the diameter of the radial neck should be in contact with the base of the head to support the implant. It is important to strive for an optimal press fit by maximizing the stem size in the neck canal [9, 10]. If a tight fit is not obtained, a longer stem or stem cementation can be another option. The elbow and forearm are placed through a full arc of motion, and the diameter, the height, the tracking, and the congruency of the RH are evaluated visually and with the aid of an image intensifier. If good alignment and tracking are confirmed, the trial components are removed.
6. *Definitive RHP insertion*: Based on the trial evaluation, the definitive RH is placed into the appropriately sized hole in the Morse taper impactor block, and the definitive stem is impacted while ensuring that the laser marks are aligned. The assembled prosthesis is then implanted (Fig. 24.3).

During stem implantation, if a small crack in the radial neck develops, it does not necessarily compromise initial stability, and in many cases, it might not be necessary to change the stem or place a cerclage wire around the fracture to ensure implant stability and promote bone ingrowth [18]. However, if there is concern about the stem stability, a longer stem can be used and possibly a preventive cerclage as well. The range of motion and the elbow stability are checked. The annular ligament is then repaired, and, in case of injured soft tissue (i.e., extensor tendon or LCL lesion), they are carefully repaired with transosseous sutures or suture anchors.

7. *Postoperative management*: In the postoperative phase, a personalized rehabilitation program is essential. Elbow stability and associated injuries should be taken into consideration to obtain a good result and to decrease the complication rate. If, at the end of the procedure, the elbow is stable, a protective brace can be applied for 2–3 weeks, and an early mobilization can be allowed. If a slight posterolateral rotatory instability is still present, the elbow is protected in a 90° brace with the wrist placed in pronation, and active overhead mobilization (flexion-extension) is allowed only after 7–10 days, avoiding elbow varus stresses for at least 4 weeks. In such situations, more frequent clinical and radiographic follow-ups are also recommended.

24.4 Results

Only few clinical studies exist on the results of anatomical radial head replacement [19–23]. Good to excellent results are reported in all the studies (Figs. 24.4 and 24.5).

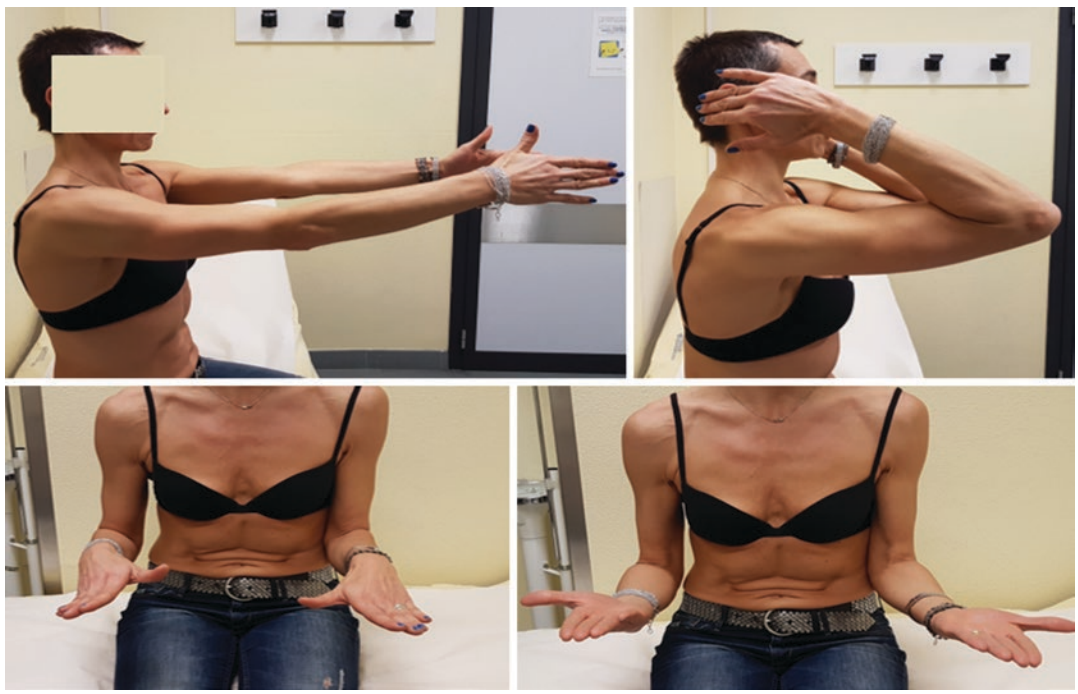

Fig. 24.4 A 10-year follow-up of an anatomic RHP implanted in a young and active patient. She does gymnastics on a regular basis. Clinically the patient has good range of motion, no pain, normal strength, and no evidence of instability

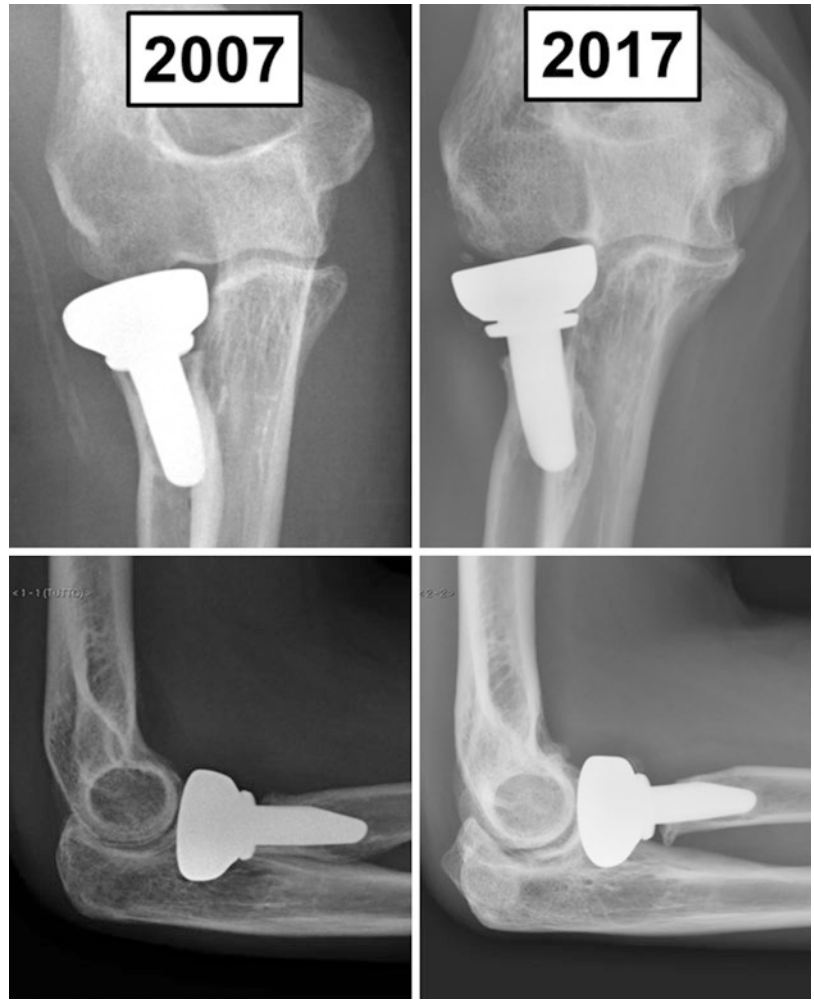

Fig. 24.5 X-rays of the same patient. Ten-year postoperative radiographs demonstrate preservation of the joint without chondral degeneration of the capitellum. Mild signs of arthritis of the ulno-humeral joint can be seen, though did not result in an inferior clinical outcome

Though several clinical outcome studies are available in the literature, one must recognize that there are limitations: the studies report the results of a relatively small number of patients (from 12 to 31); the studies report heterogeneous preoperative indications with varying associated lesions; the reported clinical outcomes are assessed with different clinical scores; the mean follow-up is relatively short (average 38 months); each report presents different complication rates. Berschback et al. [19] report some degree of periprosthetic osteolysis in 92% of the cases, while Levi et al. [22] describe a 40% loosening rate with proximal bone reabsorption in 67% of the cases. El Sallakh [20] reported asymptomatic osteolysis in 16% of the cases. Tarallo et al. [23] describe stem osteolysis in 6% of the cases, while Mou et al. [21] reported no cases of bone reabsorption (even if in the only figure shown in the paper a proximal bone reabsorption is evident). Berschback et al. [19] reported capitellar wear signs in 77% of the cases, though in the other studies, no arthritic changes are reported. The clinical result data reported in the literature are summarized in Table 24.1.

Table 24.1 Anatomic RHP studies reported in the current literature

Authors	Pts (no.)	Radial head fracture type and associated lesions	Results	Follow-up (months)	Complications
Berschback et al. [19]	13	Mason III: 6 cases Mason IV: 7 cases – Proximal ulna fractures: 6 cases – Essex-Lopresti: 1 case	– ROM: F/E: 121° P/S: 136° – MEPS 91 (65–100) – DASH 13 (0–60)	29 (18–43)	– H.O.: 4 cases, 1 excision – Stiffness: 1 contracture release – X-ray disorders: capitellum osteopenia: 9 cases Chondral depression: 1 case Osteophyte: 4 cases
El Sallakh [20]	12	Mason III + valgus instability: all 12 cases – Associated coronoid Fractures: 3 cases – Proximal ulna fractures: 3 cases	– ROM: F/E: 115° P/S: 145° – MEPS 92 (80–100) – DASH 12 (0–30)	42 (22–58)	– H.O.: 3 asymptomatic – Osteolysis: 2 asymptomatic
Mou et al. [21]	12	Mason III: 8 cases Mason IV: 4 cases Coronoid fractures: 3 cases	– ROM: F/E: 130° P/S: 155° – HSS 97/100 (94–100) – DASH 11.9/100 (0–25/100)	60 (19–77)	– H.O.: 2 asymptomatic
Levy et al. [22]	15	– Terrible triad: 10 cases – Proximal ulna fractures: 4 cases	– ROM: F/E: 124° P/S: 149° – MEPS 85 ± 21 (xx-1xx) – ASES 70 ± 28	30 (10–90)	– Stem radiolucency: 40% – Revision surgery: 2 cases – Stress shielding: 67% – H.O.: 2 excisions
Tarallo et al. [23]	31	Mason III: all 31 cases – Associated coronoid fracture: 6 cases	– ROM: F/E: 112° P/S: 134° – MEPS: 77% excellent 10% good 13% fair	30 (12–84)	– H.O. 26% (8 cases) 3: H-G I; 2: H-G IIA 2: H-GIIB; 1: H-G: IIC – Osteolysis 6%

24.5 Conclusions

For several decades, radial head resection has been one of the more reliable surgical treatments available for displaced radial head fractures in the absence of longitudinal or posterolateral instability. However, recent data have demonstrated the mechanical importance of the radial head and its role in elbow stability and its contribution in restoring proper kinematics. Consequently, in the setting of a radial head fracture that is not fixable, the shared attitude by the majority of dedicated elbow surgeons is to implant a RHP, especially in the setting of instability. However, complications after a RHP are not uncommon, and the complication rates increase in proportion to the increasing number that is implanted. In particular, there is concern regarding younger patients that undergo radial head arthroplasty. For this reason, a prosthesis that closely replicates the kinematics and the biomechanics of the native radial head is expected to improve radiocapitellar contact and kinematics, thereby increasing elbow stability and maintaining the health of the capitellar articular cartilage. Improving the contact mechanics between the

radius and capitellum during elbow movement should lead to decreased stress on parts of the articulation (i.e., edge-loading), delaying or preventing premature cartilage wear and early onset of osteoarthritis. Several biomechanical studies have analyzed the advantages of an anatomically shaped RHP in terms of load distribution and elbow stability [5, 24–26] and have demonstrated that radial head implants that mimic normal anatomy, with a precise dish depth and radius of curvature, through the effect on concavity-compression forces, are more effective than the nonanatomic implant in stabilizing the radiocapitellar joint. Also, in a terrible triad injury model, the anatomic design demonstrated more stability (higher peak force required for subluxation) versus a nonanatomic, circular RH prosthesis and versus a bipolar implant [27]. Other studies suggest that to further reduce the capitellar cartilage edge-loading, in addition to the anatomical shape of the radial head, an optimal implant alignment is important, and less stiff prosthetic materials should be used [28]. Until now, only a few clinical studies have been reported [19–23, 29]. However, all of them demonstrated promising results in short-medium-term follow-up. Osteolysis around the stem is the major complication reported [19, 29]. It is important to differentiate asymptomatic bone reabsorption of the proximal radial neck caused by stress shielding, which is common but not progressive and rarely leads to stem loosening or radiolucent lines sometimes noticed around the stem and not evolving at the time of latest X-rays, versus cases that show worrisome signs of stem loosening. In the latter situation, the patients generally present with pain [30], the osteolysis is evolutive, and this often leads to progressive bone reabsorption necessitating a secondary procedure to remove the implant. However, the reported studies in the literature are not conclusive enough to demonstrate definitive superiority of an anatomic RHP over a nonanatomic model [31]. Regardless of the prosthetic design, the current knowledge supports that proper prosthetic placement, the correct treatment of all associated injuries, and the absence of significant heterotopic ossification formation are the most important prognostic elements for a radial head replacement. Particularly for anatomically shaped RHP, which cannot be implanted in a manner as one would implant a spacer-type of implant, accuracy in sizing and precision during implantation of the prosthesis are critical to ensure proper joint alignment and to optimize radiocapitellar contact, thereby maximizing the chance of implant longevity.

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25 Bipolar Press-Fit Radial Head Arthroplasties: Surgical Technique and Expected Outcomes

Gianluca Bullitta and Giuseppe Giannicola

25.1 Surgical Technique

Preoperative anteroposterior and lateral radiographs of the elbow should be performed to identify the type of proximal radial fractures and associated osseous and ligamentous lesions. In the author's experience, anteroposterior radiographs with the forearm supinated and pronated and in neutral rotation help to better understand the pattern of radial head and neck fractures. If a RHA is being considered, a careful evaluation of the integrity of the radial neck should be carried out because the presence of a neck fracture may affect the choice of implant stem. A CT scan evaluation completes the preoperative evaluation in all cases in which radial head (RH) fractures are involved in complex elbow instability [1, 2]. Lastly, if there is clinical suspicion of associated distal injuries, such as distal radioulnar joint (DRUJ) lesions or carpal fractures, the radiographic evaluation should be extended to the forearm and wrist to exclude such injuries.

The patient is placed in a supine position on the operating table with the arm on a side arm table for the entire procedure. Just before surgery, with the patient under anesthesia, joint stability is evaluated under fluoroscopy; in particular, valgus-pronation stress testing is performed to verify the integrity of the medial collateral ligament (Fig. 25.1).

A silicon ring or pneumatic tourniquet is commonly applied. In the rare isolated radial head fractures, a posterolateral skin incision may be performed; this incision may be combined with an additional medial incision when a medial compartment lesion needs to be accessed. Alternatively, a direct posterior incision should be performed to approach all the compartments;

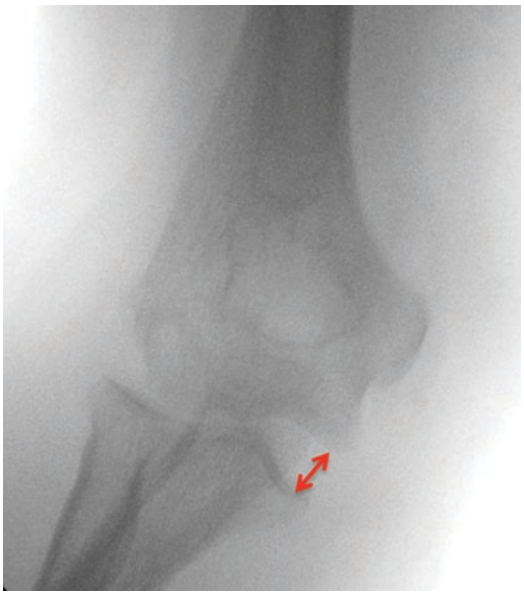

Fig. 25.1 Preoperative fluoroscopy of valgus-pronation stress testing in radial head fracture that shows the insufficiency of the medial collateral ligament

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this is the author's preferred choice in all cases of complex elbow instability.

The Kocher, Kaplan, and transtendon (through extensor digitorum communis) deep approaches are commonly used to perform the RHA. The author prefers the Kocher approach, especially when the lateral collateral ligament (LCL) is torn, as in complex elbow instability. Indeed, this surgical approach allows an optimal exposure of the entire LCL and consequently allows all types of ligament injuries to be identified more easily [3].

When Kocher's approach is used, the interval between the anconeus and the extensor carpi ulnaris muscles is extended. Some surgical steps differ slightly depending on whether the case is acute or chronic. In the case of associated elbow dislocation, the LCL and extensor origins are usually avulsed or elevated from the lateral epicondyle. If the extensor origin is intact, it can be detached from the humerus to facilitate exposure, especially when associated coronoid tip fractures need to be fixed. By elevating the extensor carpi ulnaris muscle, the lateral capsule can be exposed and then incised anteriorly to the ulnar band of the LCL, thereby allowing the radial head to be reached; alternatively, in acute cases the LCL lesion breach can be widened. Accurate irrigation is performed to remove the hematoma and all radial fracture fragments. The radial neck is cut or regularized using a sagittal saw to create a flat surface. Depending on the design of the implant, the cut is perpendicular (RHS, Tornier) or slightly oblique in relation to the radial neck axis (bipolar SBI). The manufacturer of the SBI prosthesis provides a specific resection guide; the proximal flange of the guide is placed against the articular surface of the capitellum with the axis of the alignment rod oriented over the ulnar styloid (this alignment represents the anatomic axis of forearm rotation). The flange for the resection neck is then assembled to the desired cut length. For the neck preparation, a high-speed burr can be used to remove irregularities or prominences at the end of the radial neck cut.

All the radial head fragments should be rebuilt on the table in order to recreate the native radial head. This is important as a means of ensuring that all the fragments have been removed and of evaluating the size of the head implant.

A critical point in this surgical technique is the selection of a neck level resection that corresponds to the native total length of the radius when the RHA is implanted. Each device comes with a specific resection guide: the RHS system provides two neck length gauges that are used to determine the height of resection, while the SBI device provides three different cut levels. These resection levels correspond to the height of the head component or collar stem of the two types of implant.

System retractors are placed around the radial neck to obtain adequate exposure and to protect the soft tissues. Excessive traction on the radial nerve must be avoided. The canal is then opened with a reamer and the bone is compacted against the cortex. This step, which is required to press-fit the stem, starts with the manual compactor of the smallest size and progresses sequentially. The RHS implant compactor is straight, whereas in the SBI system, the broach follows the curve of the stem implant; when the latter device is adopted, the curve should be directed away from the bicipital tuberosity and toward the radial styloid during the broaching process. In younger patients with healthy dense bone in whom the broach cannot be inserted to the full depth, an implant size corresponding to the previous impactor size should be chosen to avoid overlengthening when the definitive stem is implanted. Excessive torsion forces should be avoided to prevent neck fractures, especially in elderly patients with osteoporotic bone; in such patients, light tapping on the compactor with a mallet may be useful. When press-fit implants are used, every effort should be made to implant the biggest stem size possible to obtain the greatest primary stability. A small drill bit may prove useful in some cases to widen the proximal canal.

The next step is the implantation of the trial components, during which great attention must be paid to the correct sizing and lengthening of the implant. While the excised radial head can be used to determine the diameter and thus avoid excessive oversizing, determining the length is considerably more challenging and may lead to a range of postoperative complications [4, 5]. Indeed, it has been shown that overlengthening

(i.e., overstuffing) or over-shortening of the implant by 1–2 mm significantly affects the ulno-humeral and the radiocapitellar kinematics. Several intraoperative landmarks have been described to avoid overstuffing. In 2009, Athwal observed that AP fluoroscopy may be used to detect a widening of the lateral ulno-humeral joint when significant overstuffing occurs [6]. However, as a similar widening may also be observed in anatomical variations in which the cartilaginous layer on the lateral side of the ulno-humeral joint is thicker than normal, AP fluoroscopy may not always be a reliable indicator of overstuffing [7]; in this regard, a contralateral preoperative AP X-ray may improve the reliability of intraoperative fluoroscopy. The superior border of the lesser sigmoid notch is considered to be the best intraoperative landmark to use when selecting the length of the implant. To ensure that it is correctly positioned, the proximal edge of the trial implant should not be more than 1 mm proximal to the proximal edge of the lesser sigmoid notch [8].

In order to choose the correct diameter for the prosthesis, several authors agree that the diameter of the maximum implant head should be equal to or smaller than that of the native head. Some authors recommend that the smallest diameter of the native RH be used, others the diameter of the fovea [9, 10]. The authors of this chapter prefer, whenever possible, to use the minimum RH diameter. The previous methods cannot be used in some clinical situations, such as in cases with a very comminuted RH or during revision surgery when the RH has been previously excised. In 2013, Leclerc et al. proposed a mathematic formula based on radiologic measurements of the humeral capitellum to estimate the native radial head diameter [11]. In a 3D CT scan morphometric study, the authors observed a strong correlation between the capitellar-trochlear width (measured from the lateral aspect of the capitellum to the lateral trochlear ridge) and the maximum and minimum diameters of the native radial head. In a recent unpublished MRI study, Giannicola et al. found that the Leclerc equation may be prone to a residual error of over 2 mm by not considering the thickness of the cartilaginous layer; Giannicola et al. observed a stronger correlation between the total width of the humeral articular surface (from the lateral aspect of the capitellum to the medial trochlear ridge) and the diameters of the native radial head; this landmark is independent of the cartilaginous layer as it can be calculated by means of a CT scan. The equation, which had a mean residual error of 0.8 mm, was calculated as follows:

$$\text{Maximum diameter RH} = 0.44 \times \text{Hum width} + 5.1.\text{Minimum diameter RH} = 0.40 \times \text{Hum width} + 6.1.$$

After the trial implant has been inserted, it is crucial to verify its tracking and congruency with the capitellum in all arcs of motion. When a bipolar implant is used, self-alignment with the capitellum, which is facilitated by the dual mobility, may hide some malposition. For this reason, the surgeon should carefully ensure the congruency of the ulno-humeral joint during the arc of motion, especially in extension.

If an acceptable alignment and tracking are confirmed, the trial components are removed and the final prosthesis is inserted. When using the SBI system, the correct orientation of the stem needs to be respected. A final assessment of motion and stability is then performed. At the end of the procedure, the annular ligament is repaired with absorbable wire, and the collateral ligament complex and common extensor are carefully reattached using transosseous sutures or anchors. The main steps of RHA technique (RHS, Tornier) are illustrated in Fig. 25.2.

25.2 Expected Outcomes

The radial head acts as an important secondary stabilizer of the elbow by resisting valgus stress, especially when the primary valgus stabilizer, i.e., the medial collateral ligament, is injured. Moreover, the integrity of the radial head is fundamental for posterolateral elbow stability in cases of disruption of the lateral ulnar collateral ligament associated with a coronoid as well as for forearm stability in cases of interosseous membrane and DRUJ lesions [2]. The radial head in such cases must be reconstructed, and not resected, in order to allow the damaged stabiliz-

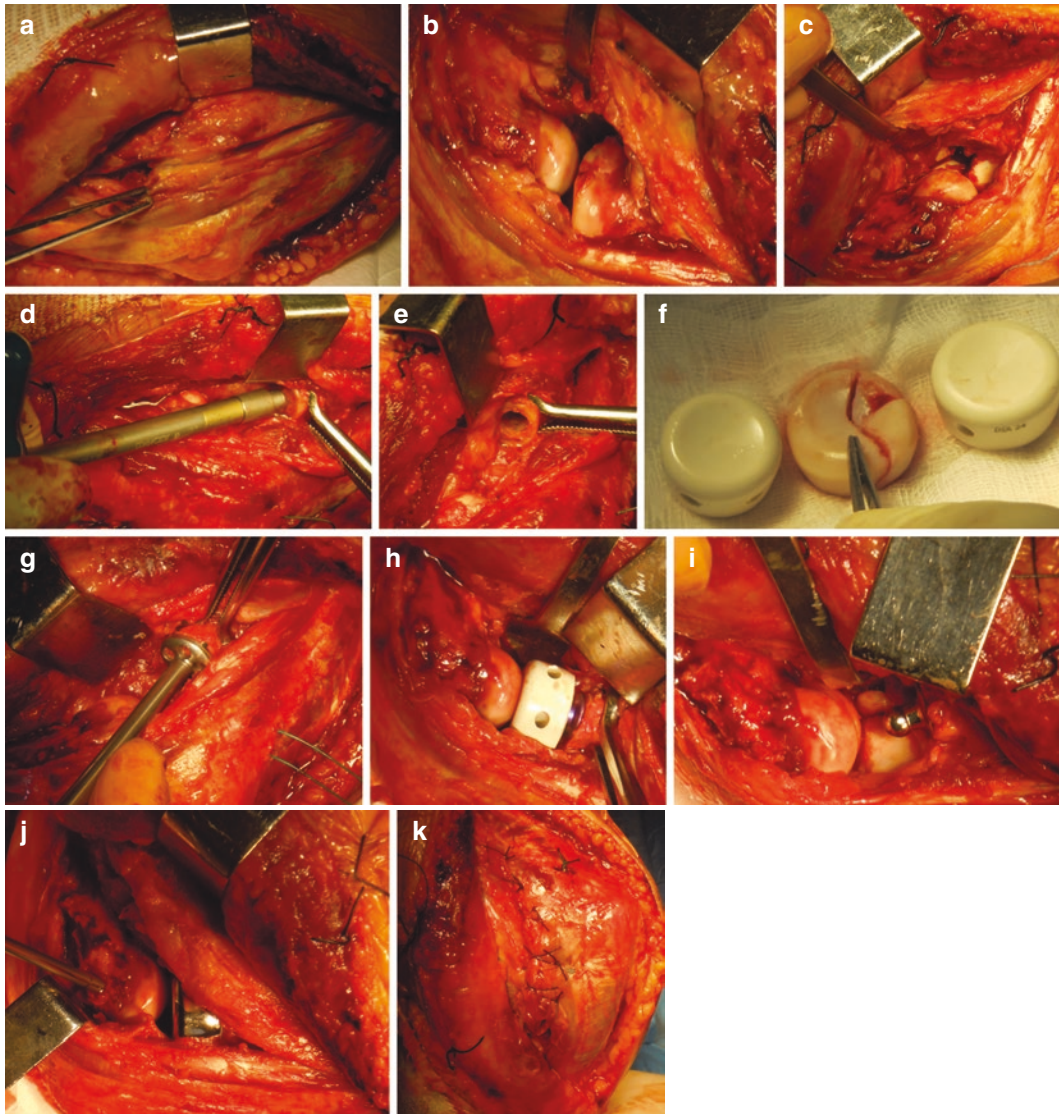

Fig. 25.2 Intraoperative photographs showing the main surgical steps of radial head arthroplasty using bipolar RHS device (Tornier). (**a**) After a posterolateral skin incision, a Kocher's approach is developed. (**b**) Exposing of the comminute radial head and neck fracture. (**c**) After careful removal of the hematoma and all radial fracture fragments, the neck is cut using a sagittal saw to create a flat surface. (**d** and **e**) Medullary canal preparation of the radial neck using a progress size of manual compactors. (**f**) Radial head rebuilt on the table to choose the radial head circumference size of the implant. (**g**) Manual radial neck planner is used to create a smooth contact surface for the stem collar. (**h**) Placement of the trial implants to verify its sizing, tracking, and congruency with the capitellum in all arcs of motion. (**i**) Implant of the definitive press-fit stem and (**j**) radial head prosthesis. (**k**) LCL and muscle lesion reparation using an anchor and side-to-side cross suture

ing soft tissue in the elbow to heal. Consequently, prosthetic replacement should always be considered in comminuted fractures of the radial head that cannot be adequately reconstructed.

Since the introduction of radial head arthroplasty by Speed in 1941, a number of implant designs have become available. Currently, the radial head prostheses can be categorized accord-

ing to the material, modularity, polarity, and method of stem fixation. As regards bipolar implants, the underlying rationale is to achieve freedom of movement of the articulating component on the stem. This prosthetic design may reduce the wear of the capitellar cartilage and reduce the stress at the implant-bone interface (press-fit implants) or at the implant-cement and bone-cement interface (cemented implants) during prono-supination. Moreover, thanks to its ability to self-align with the capitellum and the proximal ulna, not only does the bipolar implant solve the problem of the variability of the head-neck angles and fovea offset of the native radial head, but it also affords more freedom when the implant is not perfectly positioned. The bipolar radial head prosthesis was initially designed with a long stem and was cemented, whereas more recent versions have a press-fit design with a short stem (Fig. 25.3a, b). The latter method of stem fixation, which had been thoroughly studied in other joints, especially the hip, was designed to obtain biological osteointegration and, consequently, longer-term survivorship.

We found only two papers in the literature that reported the results of press-fit radial head bipolar prostheses [12, 13]. In 2012, Rotini et al. [12] were the first to retrospectively evaluate the clinical and radiological results of the press-fit bipolar and unipolar versions of the same device (radial head implant, Small Bone Innovation, Morrisville, Pennsylvania, USA) in a cohort of 31 cases (12 unipolar and 19 bipolar implants). The authors analyzed two groups of patients: 10 were treated in the acute setting, while the remaining 21 patients with stiffness or chronic instability underwent surgery at a later time. The results, as assessed by means of the MEPI, were reported to be satisfactory in 93.5% of the cases after a mean follow-up of 2 years. In two cases in whom the results were reported to be fair, the patients (one with a bipolar and one with a unipolar implant) developed elbow stiffness-associated pain and a functional limitation in daily activities. The radiographic analyses revealed a significant degree of radiolucency around the stem (greater than 2 mm) in one case (bipolar implant) and a lower degree of radiolucency (less than 2 mm) in ten cases (six bipolar and four unipolar implants). The authors reported bone resorption greater than 3 mm around the entire circumference of the radius in three cases. The prosthesis had to be removed owing to aseptic loosening in only one of these three cases, in whom bone resorption was greater than 7 mm, though the final clinical outcome was good. The overall

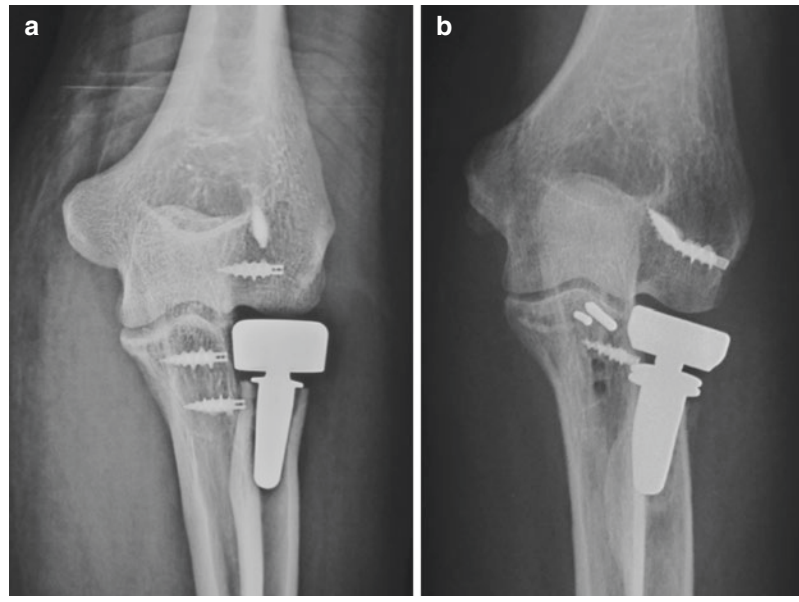

Fig. 25.3 (**a**) Radial head system (Tornier, Montbonnvot-Saint-Martin, France); (**b**) the bipolar SBI (radial head implant, Small Bone Innovation, Morrisville, Pennsylvania, USA)

reoperation rate was 6.4% (two bipolar implants): one case of aseptic loosening and one of persistent stiffness. The authors did not detect any significant differences between the two types of implant in reoperation rate, resorption and osteolysis, recovery of ROM, or development of osteoarthritis.

More recently, Kodde et al. [13] reported the results obtained in 27 patients treated with a press-fit bipolar radial head (Tornier, Montbonnot-Saint-Martin, France) for acute fracture or posttraumatic sequelae. According to the MEPI, the results were satisfactory in 70% of the cases, fair in 26%, and poor in 4% after a mean follow-up of 48 months. A relatively high radial head prosthetic revision rate (11%) due to persistent instability was reported: two patients with a symptomatic abrasion of the capitellum underwent a conversion to radiocapitellar resurfacing arthroplasty, while the radial head component in one patient was exchanged with another one of a larger size. Postoperative complications occurred in further nine patients, five of whom required surgery: two patients underwent ulnar nerve release, one was treated with the Sauvè-Kapandji procedure for a symptomatic distal radioulnar joint, one underwent a LCL reconstruction for posterolateral instability, and one patient was reoperated on owing to elbow stiffness. The remaining complications were one symptomatic ulno-humeral joint osteoarthritis, one lateral and one medial epicondylitis, and one unexplained painful elbow. No aseptic loosening was observed by the authors despite the presence of radiolucency in 92% of the cases.

In a recent comparative prospective unpublished study, Giannicola et al. analyzed the clinical outcomes in 45 patients (35 acute fractures and 10 posttraumatic sequelae) in which bipolar press-fit radial prostheses (Tornier, Montbonnot-Saint-Martin, France) and anatomic monopolar press-fit devices (Acumed, Hillsboro, USA) were implanted. The bipolar (group I) and anatomic prostheses (group II) were implanted in 25 and 20 patients, respectively. At the final mean follow-up of 28 months, the clinical results were satisfactory in all the cases, with no significant differences being observed between the two groups. In particular, the mean MEPS, Q-Dash, and m-Ases scores were 95, 13.3, and 89 in group I and 93, 9.9, and 83.5 in group II, respectively. At the final follow-up, proximal neck resorption around the implant stem was observed in 39 of the 45 cases. Neck resorption was considered mild (<3 mm) in 15 patients (9 in group I; 6 in group II), moderate (3–6 mm) in 21 (12 in group I; 9 in group II), and severe (>6 mm) in 3 (group I). One aseptic, asymptomatic gross loosening was observed at the final follow-up in one patient in group II. This patient was then reoperated on to prevent fracture and cortical erosion, with the implantation of a cemented long-stemmed bipolar prosthesis.

Postoperative complications included disassembly of the radial head prosthesis in two cases who had received a bipolar implant following a new trauma. The device was removed in one of these patients, in whom the elbow was stable, following the patient's request, while a new radial head component was implanted in the other patient. The results at the final follow-up were satisfactory in both patients.

In conclusion, the press-fit radial head bipolar prosthesis appears to yield satisfactory results, with a good recovery of elbow function being achieved in over 80% of cases (70–93.5%) at the short-term follow-up. The majority of these implants develop some degree of radiolucency around the stem or of proximal resorption of the radial neck, probably as a result of stress shielding, within 2 years of surgery [14], whereas relatively few cases of aseptic loosening occur. The average removal and revision rate was found to be about 9%, which is comparable to the results observed in implants in which a different type of polarity or stem fixation is used (10%) [15]. Further studies based on a medium- to long-term follow-up are needed to determine the effectiveness of this type of implant.

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26 Cemented Radial Head Arthroplasty: Surgical Technique and Outcomes

Enrico Bellato, Andrea Celli, Lorenzo Mattei, Alessandro Cunotto, Giovanni Ferrero, and Filippo Castoldi

26.1 Introduction

Radial head replacement is typically indicated in cases of unrepairable radial head fractures (often in the elderly patient), in particular when the radial head is needed as a joint stabilizer. Other indications are longitudinal instability of the forearm, the fracture sequelae (such as radial head malunion of failed osteosynthesis), instability after radial head resection, and radiocapitellar osteoarthritis.

Regardless of the indication, four types of stem fixation can be chosen. In a recent literature review that included 30 articles involving 727 patients, 21% of the stems were cemented, 32% press-fit, 32% intentionally loose-fit, and 15% of the prostheses were fixed with an expandable stem [1]. Leaving out the latter method, which is rarely chosen, the intentional loose-fit approach involves the use of a smooth stem that can neither undergo osteointegration nor be press-fitted. Therefore, it has endomedullary movements within the medullary canal that seem to permit a better congruence of the radial head with the humeral condyle during the pronation–supination and extension–flexion [2]. The surface of the rough stems consists of an osteoconductive biomaterial that facilitates the primary press fit and osteointegration of the prosthesis without the requirement of cementation or is grit-blasted to promote bony ingrowth.

How to choose stem fixation is still under debate, with no clear evidence of better clinical results of one type over another. We here describe our preferred surgical technique for cemented radial head replacement, and we then summarize the most recent clinical results available in the literature.

26.2 Surgical Technique

The patient is placed in a supine position. Surgery is usually performed under brachial plexus anesthesia. Either a sterile or non-sterile tourniquet should be used in order to reduce intraoperative bleeding. A sterile drape may be used.

Two main surgical lateral approaches can be used. The Kocher approach is more posterior and uses the anatomical interval between the anconeus and extensor carpi ulnaris muscles.

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The Kaplan approach is more anterior in the vicinity of the wrist extensors on the hypothetical line joining the epicondyle with the Lister's tubercle. In a recent study, we observed that the lateral ulnar collateral ligament (which is considered to play the main role in posterolateral rotatory instability) often lies in the Kocher's interval [3]. Hence, when a surgical repair of the lateral collateral ligament is not needed, we prefer the Kaplan approach. In cases where also the medial compartment has to be exposed, a posterior approach may be chosen.

The annular ligament is found beneath the tendons and (if intact) cut to fully expose the radial head. While exposing the radial neck, the surgeon has to remember that the PIN penetrates the supinator muscle posteriorly around 4 cm distal from the radial head. Some authors suggest the surgeon should keep the forearm in a pronated position in order to place the PIN as far as possible from the surgical field [4]. Two Hohmann retractors are placed anterior and posterior to the radial neck in order to fully expose the proximal radius. The anterior retractor does have to be placed with caution (i.e., close to the bone and without over-retraction) in order to avoid PIN injuries (Fig. 26.1).

The radial head should be removed as intact as possible in order to help the surgeon in selecting the right size. In cases of fractures with multiple small fragments, the capitellum is a good reference since its vertical diameter plus 1 mm approximates the radial head size [5]. The surgeon should check for radial neck/proximal shaft fracture since they represent a potential source of PIN damage during the cementing process.

A piece of bone harvested from the resected/fractured radial head is used as a plug to prevent cement from excessive distal migration in the medullary canal (Fig. 26.2).

The rasp is then used to prepare the medullary canal and to push the bone plug slightly distal to the tip of the prosthetic stem in order to help minimize the amount of cement needed. A trial implant is usually inserted to make sure that the implant is not overstuffed and intraoperative fluoroscopy may be used in case of doubt. After trial implant removal, the medullary canal is carefully cleaned using saline to allow for proper cement grip. The cement is prepared in a standard fashion and inserted using a syringe with a large, soft, plastic needle (Fig. 26.3a–c).

After inserting the stem, the surgeon should meticulously remove all the extra cement around the radial neck (Fig. 26.4) and wait until the cement hardens.

Then, when bipolar implants are used, the prosthetic radial head is locked, and the wound is closed in a standard fashion (Fig. 26.5).

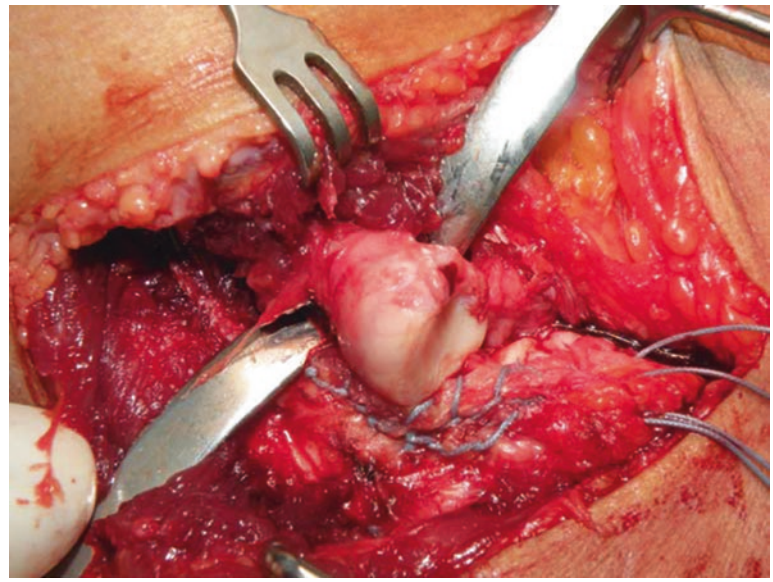

Fig. 26.1 The proximal radius is exposed through the lateral approach. In order to enhance the radial head exposure, two Hohmann retractors are placed anterior and posterior to the neck

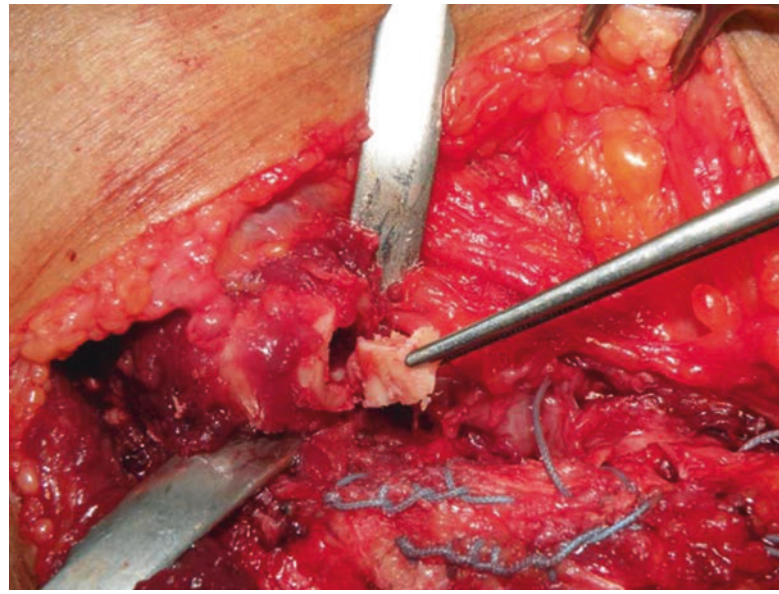

Fig. 26.2 A small bone plug is inserted into the radius shaft to restrict excessive cement migration

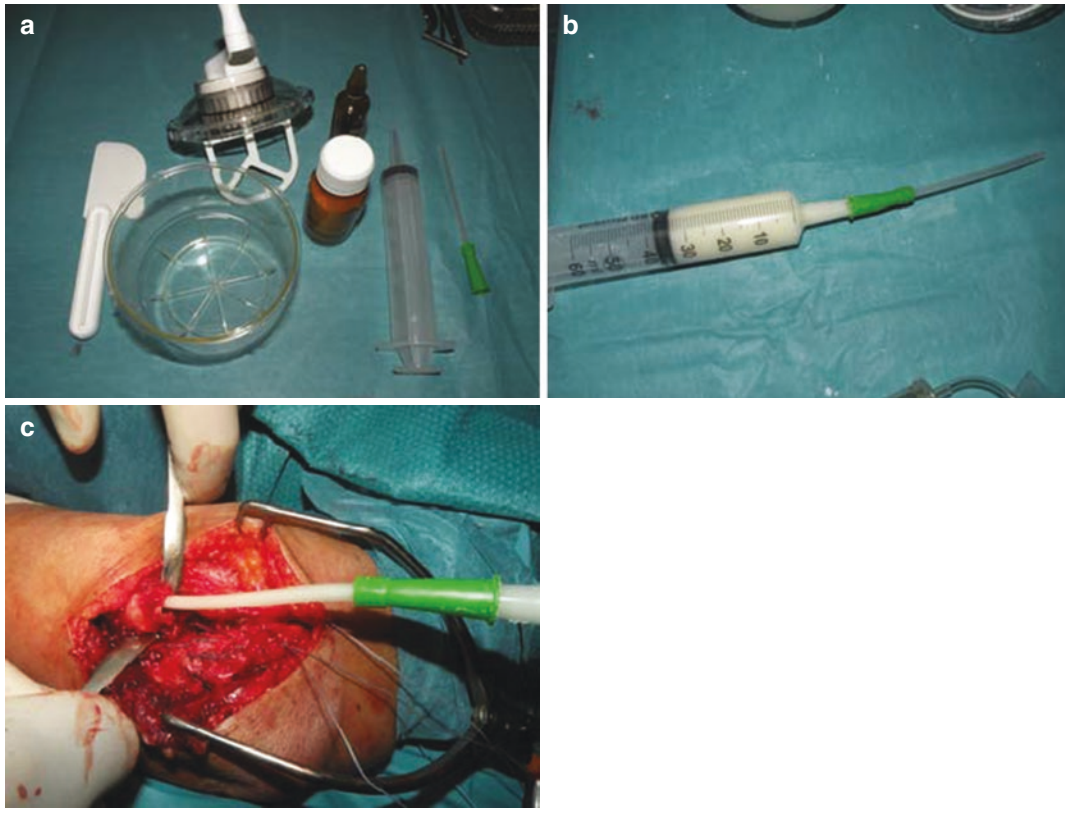

Fig. 26.3 Standard instrumentation is used to prepare the bone cement (**a**). A syringe with a soft plastic needle is filled with bone cement (**b**), which is inserted in the medullary canal (**c**)

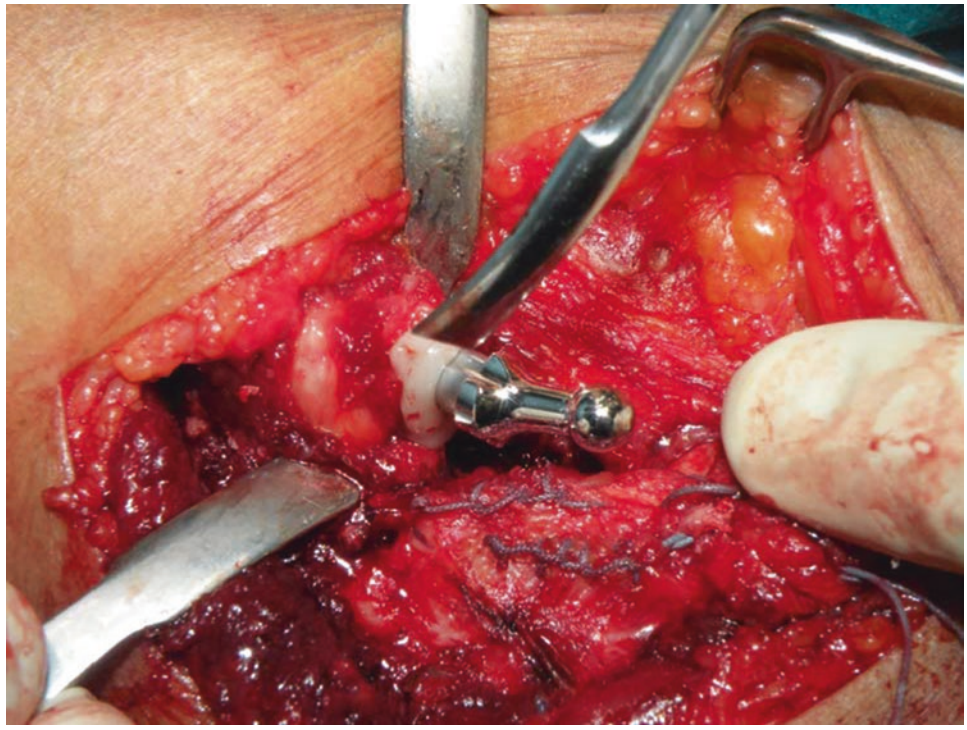

Fig. 26.4 The stem is inserted and the extra cement is carefully removed

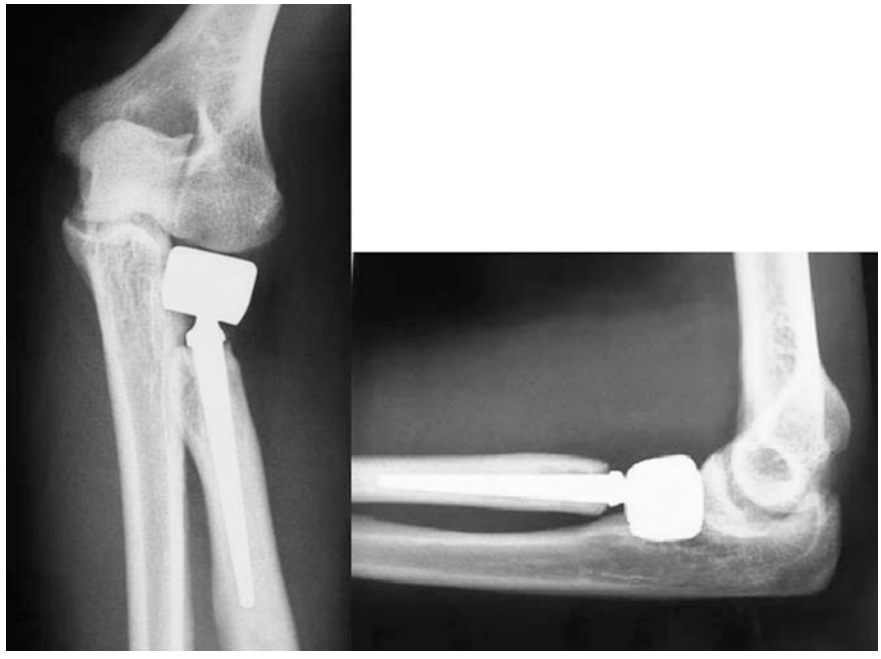

Fig. 26.5 Radiographic follow-up after cemented bipolar radial head replacement

26.2.1 Postoperative Care

We do not routinely place drains or splints after surgery. The elbow is placed in a soft bandage and elevated during the first postoperative hours to prevent and reduce swelling and hematoma. In cases where the surgery is performed for isolated radial head fracture, we usually do not restrict the elbow motion. Initially, passive movement is permitted followed by progressively more active motion. Care should be taken to minimize or avoid initial full extension and full supination movements.

Following procedures requiring surgical exposures where the lateral ligamentous structures have to be detached and subsequently reattached, we suggest the patient should avoid shoulder abduction for 6 weeks to avoid stressing the lateral collateral ligament during the healing process.

26.3 Results

To our knowledge, no clinical studies have specifically focused on the cementing process of radial head prostheses. Here we summarize the results of the most relevant studies over the last 10 years where cemented implants were used.

Popovic et al. [6] included 51 patients who underwent bipolar radial head replacement after trauma (11 isolated comminuted fractures, 34 fractures associated with a posterior elbow dislocation, and 6 posterior Monteggia lesions). After 8.4 years of follow-up, 14 elbows were graded as excellent, 25 as good, 9 as fair, and 3 as poor according to the Mayo Elbow Performance Score (MEPS). However, despite these good clinical outcomes, they reported concerning radiographic results. The authors analyzed changes in the proximal part of the radius, including radiolucent lines, osteolysis, and proximal resorption of the radial neck. Twenty-seven patients (53%) showed periprosthetic lucency within the medullary canal, 16 (31%) patients developed progressive bone loss in the radial neck region, and 5 patients (10%) had progressive balloon-shaped osteolysis in the midstem region with important changes in cortical wall thickness with associated migration of the stem more than 1 mm. The authors concluded that the early development of radiolucent lines should be attributed to suboptimal cementing technique, while progressive radiolucent lines could reflect progressive stem loosening as a result of mechanical factors and/or progressive osteolysis.

A high incidence of this complication was also reported by Lim et al. [7], who reported on six patients affected either by Mason III or IV radial head fractures whom were treated with a cemented, monobloc, vitallium prosthesis. They concluded after a short-midterm follow-up that this type of surgery was effective in restoring elbow stability, but they also reported four cases of aseptic loosening. This complication did not correlate with clinical outcomes, but raises concern.

Burkhart et al. [8] reported their 8.8-year results after treating 17 patients with a cemented bipolar radial head prosthesis (9 prostheses were implanted primarily after fracture, 7 secondarily, and 1 because of a chondrosarcoma). According to the MEPS, six patients achieved an excellent result, ten a good result, and one a fair result, with no differences between primary and secondary implantation. No evidence of radiological signs of loosening or proximal bone resorption was seen. Hence, the authors concluded that the previous observations of Popovic et al. [6] have to be interpreted differently, and one must assume that all the radiologic findings of aseptic loosening may be the result of an initial insufficient cementing technique, perhaps worsened by mechanical factors and/or wear debris over the years.

After a mean follow-up of 50 months, Allavena et al. [9] described controversial results of 22 patients (16 affected by acute fractures and 6 by fracture sequelae) who underwent radial head replacement with a bipolar cemented prosthesis. Six patients (27%) experienced early posterolateral subluxation of the elbow, which was consistently managed with revision surgery. The radial head prosthesis was removed in four (18%)

patients. Mean MEPS was 79 (3 patients had excellent results, 11 good results, 3 fair results, and 1 poor results). Dealing with radiographic results, osteolysis was visible under the prosthetic stem in eight patients, in four patients lucencies were observed around the stem, and one prosthesis had frank loosening.

Laun et al. [10] reported promising short-term results after using a bipolar cemented radial head prosthesis in 12 patients affected by comminuted radial head fracture either with or without an associated coronoid fracture. They showed a mean MEPS of 90.8 points, no patients experienced instability, and 11 patients out of 12 were subjectively satisfied. There were no signs of loosening of the implant, and only mild signs of osteoarthritis were seen.

Heijink et al. [11] recently reported on the 50-month follow-up of 25 patients affected by acute radial head fracture, failed treatment, or fracture sequelae who underwent cemented bipolar radial head arthroplasty. According to the MEPS, results were excellent in 13 (54%), good in 7 (29%), fair in 3 (13%), and poor in 1 (4%). One prosthesis frankly dissociated and two were subluxated. No signs of loosening were detected, but seven patients showed osteolysis of the proximal radius to some degree. In eight patients, the bipolar design compensated for radiocapitellar malalignment.

26.4 Discussion

The use of bone cement to fix the radial head stem is still controversial. This is due to the lack of evidence in the literature. It is difficult to compare cemented fixation with other types of fixation because of several factors. First, the number of patients included in the studies is usually low. Second, patients included are affected by various types of problems (e.g., fractures, fracture-dislocations, fracture sequelae, osteoarthritis, and tumors). Third, radial head replacement is characterized by several features that can be combined (e.g., type of fixation, modularity, head shape, polarity, material), and leaving out the differences between each manufacturer, there are many possible combinations. A recent literature review, which included 30 articles involving 727 patients who underwent radial head replacement, showed that the type of fixation does not significantly affect both range of motion and revision rate. Dealing with the MEPS, it seems that, although the coded interpreted outcome for all four fixation techniques on average was between good and excellent, press-fit fixation and fixation with an expandable stem resulted in better outcome scores on average than cemented fixation [1].

A cemented stem may be chosen in order to avoid/reduce the risk of an intraoperative radius fracture. This risk is obviously higher in cases of poor bone quality (i.e., elderly people). However, younger patients may also be at risk since some companies do not provide stems with 1 mm progressive increases in diameter. Therefore, this raises two considerations. First, it is not clear if a press-fit stem is better than a loose one, so one could wonder why the surgeon should strive for rigid fixation [12, 13]. Second, it has been reported that an intraoperative radial neck fracture might not be cause of concern. Biomechanical tests showed that initial stability may not be compromised after a hoop-stress fracture occurred in the radial neck during insertion of a stem that was oversized by 1 mm. The stability is not lost provided that the fracture does not displace a piece of bone and does not propagate [14].

If the surgeon wants to cement the stem, we suggest he or she should be sure about the integrity of the radial shaft, in order to prevent the posterior interosseous nerve (PIN) from being damaged by cement.

Stress shielding is a possible complication after radial head arthroplasty. Although in our clinical practice we've found it typically associated with press-fit stems, it has been described in both cemented and non-cemented stems [15]. Hence, this does not seem to represent a possible indication/contraindication to a specific type of stem fixation. Moreover, it seems that stress shielding does not harm the stability and function of the implant, although longer follow-up is needed to confirm this [15, 16].

A cemented implant is typically needed in cases of revision surgery.

Table 26.1 The table shows the main prosthesis available in the market (excluding the ones with a loose-fit or expandable stem. The surgical technique description with respect to stem fixation is reported in the right column

Name	Company	Surgical technique
Anatomic radial head system	Acumed	"The stem is designed to press fit into the neck canal"
rHead	Stryker	"If a firm fixation is not present at the time of the insertion of the trial stem (i.e., stem can be easily extracted from or rotated in the medullary canal), then bone cement (PMMA) is recommended"
Ascension modular radial head	Integra life sciences orthopaedics	"The radial head trial has an undersized stem to allow insertion without dislocation of the elbow and for maintaining the integrity of the medullary canal for the final press fit"
Radial head system	Tornier	*Short stem*: this stem is designed to be press fit; however "If a firm fixation is not obtained at the time of the insertion (i.e., stem can be easily extracted from or rotated in the medullary canal) then the use of cement is recommended" *Long stem*: this stem is designed to be cemented

Rigid fixation is needed when an anatomic prosthesis is used since the orientation of the head plays a key role in the success of the surgery. Hence, if press-fit fixation is not obtained with this type of prosthesis, it is probably better to use bone cement even though the stem was not designed to be cemented.

Some surgeons prefer not to cement in order to avoid problems in cases of revision surgery. This fear is reasonable, considering the small diameter of the radius and that missing bone stock can prevent the insertion of a new stem. However, to our knowledge, this issue has not been described in the literature and has never occurred in our clinical experience.

Despite all these considerations, the choice is typically based on surgeon's preference and experience. Cementing is preferable for some prosthetic models, and the choice of whether or not to cement a prosthesis is dependent upon the model of prosthesis chosen. For instance, if the surgeon prefers bipolar implants and wants to use the Tornier–Wright prosthesis, he or she has to accept that a long stem (which might be chosen since it allows a higher range of bipolarity compared to the short stem) has to be cemented. Conversely, if he or she believes in the importance of the anatomical shape of the implant and chooses the Acumed prosthesis, he or she has to accept that the stem is designed to press-fit into the neck canal. Of important note, several implants, despite being designed for being press fit, can also be cemented (Table 26.1).

26.5 Conclusions

The decision of whether or not to cement the stem still mainly depends on the surgeon's experience and on the type of prosthesis the surgeon decides to choose. If cemented fixation is chosen, some simple steps are to be followed in order to obtain a good result.

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27 Complications and Revision of Radial Head Arthroplasty: Management and Outcomes

Jetske Viveen, Izaäk F. Kodde, Ante Prkic, Bertram The, and Denise Eygendaal

27.1 Introduction

During the past 75 years, radial head prostheses (RHP) have been used as treatment for a wide range of traumatic conditions, including acute comminuted radial head fractures and other posttraumatic deformities such as nonunion, malunion, posttraumatic osteoarthritis and chronic instability of the elbow or forearm [1].

Since the introduction of RHP by Speed [2], many modifications have been developed that varied in terms of material, fixation technique, modularity and polarity. To date, it is unclear which type of RHP is superior. Silicone RHP have proved to be biologically and biomechanically insufficient, with a substantial risk of fragmentation of the implant [3] and silicone synovitis as a result. Although good results have been reported in primary [4] and revision surgery of RHP, complication rates up to 30% have been reported [4, 5] with implant revision and removal rates of 8–10% at 3–4 years [4, 6]. This survival rate is far less favourable than rates reported for hip and knee arthroplasties [7].

Because of the relatively high complication and failure rates of primary RHP, there is need for an algorithm whether to revise, replace or remove the failed prosthesis. An overview of the functional outcomes that can be expected after these different types of surgeries is provided in this chapter.

27.2 Complications and Failure Patterns of Primary Radial Head Arthroplasty

Many papers are available about the outcomes of different types of primary RHP. Complication rates up to 30% have been reported, including infection, persistent pain, stiffness, heterotopic ossifications, loosening, overstuffing, oversizing of the head and dissociation of the head from the stem of the prosthesis [4–6, 8, 9]. The reason for this relatively high complication rate is still unclear, and it is questionable if this depends on the type of the prosthesis and fixation technique used or the applied surgical technique.

Interestingly, most revisions or removals are performed within 2 years after placement of the primary prosthesis [6]. Moreover, the decision whether to revise or remove the prosthesis seems more likely to depend on the preference of the surgeon or the hospital, rather than on objectifiable problems with the prosthesis [10].

Therefore, it would be helpful to provide an algorithm whether to revise, replace or remove the prosthesis taking into account the failure pattern of the prosthesis and the chondral condition of the elbow joint. Because it is proven that sili-

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cone RHP are biologically and biomechanically insufficient [3], it is not preferable to use this design anymore. Nevertheless, there are many more designs of RHP available which are varying in material (cobalt-chromium, titanium, pyrocarbon and vitallium), fixation technique (press fit, intentional loose-fit, cemented or fixation by an expandable stem), modularity (monobloc or modular) and polarity (monopolar or bipolar).

Indications for revision or removal of RHP are excision of heterotopic ossifications (47%) and stiffness (42%) and persistent pain. Less common indications are loosening of the implant (16), overstuffing (13%) and infection (8%) [4, 6]. Although some suggested that revision and removal rates are not affected by the design of the prosthesis [4], others reported that subgroup analyses showed the lowest incidence of RHP failure in cemented, long-stemmed, vitallium and bipolar prostheses [6].

27.3 Revision of Radial Head Arthroplasty: Workup

Revision surgery after radial head arthroplasty is predominately performed because of painful elbow stiffness, overstuffing of the prosthesis (overlengthening and oversizing), subluxation or dissociation of the prosthesis, loosening of the implant, painful erosion of capitellum or infection [4]. Before the decision to perform revision surgery is made, it is essential to define the potential problems that are likely to have caused failure of the implant. This is done by performing a broad workup to identify the mode of failure and to exclude other potential causes of failure.

As always, the workup starts with careful history taking. The patient may have had pain from the first moment after the implantation of the radial head or may have developed pain later on. The first is more likely with overstuffing and malalignment or early failure either based on septic or aseptic failure of implant fixation. The latter may be the case in late loosening of the prosthesis or capitellar erosion. A history of wound healing problems may suggest an infection, whereas a prolonged period of immobilisation before or after surgery and malalignment may both result in elbow stiffness. In addition, a history of progressive (pain) complaints of the wrist may suggest proximal migration of the radius.

Physical examination focuses on scars around the elbow, range of motion, soft tissue swelling, joint effusion, pain on palpation or during loaded and unloaded motion of the joint, stability of the elbow and neurovascular status. Moreover, examination of the wrist and the distal radioulnar joint (DRUJ) should not be underestimated. Radiographs in anteroposterior (AP) and lateral direction give information on possible loosening, subluxation or dissociation of the prosthesis. It is essential to know that many radial head implants show signs of proximal, subcollar, osteolysis, but are not loose [5]. Additional imaging with CT is often needed to assess other variables needed for pinpointing the cause of failure. It is more accurate for assessment of overstuffing [11], gives more detailed information on the exact location and geometry of heterotopic ossifications (HO) and can more accurately detect loose bodies, osteoarthritis or erosion of the capitellum. Dual-energy CT scanning reduces the scattering that is produced by the prosthesis and makes further evaluation more accurate. Standard radiographs of both sides of the wrist can be useful in detecting proximal migration of the radius [12].

Laboratory testing of inflammation parameters such as C-reactive protein (CRP) and subsequent aspiration for cultures may offer information on the possibility of an infection but is less sensitive in comparison to its use in lower extremity infections [13].

The planning of the surgery starts with patient positioning and planning the incision. If a previous incision was made posterior on the elbow, a lateral decubitus positioning may be easier, whereas supine position with the arm on an arm table is adequate for a lateral incision. An advantage of using the posterior approach is the possibility to perform surgery on the lateral, medial, and posterior side of the elbow with easy access to the ulnar nerve, even if the patient has fairly limited shoulder motion. A lateral incision allows for good access to the radial head prosthesis

itself, as well as facilitating an anterior and posterior arthrotomy of the elbow joint, but will have to be complemented by an additional medial incision if access to the ulnar nerve or the medial side of the joint is needed. This second incision may seem to be adding to the morbidity of the procedure, but an extensive posterior approach with development of large skin flaps may sometimes prove to be more of a risk, especially if wound breakdown is a concern in the case at hand. In some cases, the planned procedure will dictate the approach: A radiocapitellar prosthesis can be implanted through either a lateral or posterior approach, whereas a total elbow prosthesis is always implanted through a posterior approach.

In case of stiffness, it is important to assess the RHP for possible overstuffing during the arthrolysis. Overstuffing can mean either oversizing, when the head of the prosthesis is too big, or overlengthening, when the head of the prosthesis is placed too high in relation to the ulna. In case of overstuffing, it is sometimes necessary to revise the implant, whereas some implants can be shortened in situ. For other—bipolar—implants, changing the head component may be enough. Dissociation of the head component is clearly only seen in bipolar implants. In case of dissociation of the head, it is essential to critically evaluate the snap-on mechanism, malalignment, malrotation and stability of both the radioulnar and the ulnohumeral joint and the congruity of the capitellum [14]. A new head component or a complete new prosthesis may be needed, but more extensive surgery may be called for if instability is present. With unipolar designs, subluxation of the radial head is sometimes seen in cases of instability or chronic malalignment of the radius on the capitellum [15]. In these cases a revision with a cemented bipolar implant may compensate for a mild malalignment [15]. Otherwise, the source of malalignment may have to be addressed by repositioning of the stem during revision or stabilising the joint. In case of a chronic malalignment, however, the capitellar cartilage may have been severely damaged, adding a difficult problem to solve. It should then be decided to either ignore the capitellum, 'understuff' the revised radial head or remove it without replacing it with or without reconstruction of the interosseous membrane (IM).

The surgical plan for infection of a prosthesis depends on numerous factors including the type of micro-organism, comorbidity, soft tissue status and duration of the infection. There are two options available in case of infection. The surgeon can decide to perform an extended debridement of the elbow joint or to remove the prosthesis. In most cases, both treatment options are combined with antibiotics. The type and length of antibiotics depend on the type of micro-organism; therefore perioperative cultures should always be taken before antibiotics are given. Guidelines on treatment options such as removal versus retention of the implant in case of prosthetic infection have been written by Morrey et al. previously [13].

In all cases the surgeon should assess the stability of the elbow joint and the chondral status of the capitellum and ulnohumeral joint. In cases of instability with insufficiency of the LCL or MCL, IM or reduced buttress of the coronoid removal of the prosthesis should not be performed. In selected cases, revision of the implant is combined with reconstruction of the LCL, MCL, IM or coronoid. In cases of symptomatic osteoarthritis (chondromalacia grade IV) of the capitellum or erosion of the capitellum with an incongruency of the joint, resurfacing of the capitellum with a capitellar component is mandatory [16]. Symptomatic ulnohumeral osteoarthritis or severe instability of the elbow in patients above 70 may be a reason to convert to a total elbow arthroplasty (TEA).

27.4 Outcomes of Revision Surgery of Radial Head Arthroplasty

Concerning the outcomes of radial head arthroplasty revisions, subjective and objective outcomes clearly have to be distinguished. Gain in range of motion as an objective parameter and decrease of pain as a subjective parameter are generally the two main goals of revision surgery of RHP.

After primary radial head arthroplasty, range of motion varies between 115° and 125° of flexion-extension and 130–155° of pronation-supination [4]. Revision of the RHP may be helpful in increasing the range of motion, when stiffness interferes with the patient's demands of activity. A single study on revision of RHP for persistent pain in combination with loosening and instability showed that a flexion-extension range of motion of 105° improved to 127° and pronation-supination improved from 113° to 138° [16]. Pain scores lowered from 8 out of 10 during activities to 4 out of 10 [16]. In addition, revision surgery also improved poor and fair patient-reported outcomes to excellent to fair on the Mayo Elbow Performance Score [16].

At a mean follow-up of 57 months, there was only one major complication: a dissociation of the head from the stem of the prosthesis, probably due to polyethylene wear. Other minor complications were transient ulnar nerve dysfunction (19%) and lateral epicondylitis (5%) which is probably unrelated to the surgery. Ninety-five percent of patients were satisfied with the outcome after a mean follow-up period of 75 months [16]. No second revisions were performed, yet this may occur on the long term.

When degeneration of the capitellum is present, revision to a radiocapitellar prosthesis or even a TEA might prove beneficial when the impairments after arthroplasty outweigh the symptoms of failed radial head prosthesis [17]. When implanted for osteoarthritis, radiocapitellar prosthesis yields good outcomes, yet the ligamentous structures should be all intact [18]. When TEA is implanted for posttraumatic sequelae, only 8% involve primarily the radial head; majority of cases have a distal humeral fracture or severe ligamentous injury [19]. According to the Dutch Arthroplasty Register data, 6 out of 50 failed RHP are revised to a TEA in 2015; the remainder is either revised (5 out of 50) or removed (39 out of 50) [20, 21]. Unfortunately, reasons for secondary surgery after primary RHP are not mentioned. Overall, revision of a RHP to a TEA remains uncommon and is only performed in selected cases.

27.5 Outcomes After Removal of Radial Head Arthroplasty

Another option to treat a patient with pain, restricted range of motion or infection of the elbow joint after radial head arthroplasty is removal of the prosthesis without replacement.

Pain can be the result of loosening, overstuffing of the radiocapitellar joint, infection, degeneration of the capitellum and instability [9, 17]. Restriction in range of motion often is the result of capsular adhesions or HO around the arthroplasty, leading to impingement. This can be managed by open or arthroscopic removal of the HO around the radial head [9, 22]. Administration of nonsteroidal anti-inflammatory drugs following surgery might prevent recurrence of HO [23, 24].

After removal of the prosthesis, proximal radioulnar convergence or longitudinal forearm instability (especially after an initial acute longitudinal radioulnar dissociation injury) may occur [25]. Proximal migration of the radius may result in distal radioulnar incongruence, with a positive ulnar variance, leading to an ulnar impaction syndrome which is reported by the patient as ulnar-sided wrist pain [26].

The radial head is considered to be a secondary stabiliser during valgus load, but when the medial collateral ligament is also insufficient, removal of a RHP leads to valgus instability with ulnar nerve overstretching and increased varus and valgus load on the ulnohumeral joint in the long term [9, 27]. Therefore, during radial head arthroplasty removal, careful assessment of the medial collateral ligament is necessary, and ulnar nerve transposition can be considered when the medial collateral ligament is insufficient [9, 28]. Thus, removal of a failed radial head prosthesis has to be seen in the light of its potential complications. In specific patient groups, for example, low-demanding or elderly patients, these complications may outweigh the risk of a second reoperation after a radial head prosthesis revision [29, 30]. In contrast, several studies are available about functional outcomes after radial head resection directly after trauma. Good functional outcomes are reported in the majority of these patients, including satisfying MEPS and DASH

scores [26, 27, 31, 32]. However, in some patients radiological outcomes were poor [33].

27.6 Conclusion

Indications for revision surgery of primary RHP are HO and stiffness, with or without persistent pain. Other less common indications are loosening and overstuffing. In case of overstuffing, instability or malalignment replacement of the RHP should be considered. If an infection occurred, removal of the prosthesis is usually preferred. Revision to a radiocapitellar should be considered in case of erosion of the capitellum. Replacement by a TEA is indicated if there is osteoarthritis of the entire elbow joint.

In short, whether to revise, replace or remove a failed RHP is based on the chondral condition and the stability of the joint. The clinical and functional outcomes after surgery of a failed RHP are in general satisfying; however, the complication rates are still relatively high.

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28 Radiocapitellar Arthroplasty: Indications, Surgical Technique and Outcomes

Christian Spross and Roger van Riet

28.1 Introduction

In comparison with other joints of the human body, the incidence of arthritis of the elbow is low. Risk factors are known to include genetic predisposition, manual labour and sports or previous trauma to the elbow. In the symptomatic arthritic elbow, the joint space is often preserved, and osteophytes or intra-articular loose bodies are the most prominent findings [1]. These degenerative changes lead to pain and significant mechanical symptoms like stiffness or locking of the elbow. Symptomatic, primary osteoarthritis, isolated to the radiocapitellar joint, is even more rare, even though elbow degeneration may start on the lateral side of the joint [2, 3]. These lateral-sided changes are often asymptomatic, and most patients do not seek medical intervention until the ulnohumeral joint becomes involved [1]. The gold standard to treat these patients has become arthroscopic debridement with removal of loose bodies and osteophytes. This offers very satisfying results in terms of pain and improvement of range of motion [4, 5]. However, results are less favourable in patients with a significant loss of cartilage. In early stages of the disease especially in younger patients or in post-traumatic patients, this is often more prevalent at the radiocapitellar joint [2, 3, 6] (Fig. 28.1). Radiocapitellar replacement may be indicated in patients with severe loss of radiocapitellar cartilage. Other options that may be considered would be radial head resection, with or without interposition of tissue [7, 8]. Both have the theoretical disadvantage of increased valgus strain on the joint, potentially leading to ulnohumeral degeneration in the long term [9], whereas elbow kinematics are restored by replacing the radiocapitellar joint with a prosthesis [10].

This book chapter will discuss the specific indications, surgical technique and outcome after radiocapitellar replacements. Furthermore, we will present some preliminary data of the patients treated by the senior author.

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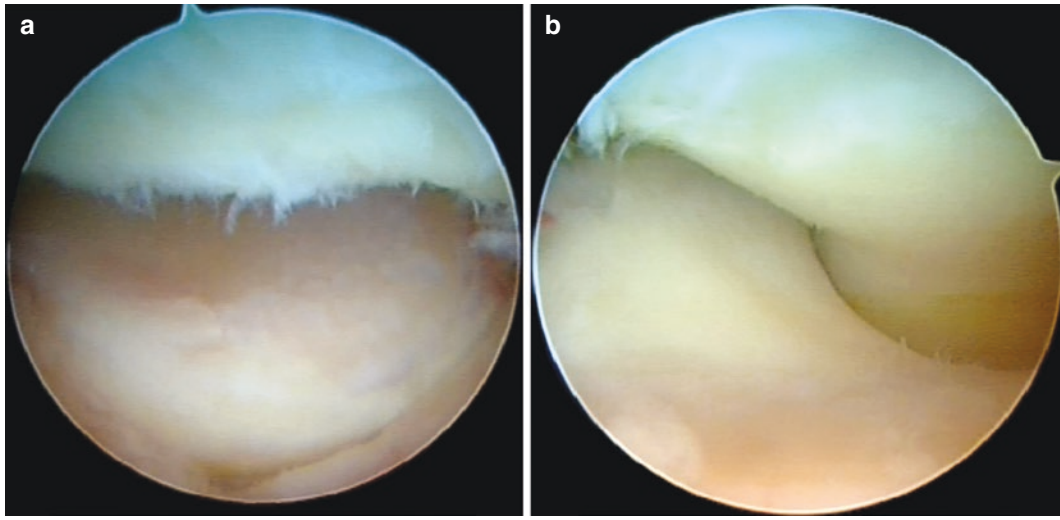

Fig. 28.1 Intraoperative, arthroscopic images of a 53-year-old male. (**a**) Radiocapitellar joint with significant loss of cartilage. (**b**) Ulnohumeral joint with well-preserved cartilage (Courtesy of MoRe Foundation)

28.2 Clinical Examination

Typically, patients complain of radial-sided elbow pain with or without a history of previous trauma. This pain normally occurs during certain loading movements of the elbow, for example, when using a screwdriver. Non-traumatic degenerative changes are mainly found in manual labourers.

During the physical examination, the patients may demonstrate a decreased range of motion, and a hydrops can often be palpated in the soft spot, as a sign of inflammation in the joint. Lateral-sided elbow pain can easily be misdiagnosed as tennis elbow, and special attention should be paid to differentiate [11]. Rajeev and Pooley described arthroscopic findings of radiocapitellar arthritis in half of their patients who underwent arthroscopy for lateral elbow pain resistant to conservative therapy [11].

In patients with isolated radiocapitellar arthritis, passive pro- and supination is typically not painful but the "grip-and-grind" test is. For this test, the patient is asked to firmly grip two fingers of the examiner and then pro- and supinate with maximal strength. This exercise maximally loads the radiocapitellar joint. The test is positive for radiocapitellar arthritis if the patient experiences pain and/or if crepitus is felt over the radial head during the rotational movements.

28.3 Radiographic Examination

Plain radiographs including anteroposterior and lateral views are usually the first step. They often show narrowing of the radiocapitellar joint space, deformity of the radial head and osteophytes (Fig. 28.2). Loose bodies may be suspected on plain radiographs, but a CT scan will be more sensitive. In our opinion, a CT scan with 3-D reconstructions belongs to the workup of the osteoarthritic elbow.

Magnetic resonance imaging (MRI) and bone scans do not belong to our routine assessment in these patients, but they may provide additional information. An MRI may be helpful to show the cartilage on the ulnohumeral side, and Technetium (Tc-99) bone scanning or SPECT scans may further prove the isolated involvement of the radiocapitellar compartment of the elbow.

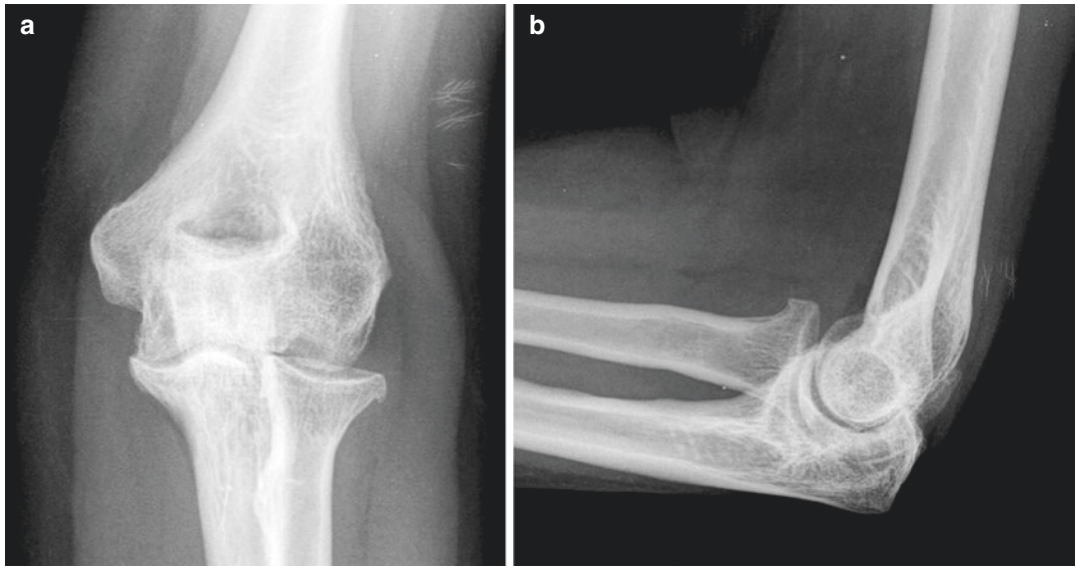

Fig. 28.2 (**a**) Anteroposterior and (**b**) lateral plain radiographs of the same patient, showing thinning of the radiocapitellar joint space, osteophytes of the radial head and bone cysts in the capitellum (Courtesy of MoRe Foundation)

28.4 Conservative Treatment

Conservative therapy is the first line of treatment as in any other arthritic conditions. For the elbow, a change of profession may be important as heavy manual labour (e.g., compression drilling) is known to predispose to osteoarthritis [12]. Non-steroidal anti-inflammatory drugs may be helpful for pain relief for some time, but side-effects may limit their use. There is no proof, so far, that dietary supplements, such as glucosamine, have any beneficial effect in the elbow. In terms of intra-articular injections, viscosupplementation with hyaluronic acid or its derivatives have been shown to decrease symptoms and slightly increase activity level for up to 3 months. After 6 months, no positive effect could be found anymore, when compared to a wait and see regimen. However, the risk of these infiltrations is minimal [13]. Corticosteroid injections may be helpful for some time, especially in patients where inflammatory symptoms predominate. Unless there is a mechanical block, physiotherapy may be helpful to maintain mobility.

28.5 Surgical Treatment

28.5.1 Indications

The indications for radiocapitellar replacements are rare and very specific. The "ideal" indication would be a patient aged between 30 and 60 years of age, with severe, radial-sided pain from isolated radiocapitellar arthritis, persisting after more than 6 months of conservative therapy. Physical examination shows a positive grip-and-grind test without signs of instability and a functional range of motion of the elbow. Radiographic examination should ideally show isolated degenerative or post-traumatic changes of both the capitellum and the radial head, with an intact ulnohumeral joint space without any relevant osteophytes [14–16]. It seems clear that such an "ideal" situation hardly ever exists in patients with primary osteoarthritis. Giannicola et al. successfully used radiocapitellar prostheses in combination with an open debridement for patients with mild to severe pain and stiffness, essentially due to degenerative changes in the lateral compartment

but also with medial-sided osteophytes [15]. Neither stiffness nor medial osteophytes seem to be absolute contraindications for a radiocapitellar arthroplasty.

Besides primary or post-traumatic osteoarthritis of the lateral elbow, radiocapitellar replacements have also been used for salvage surgery in cases of capitellar erosion after radial head replacement or late sequelae with longitudinal instability of the forearm after radial head resection or missed Essex-Lopresti fractures [17, 18] (Fig. 28.3).

Important to note is that while radiocapitellar replacements may be used for osteoarthritis in Europe, they are still considered an off label used in the United States.

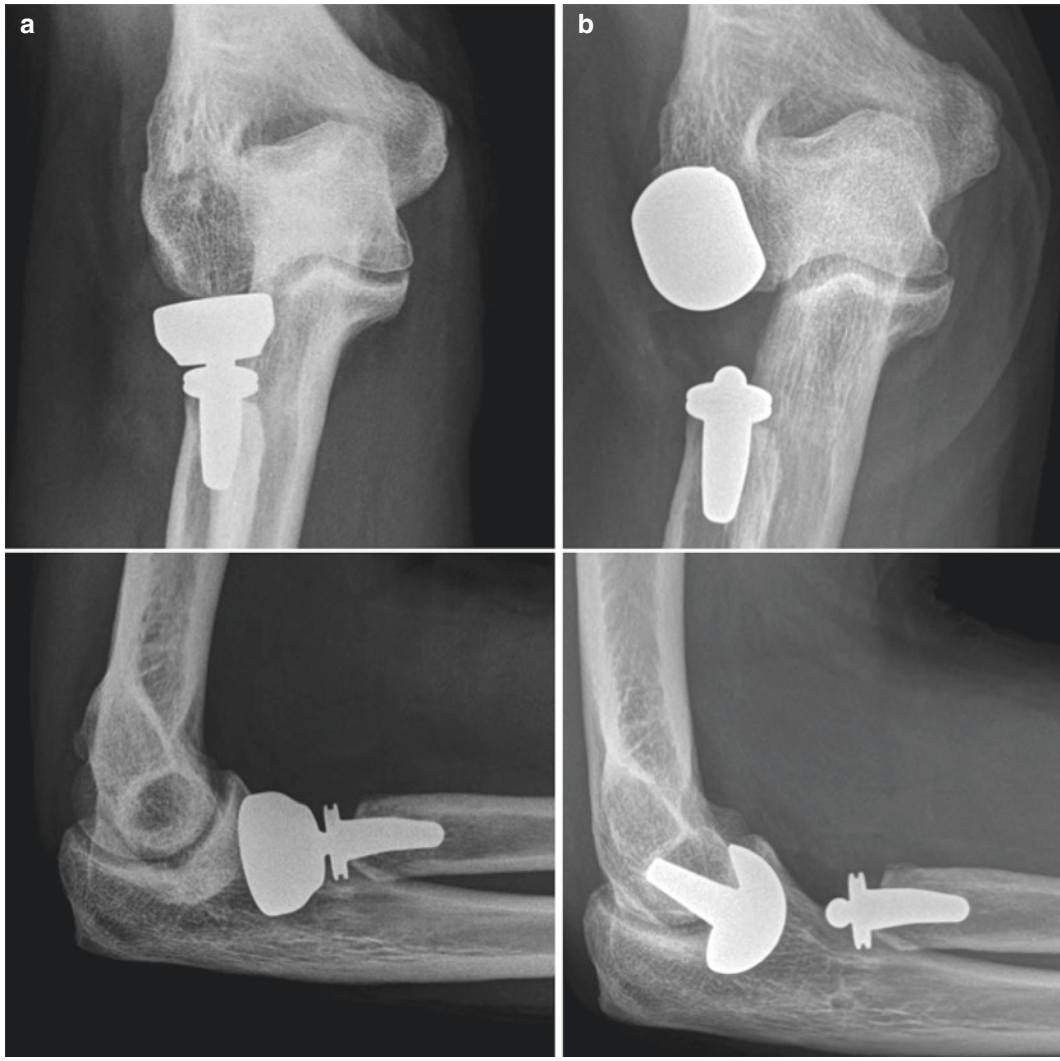

Fig. 28.3 (**a**) Anteroposterior and lateral plain radiographs of a 59 year old. He presented with pain and wear of the capitellum (MEPS: 50 points) 2 years after implantation of a bipolar radial head prosthesis for a comminuted radial head fracture. (**b**) Anteroposterior and lateral views 3 years of the same patient, after conversion to a bipolar radiocapitellar prosthesis (RCA). A capitellar replacement was performed. The well-fixed stem was left in place, and the radial head component was exchanged to an all polyethylene component (MEPS: 80 points) (Courtesy of MoRe Foundation)

28.5.2 Alternatives to Radiocapitellar Replacement

As there are no long-term results available in the literature, radiocapitellar replacement should not be the first line of treatment. Arthroscopic debridement with removal of osteophytes is known to yield satisfactory results in terms of pain and improvement of range of motion [8, 19].

Open or arthroscopic debridement with radial head excision is the most common procedure for a severely degenerated lateral joint compartment [8]. Interposition of anconeus muscle has been shown to yield satisfactory short- to mid-term results [7, 20]. A potential problem with these procedures is that the resection of the radial head changes joint kinematics, which could lead to long-term degenerative changes of the ulnohumeral joint. Radial head resection yields satisfactory long-term results in case of isolated radial head fractures [21], but these results are maybe not applicable to osteoarthritic elbows.

One of the advantages of a radiocapitellar arthroplasty is that the joint kinematics of the elbow may be restored as long as the medial collateral ligament is intact [10].

28.5.3 Surgical Technique

The surgical approach and technique depends on the different prosthetic systems that are available for radiocapitellar replacements. Wright Medical (USA) offers a custom-made prosthesis, which may be used with the Judet floating radial head prosthesis. At this moment this is the only option to replace the capitellum. The size of the capitellar component is based on preoperative radiographic measurements.

Zimmer Biomet provided a system for a replacement of the capitellum with a resurfacing of the radial head using a polyethylene cap, but this is no longer available.

The unilateral radiocapitellar arthroplasty by Stryker (USA) was the only "off-the-shelf" option for isolated radiocapitellar osteoarthritis in Europe. An upside of this system is that the radial head component may be used either as a bipolar (Fig. 28.3) or a monoblock (Fig. 28.4) replacement. This system has recently been discontinued as well.

We herein describe our preferred surgical technique for this procedure. The patient is placed supine with the arm on a hand table and the shoul-

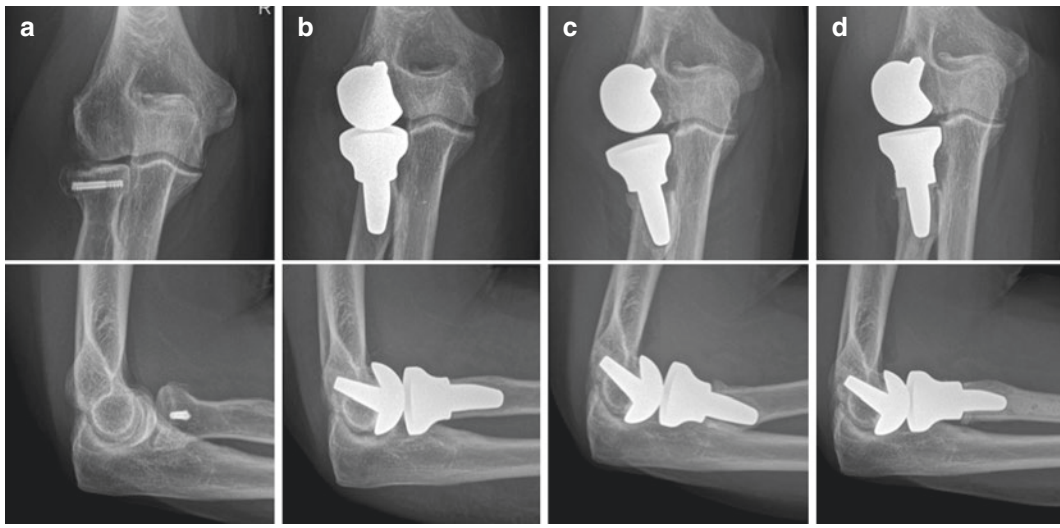

Fig. 28.4 (**a**) Anteroposterior and lateral plain radiographic views of a 57-year-old female patient 2 years after screw fixation of a radial head fracture resulting in posttraumatic degeneration of the radiocapitellar joint. (**b**) Anteroposterior and lateral views 3 months after RCA. (**c**) Anteroposterior and lateral views with early aseptic loosening of the radial head. (**d**) Anteroposterior and lateral views 5 years after cemented revision of the radial head component. (**e**) Clinical outcome at final follow-up (MEPS: 70 points) (Courtesy of MoRe Foundation)

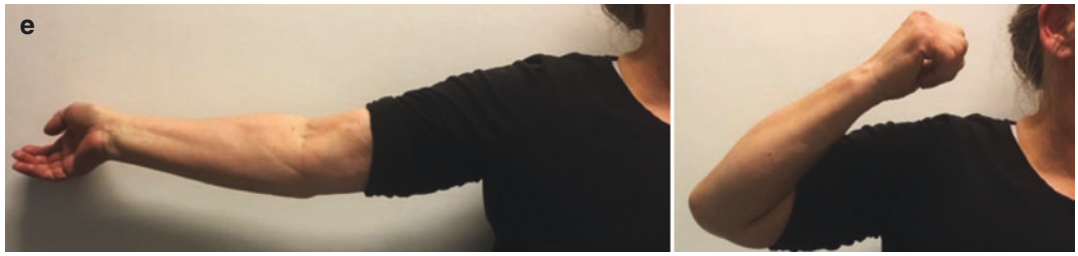

Fig. 28.4 (continued)

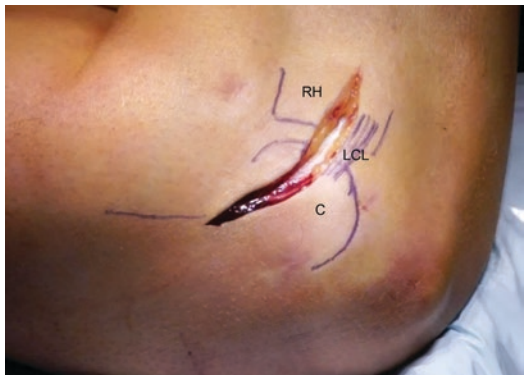

Fig. 28.5 Intraoperative picture showing the lateral incision. The incision is made directly anterior to the lateral collateral ligament complex (LCL) (*RH* radial head, *C* capitellum) (Courtesy of MoRe Foundation)

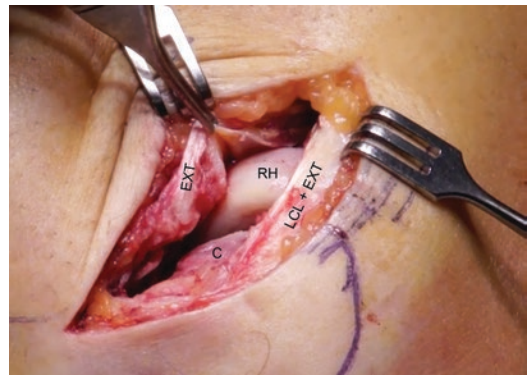

Fig. 28.6 Exposure after extensor tendon split (Ext) with the LCL still attached (Courtesy of MoRe Foundation)

der in internal rotation. Depending on the patient's preference, we perform this surgery under general or locoregional anaesthesia. The arm is exsanguinated and a non-sterile tourniquet used, followed by standard prepping and draping.

The LCL is palpated. The incision is made along the anterior border of the lateral collateral ligament complex (LCL), and an extensor tendon split is used to gain access to the joint (Figs. 28.5 and 28.6), but this can also be achieved using Kocher's interval. This procedure can be performed with the LCL in situ, but, as placement of the capitellar implant is more accurate with the LCL detached, we prefer to detach the LCL from its insertion at the humerus and mark it with stay sutures for later reinsertion.

Next, the radial head is resected at the head-neck junction. The radial intramedullary canal is rasped until adequate press fit is obtained. The height of the radial head component is determined relative to the lesser sigmoid notch of the ulna [22].

Orientation of the capitellar component is based on the rotational axis of the elbow, between the centre of the capitellum and the anterior distal margin of the medial epicondyle. A specific guide can be used to identify and mark the rotational axis with a *K*-wire (Fig. 28.7). A capitellar cutting guide is placed over the *K*-wire, and an oscillating saw is used to perform the humeral osteotomy. Care has to be taken only to cut the capitellar surface and not to cut into the trochlea. This can be avoided both visually and tactile, as the subchondral bone becomes more dense between the capitellum and the trochlea. The osteotomy should not extend past this point, and a 10 mm osteotome is used to finalize the osteotomy and elevate and remove the cut bone from the humerus. The resected radial head and the capitellar surface are used to size the prosthetic

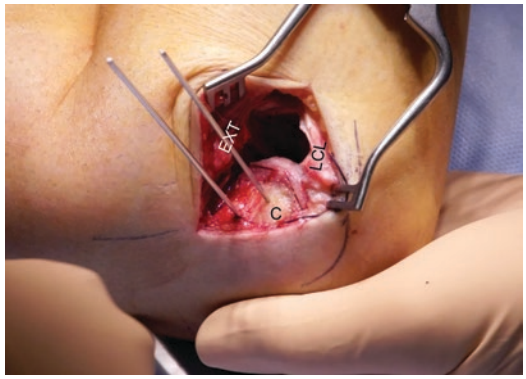

Fig. 28.7 Exposure after detachment of the LCL and resection of the radial head. The rotation axis of the elbow is marked with a *K*-wire at the level of the capitellum (C). The osteotomy of the capitellum is performed with the use of an aiming guide (Courtesy of MoRe Foundation)

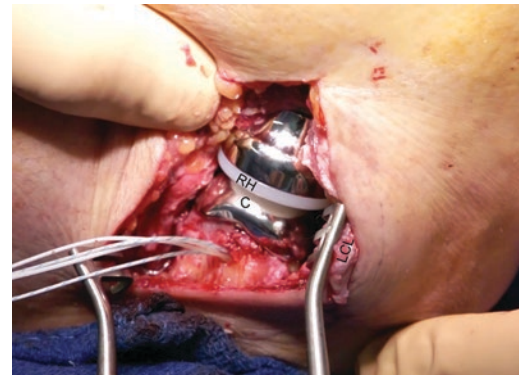

Fig. 28.8 After the implantation of the definitive components, the LCL is fixed firmly at its origin with the help of a bone anchor (Courtesy of MoRe Foundation)

components. The trial capitellar component is then inserted and used to assess the shape and fit of the osteotomy of the capitellum. At this point, the bone cut may still be levelled, if the trial component does not have a perfect fit. A *K*-wire is placed through the trial, into the intramedullary canal of the humerus. The trial is removed and the *K*-wire is overdrilled. The canal is opened further with specific cannulated reamers.

Before cementing, the joint should be rinsed thoroughly to remove all bone debris from the elbow. The cement is only placed on the back of the capitellar component and not on the stem. The radial head component is a press fit design and may be implanted after the capitellum has been placed. If the radial stem does not achieve enough press fit, it should be cemented.

The released LCL can now be reinserted using bone anchors or bone tunnels, and the extensor tendon split is closed with a running suture (Fig. 28.8).

28.5.4 Rehabilitation

Postoperatively, we allow the patient to mobilize the elbow immediately. A dynamic brace can be used with full range of motion to protect the LCL repair, but there is no evidence showing that this is absolutely necessary. Sutures are removed after 2 weeks at which time radiographs are taken. Usually no physiotherapy is prescribed, but the patient is instructed to mobilize the elbow without loading. If a relevant deficit in ROM persists after 6 weeks, we prescribe physiotherapy for active and passive mobilization. After 3 months unrestricted activity is allowed, but patients are advised that we feel that excessive loading may be detrimental for the longevity of the prosthesis.

28.6 Results

Our knowledge and experiences so far are only based on relatively small case series in the literature. Generally, the results are good in terms of pain relief [14, 15–18].

Heijink et al. reported a case series of six patients treated for either primary or post-traumatic osteoarthritis. All but one patient had previous surgeries on the affected elbow before the radiocapitellar replacement was placed. After a mean follow-up of 50 months, all patients showed a clear improvement of pain and were satisfied with the treatment. However, the mean flexion improved only marginally from 124° pre- to 128° postoperatively, and the mean extension deficit decreased from 26° pre- to 18° postoperatively. All the components were still stable without any radiographic signs of loosening at the final follow-up.

In the larger series of Giannicola et al., the results of 17 patients treated with radiocapitellar replacements for either primary or post-traumatic osteoarthritis are presented [15]. They also performed an open debridement, together with the implantation of the prosthesis. At a mean follow-up of 22.6 months, the mean Mayo Elbow Performance Score had improved significantly. The mean flexion improved from 100° pre- to 125° postoperatively and the mean extension deficit decreased from 37° pro- to 25° postoperatively. At the final follow-up, all implant components were intact and showed no radiographic signs of loosening.

28.6.1 Author's Experience

We performed RCA 16 times in 15 patients in a time span of 5 years. The indication was primary OA in 5 and 11 post-traumatic osteoarthritis in 11. These patients were followed for a minimum of 2 years postoperatively. After a mean of 3.6 years of follow-up, patients reported a significant improvement of pain, and a significant improvement of the Mayo Elbow Performance Score (MEPS) was found (from a mean of 46–85 points). The mean flexion improved from 133° pre- to 134° postoperatively (not significant), and the mean extension deficit decreased from 26° pre- to 17° postoperatively (also not significant).

28.7 Complications

General complications may include postoperative haematoma, wound problems, infection and nerve lesions. However, based on the available literature, these complications seem to be very rare.

More specific complications are postoperative ulnar neuropathy, elbow stiffness, instability, malpositioning of the implant and implant loosening [14, 15, 17]. In the series of Giannicola et al., four patients (20%) showed an unsatisfactory outcome mostly due to stiffness. However, in most of these patients, a malposition of the capitellar component was found. Three patients needed revision surgery with open debridement, including a release of the ulnar nerve in one. In their radiographic analysis, they found a slight overstuffing of the radial component in five patients (29%), which was not symptomatic in all but one patient [15].

Heijink et al. described loosening of the radial component which needed revision, in one patient [17], and they also found one patient with a grade 1 varus instability postoperatively [16].

Bigazzi et al. found asymptomatic loosening of the press fit radial head component in two of their seven patients. Furthermore, they had to perform one revision because of heterotopic ossifications and postoperative stiffness [14].

28.7.1 Author's Experience

In our series of patients, we did not find any varus or valgus instability even though we routinely release the LCL for the implantation of the prosthesis. Of our 16 prosthesis with 2-year results, we had to revise 4 (25%) prosthesis due to aseptic loosening of the radial component (Fig. 28.4). The radial head component was later removed in one of these patients, due to persistent pain. The RCA was considered to be a failure. One other patient needed a release of the ulnar nerve 1 year after RCA.

28.8 Conclusion

The indications for radiocapitellar replacements are relatively rare and include mainly primary and post-traumatic osteoarthritis of the radiocapitellar joint, with no or little involvement of the ulnohumeral joint. It is considered in younger patients not responding to conservative management and who are still symptomatic after a first arthroscopic debridement. The literature is still scarce on postoperative outcomes, and no long-term results have been published, so radiocapitellar arthroplasty should be indicated with caution. The surgery itself may be challenging, and the risk of postoperative complications can be decreased

with perfect positioning of the components. Loosening was a major concern in our patient group. This has been recognized by the company, who have since discontinued the distribution of the device we used. Without any complications, the results were good especially in terms of pain relief, and range of motion may be improved to a certain degree. There certainly is an indication for radiocapitellar arthroplasty, but improved design is necessary.

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Part V

Post-operative Management

29 Rehabilitation, Use of Elbow Braces, and Continuous Passive Motion After Elbow Arthroplasty

Susanna Stignani Kantar and Isabella Fusaro

29.1 Rehabilitative Rational principles after total elbow arthroplasty: use of elbow braces and continuous passive movement

Total elbow arthroplasty (TEA) is a surgical procedure by which the injured or irreversibly damaged elbow anatomical components are definitively replaced with an artificial joint. Commonly this procedure is performed for degenerative disease such as arthritis. Both main types of arthritis, degenerative (osteoarthritis) or systemic (among which the most widespread form is rheumatoid arthritis), in their end-stage, often successfully respond to elbow replacement. Moreover this procedure is becoming more and more commonly used immediately following certain types of fractures, usually in aging adults: the weakened bone by osteoporosis in fact makes a stable synthesis much harder for surgeon.

The goal of elbow replacement is to restore the function of the elbow joint as a link that positions the hand in space and as a stabilizer for power and fine motor function [1].

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There are two broad classes of total elbow prosthesis in current use: the linked and the unlinked ones (the latter are also called resurfacing).

By definition, the prosthetic elbow has a greater intrinsic stability with the linked implant in comparison to the unlinked one because it has a sort of mechanical linkage between the humeral and the ulnar components.

For this same design feature, however, mechanical stresses that arise when using the limb are transferred directly to the prosthetic interface resulting in a quite high rate of aseptic loosening.

This is the reason why modern linked implant has a "loose-hinge" mechanical linkage that more accurately replicates the native elbow by allowing more physiologic varus-valgus motion and axial rotation [2] and why unlinked implants were originally designed.

In fact, unlinked prosthesis can reproduce a more anatomical ulno-humeral joint but has a lower intrinsic stability which relies on the presence and good health of the elbow collateral ligaments and soft tissues. In this case, stability may be influenced by many factors affecting the surgeon, the surgical approach, the patient, and the postoperative management [3].

Rehabilitation aim after total elbow arthroplasty, whether a linked or an unlinked model has been implanted, is to recover as much as possible elbow motion preventing its restriction and instability and strength, respecting the progressive

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stages of soft tissues healing so as not to cause pain and inflammation in turn [1].

Pain resolution is a goal that can be reached with both prosthetic designs.

Every rehabilitation program has to be individualized according to multiple factors: patient's pathology, implant used, surgical approach and procedure performed by the surgeon, stability obtained during the surgery, and ulnar nerve involvement. Likewise, the clinical condition of the patient, age, and the activity level are extremely important: in very active patients, in fact, particular extra-recommendations are often necessary to meet the restrictions imposed by wearing an elbow prosthesis and prevent its overuse [4].

To perform a good rehabilitation treatment, a dedicated therapist who has a deep knowledge of the anatomic-functional characteristics of this joint is required, and the technical and clinical information sharing between all members of the team is mandatory: orthopedic surgeon, physiatrist, physical therapist and patient [5].

Prosthetic elbow rehabilitation consists of different successive phases, and it is not possible to proceed to the next step if the goals of the previous one are not reached, always respecting the biological tissue recovery [6].

Indeed there is scope for rehabilitation even before the patient undergoes surgery. Purpose of physiotherapy before replacement is manifold: check patient current pain level, the ability to perform activities (evaluating not only the elbow that will be replaced!), better prepare the elbow to operation if needed and possible, to inform the patient about the post-operative program and how to prevent the likelihood of any needs or common problems occurring after replacement. Moreover, patient has the chance to learn some exercises that will be performed after surgery during the recovery period and after it.

Patient level of activity evaluation should comprehend the elbow joint and all the correlated articulations of both the upper limbs and has to be performed in both analytical and global paths to highlight possible wrong postural attitudes which could be correlated to the articular pathology.

To perform a good joint evaluation is necessary to use validated scores to monitor the clinical evolution and the treatment effectiveness, to compare the results obtained by different prostheses models, and to facilitate data exchange in the scientific environment.

Investigate fields in elbow evaluation scores are range of motion (ROM), pain, and the ability to perform ADL. Because no evaluation scores are indicated to assess all pathologies that could involve the elbow, we can use many useful scores, and among these the most indicated in cases of prosthetic replacement are Mayo Elbow Performance Score (MEPS), Hospital for Special Surgery Score (HSS), and the Score of the European Society of Shoulder and Elbow Surgery (SECEC) [7–10].

As stated before, one of the main aims of the preoperative treatment is to reduce pain with physical therapy and eventually with drugs and to maintain ROM with active assisted exercises. If we can obtain pain relief before surgery, also the postoperative management will be easier; chronical pain in fact cause a prolonged pathologic sensitization of nociceptors. This can induce a change in the central processing of the sensitive afferents and consequently causes a spinal and/or supraspinal hyperexcitability which in turn leads to C-fiber degeneration and the dorsal horn of spinal cord to an anatomical reorganization. Thereby, the different mechanisms of neuropathic pain may overlap one another over time, becoming pain chronic and self-maintaining.

Immediately after surgery, patient will experience pain, discomfort, and an important swelling in and around the "new joint." This is the reason why a drainage tube is left in the joint for 24–48 h and the elbow is bandaged and positioned in a splint (Fig. 29.1) asking the patient to keep it elevated above chest level when sitting or sleeping for as long as he can. In the splint the arm can be positioned extended or slightly bent or flexed at about 80–90° depending on surgical technique or on surgeon's preferences: this is the most comfortable resting position for the patient because joint capsule at 90° of flexion is at its maximum capacity and therefore any fluid collection is less painful.

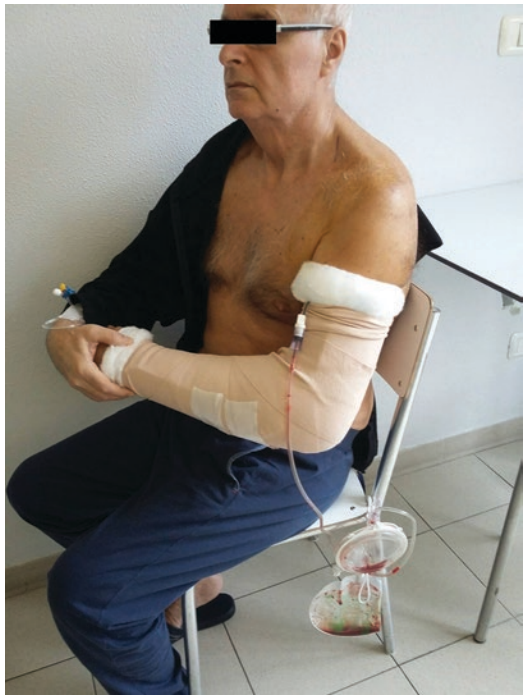

Fig. 29.1 Patient 24 h after surgery with drainage tube in the joint and elbow bandaged positioned in a splint

Aims of the postoperative phase are to solve edema, pain, and muscle spasm and to maintain ROM obtained in the operating room reducing as much as possible the onset of stiffness. If pain and edema are not handled since the immediate post-surgery, rehabilitation time could be prolonged and the final result could be worse.

After 36–48 h or however within the discharge from hospital, patient will be provided with a sling for support and protection during everyday tasks.

There are several ways to control pain. One of the simplest but effective ways is the use of ice (or cryotherapy if available) applied three or more times per day for about 10–15 min each and avoiding the direct contact to the skin. Usually nonsteroidal anti-inflammatory drugs (NSAID) are associated and sometimes together with pure analgesic drugs. We prefer do not use the latter because of their collateral effects, because they are not so easy to handle (dosage, duration of therapy, use or abuse by the patient) but above all because postoperative pain is a physiological consequence of the body inflammatory response of the early phase of healing so at this point, if it isn't completely unbearable, it's more useful to treat inflammation rather than only pain.

Another method that is proved to be useful to control pain is a peripheral block achieved with a perinervous catheter. However, this system can't be used for all patients but only in selected cases because it requires to be strictly monitored. Moreover, the use of a peripheral block, requires an extra caution rehabilitation, due to the patient sensibility and thermic pain reduction.

Modalities (e.g., laser therapy, ultrasounds, Tecar therapy, etc.) aren't often used at this stage not for their ineffectiveness but for a logistic question: these therapies are handled in rehabilitation centers to which usually the patient is not able to access in the immediate postoperative period. TENS could be the only exception because it is very easy to handle even at home for its small size, ease of use even by older people, and low cost.

Finally, in order to contain pain but also to prevent possible further and worst complications, protection of wound and the skin is quite important because often these patients have vulnerable skin and soft tissues due to prior medical treatment or metabolic or systemic diseases [11].

To treat edema and swelling when the splint, sling, or brace is in place, the only solution, as we told before, is asking the patient to keep the arm elevated, but it is very useful to introduce lymphatic drainage (according to Vodder or Leduc technique) (Fig. 29.2a, b) or a draining massage (Fig. 29.3) whenever possible and maintaining the results obtained with a compression bandage. We always associate flexion-extension finger exercises for their useful effect on blood circulation. Make sure the patient is not aggressive in grip strengthening so that muscular attachments heal.

Muscle spasm treatment refers not only to the muscles around the elbow but even to the neck muscles often contract for compensation in response to the emotional stress that arises from surgery and to the altered posture taken with the use of the brace. For this aim we usually prefer various massage techniques possibly preceded by

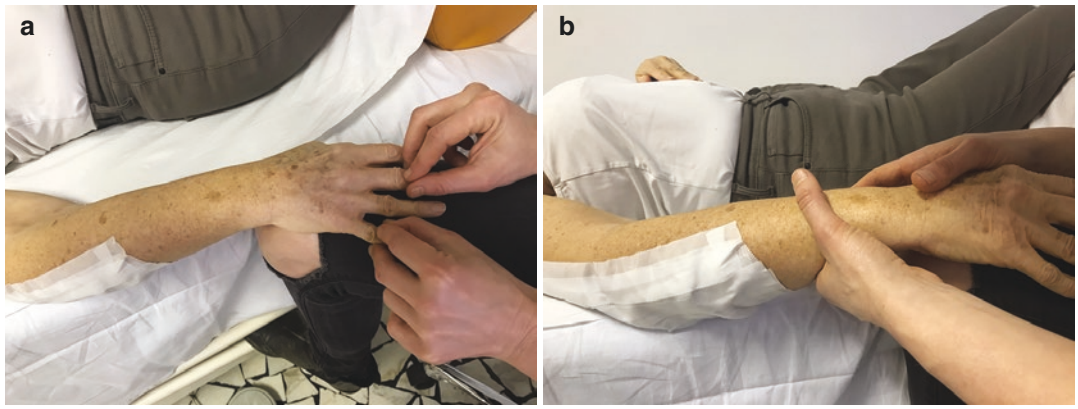

Fig. 29.2 (**a**, **b**) Upper limb lymphatic drainage according to Vodder technique

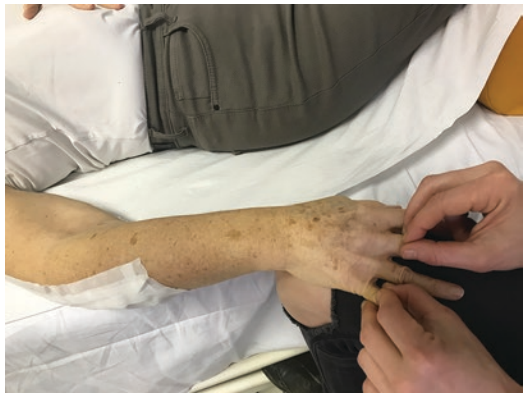

Fig. 29.3 Upper limb draining massage

the application of local heat if we refer to the cervical spine.

Since the first postoperative day, patient is encouraged to gradually restore active range of motion (AROM) of cervical spine, shoulder, wrist, and hand (Fig. 29.4a–g).

Furthermore, patient starts a cautious auto-assisted passive mobilization of the elbow: 30–40° of flexion/extension are allowed (Fig. 29.5a, b).

It's essential that early joint recovery occurs within a safe arc of movement that allows healing of soft tissues by maintaining the integrity of the replaced joint, triceps tendon, and the eventual ligamentous reconstruction. Thus, the "amount" of flexion/extension and pronation/supination, the quality of movement (passive or active), the position of the elbow during movement, and the need to use a brace after splint depend on triceps involvement and type of prosthesis.

Obviously, if during the procedure the triceps tendon is not detached from its insertion, no postoperative protection is needed, and no limits are settled to an active full extension or the passive flexion of the elbow; the latter won't be forced anyway in order not to disturb the surgical wound cicatrization. This triceps-sparing approach allows the patient to quickly recover his autonomy and to return to his daily activities therefore counteracting muscle atrophy and adhesion development.

Conversely, if triceps is reattached to the olecranon, only passive or gravity-assisted extension (Fig. 29.6) will be allowed for about 1 month, and then active extension will be performed in a gravity-assisted position for about another 2 weeks. Coherently, exercises for extension against resistance recovery will be started at least 10 weeks after surgery (Fig. 29.7). In these patients even flexion must be recovered with caution to reduce detachment risk. It's auspicable to reach 100° of flexion in the first postoperative week and to improve 10° for each incoming week [4].

Even the exercises to gain flexion are initially gravity-assisted in supine position with the support of the healthy limb, which drives the operated arm hand toward the nose and toward the opposite shoulder as the ROM increases [12] (Fig. 29.8a–c).

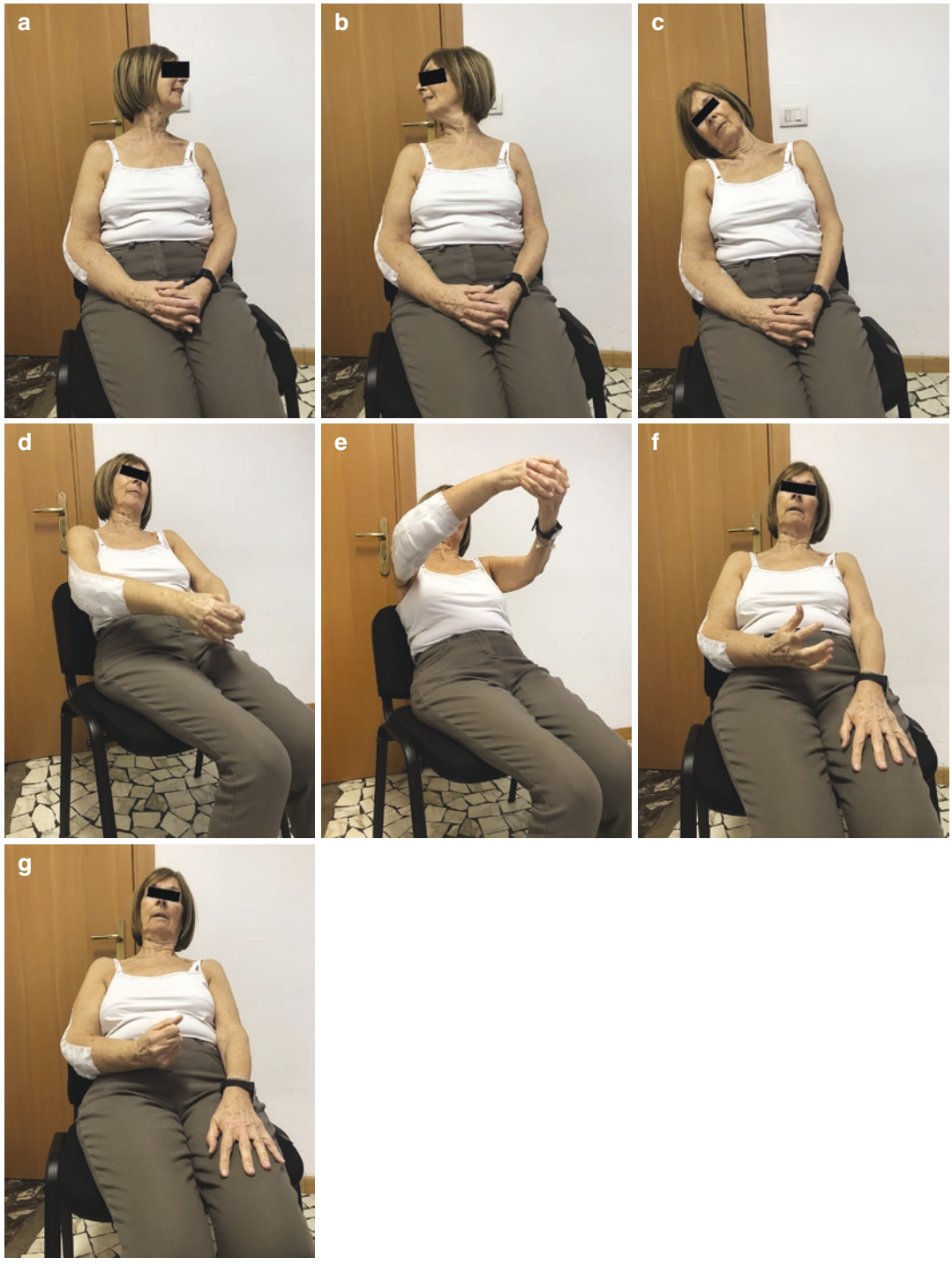

Fig. 29.4 (**a**–**g**) Examples of very simple exercises to gradually restore active range of motion of cervical spine (**a**–**c**), shoulder (**d**, **e**) and hand (**f**, **g**)

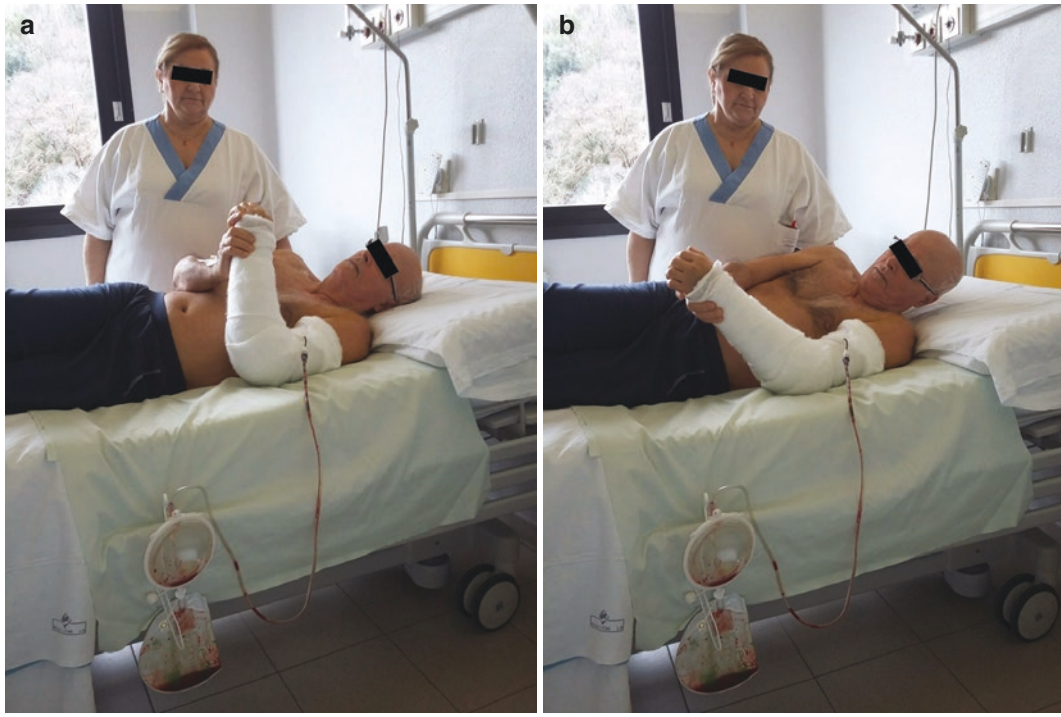

Fig. 29.5 (**a**, **b**) Immediate cautious flexion\extension auto-assisted passive mobilization of the elbow

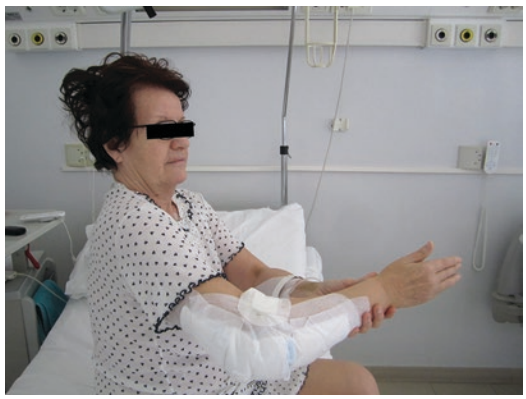

Fig. 29.6 Passive or gravity assisted extension in case of triceps reattachement to the olecranon

Recovery of pronation/supination involves very simple exercises: we ask the patient to rotate the forearm as to bring the hand palmar face up and down alternately (Fig. 29.9a, b). But the most important thing we need to know is whether the patient is allowed this movement or not, and it depends on the type of surgical gesture performed on the soft tissues as will be explained later.

At the drainage removal, usually in the second day, the patient can go on wearing the sling for the next 2 weeks for comfort only or rather a hinged elbow brace or an hard posterior elbow splint: it depends on the type of the implanted prosthesis.

The first one is the scenario of patients with linked prostheses. Patient will remove it several times during the day only to perform self-assisted exercises, but this is very important to prevent excessive liquid accumulation in the capsule maximum capacity position and so the development of flexion contractures. Movements are gradually performed without limitations in all planes.

Different is the situation with an unlinked prosthesis. Because this prosthesis requires greater protection, patient is provided with a hinged tutor, which must be worn for the next 4–6 weeks, allowing motion in a safe ROM.

Forearm position in the brace depends on which surgery was performed on the collateral ligaments: if the lateral collateral ligaments have

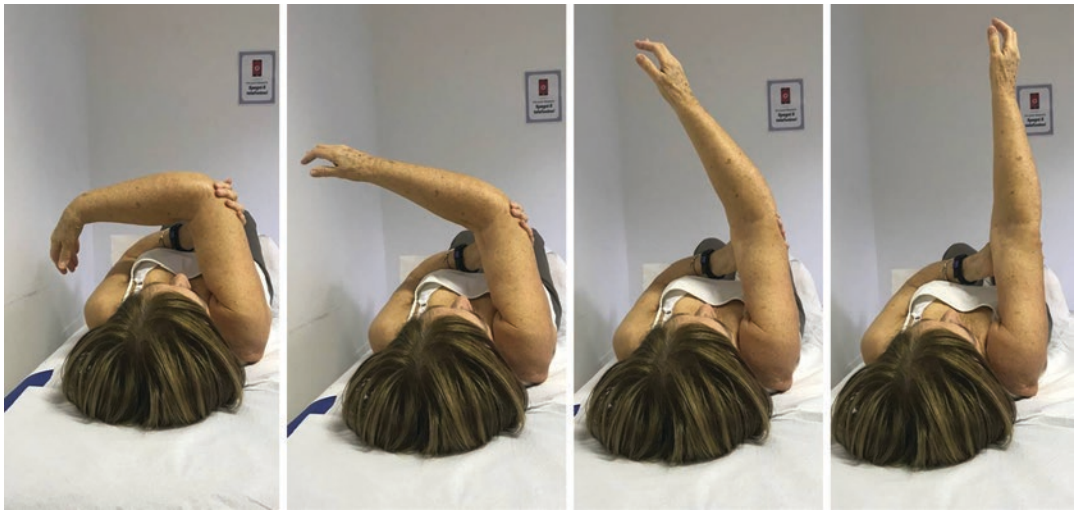

Fig. 29.7 Example of exercise for extension recovery against resistance

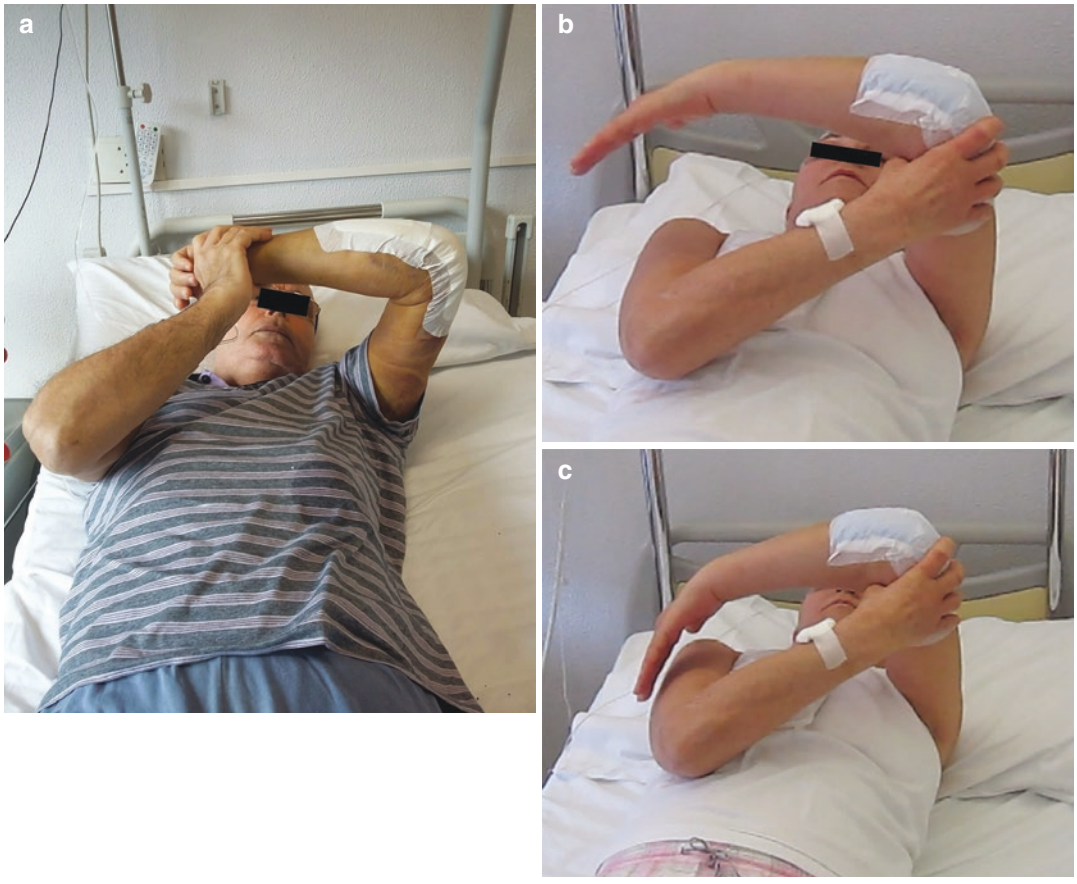

Fig. 29.8 (**a**–**c**) Exercises to gain flexion initially gravity-assisted in supine position first bringing the hand towards the nose (**a**) and then more and more towards the opposite shoulder (**b**, **c**) as the range of movement increases

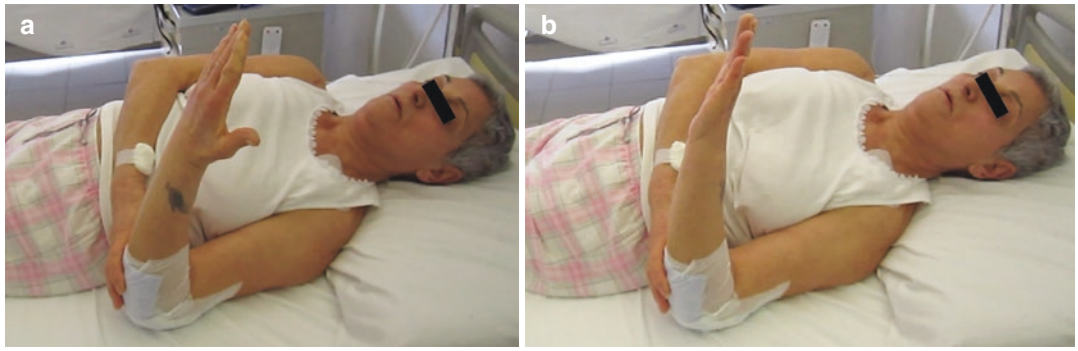

Fig. 29.9 (**a**, **b**) Recovery of supination (**a**)/pronation (**b**)

Fig. 29.10 Forearm pronated position in the brace in case of lateral collateral ligaments reconstruction

been reconstructed, forearm will be pronated (Fig. 29.10); if the medial collateral ligaments have been reconstructed, forearm will be supinated; and if both ligaments have been reconstructed, forearm will be in neutral position.

Wearing the brace, active-assisted flexion-extension and pronation-supination movements will be performed, but the latter must be performed with the elbow flexed at 90° and kept to the side not to excessively stress the reconstructed collateral ligaments.

In this regard we want to remember that it's necessary to turn our attention not just to the proximal radioulnar joint only but even the distal radioulnar joint.

Collateral ligament protection is mandatory since their rupture or elongation is responsible for one of the most feared complications after an elbow prosthesis, that is, an early instability up to a frank dislocation. In particular, we must protect and teach the patient how to protect the lateral ligament complex which is subjected to repetitive varus stress in a large part of the gestures intrinsic to daily life as the force of gravity when the forearm moves on a horizontal plane (e.g., eating, use of mobile, etc.) or anyway in any plane other than the vertical one [3].

The use of continuous passive motion (CPM) device to regain motion (Fig. 29.11a, b) is controversial in these patients. In agreement with conduct of famous authors who daily deal with elbow and to whom we asked for a personal opinion, we prefer to not use it. This choice depends on the fact that we do not see any advantage in terms of joint gain or reduction in rehabilitation times but rather an increased probability of potential damage.

In fact, for all patients who don't have movement limitations or any particular precautions to be taken, limits are dictated by pain and surgical wound cicatrization, and these limits are the same ones that they would have using CPM.

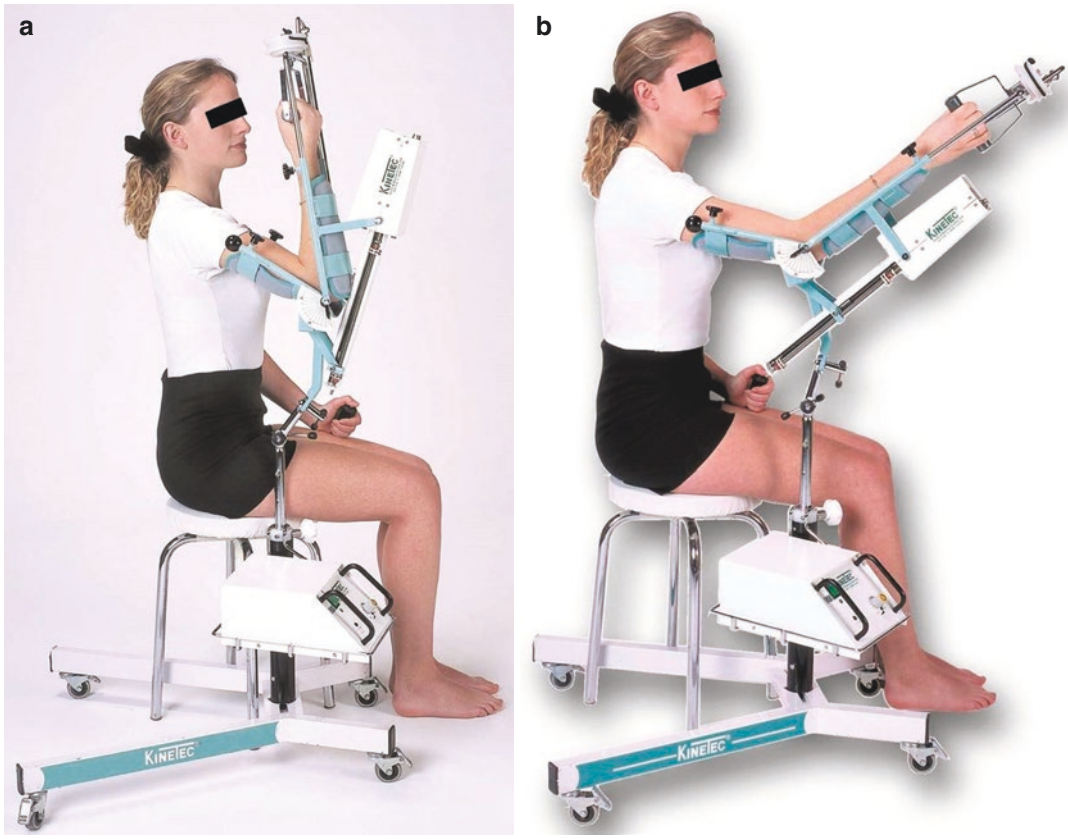

Fig. 29.11 (**a**, **b**) Elbow motor device mobilizator (CPM)

Patients with associated important surgical gestures for a good function and stability of the prosthesis (triceps reinsertion or collateral ligaments suture), the use of the device is procrastinated until cicatrization occurred because, on the motorized device, the elbow tends to lose its joint rotation center and could therefore undergo to varus-valgus stress damaging the repairing tissues. Even in this case, we do not see any CPM particular advantages.

Only on two special occasions we evaluate its use: upper limb amputated patients who therefore couldn't perform self-assisted movements and noncompliant patients who wouldn't do the assigned exercises or wouldn't do them correctly.

In these cases CPM mobilization is done two times a day for 20 min each session for the greatest possible ROM and performed in slow motion, not to cause rebounded contractures. In any case CPM use requires close supervision especially to notice as soon as possible any ulnar nerve signs of irritation. To avoid this, frequent adjustments of position are necessary.

Keep in mind that, if you decide to use the device, it ought to be done as soon as possible following surgery, that is, in the first (bleeding) or second stage (edema) of stiffness [13].

As soon as possible, even scar management starts because a tight scar can be responsible for a movement restriction as well as a source of pain (Fig. 29.12).

Goals of the weeks following surgery are to encourage functional ROM and strengthen the elbow for coping the everyday life needs while going on protecting soft tissue healing and minimizing pain and inflammation. In short words, we have to re-establish dynamic elbow stability.

To obtain this, first of all, shoulder, elbow, and wrist ROM recovery has to continue. In our experience cognitive therapeutic exercises are proved to

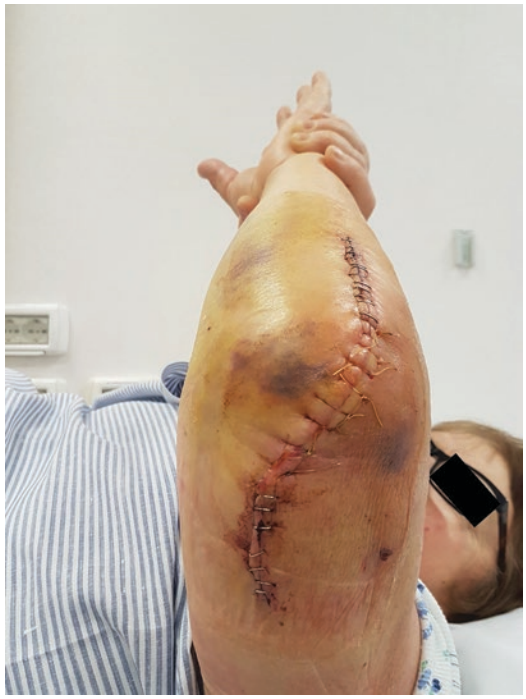

Fig. 29.12 Scar extension needed in elbow prosthesis surgery that suggests the importance of the relative treatment

be very effective for this purpose in the beginning without muscular recruitment until perceptive function is recovered.

Once again, our attention is primarily focused on movement recovery even before the muscular strength: this depends on the fact that the better the muscle recruitment and strength will be, the more we can re-establish the correct length/tension ratio.

For this reason, if joint recovery after 6–7 weeks after surgery is not satisfactory yet, it's also possible to recur to more intense recovery procedures that include stretching techniques and the use of braces.

Stretching exercises to regain flexion and extension can be done assuming specific postures (Fig. 29.13) or with elastic bands, holding them at non-painful limit in matter not to stimulate the stretch muscular reflex.

Stretching exercises are performed in all planes: elongation is maintained for 10–15 s to the maximum stretch tolerated by the patient to allow the retracted soft tissues to length; it should be repeated ten times a day. Stretching extension

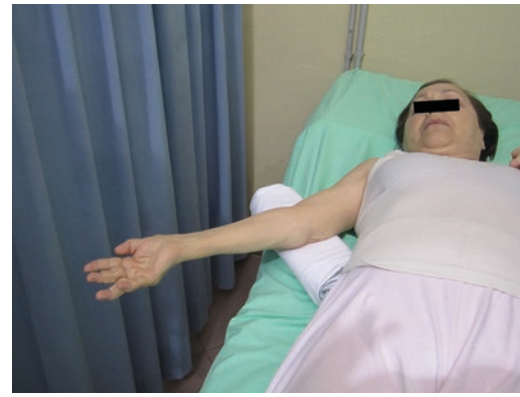

Fig. 29.13 Example of stretching exercises to regain extension

exercises using weights upon forearm are avoided because this may increase the biceps muscle hyperactivity. It's useful to prepare tissues to stretch with superficial heat modalities to increase tissue extensibility and to decrease the spasm of the muscles crossing the joint which can be an obstacle to movement recovery [4].

As regards splints use, the speech is more complex. After elbow prosthesis, in fact, different slings can be used for different purposes. Therefore, even if it's outside the scope of the present discussion, we cannot fail at least to mention the different types of splints and their use. In the immediate postoperative or post-injury period, we've already said that it is necessary to use a *protective brace*: usually it's a plastic unhinged brace that keeps the elbow and the forearm in a fixed position (at different degrees of extension or flexion and pronation/supination) preventing any movement that could worsen pain and/or edema. Usually a protective sling is replaced by a *hinged brace* that is a brace with an adjustable ROM: it allows movement only in a safe established ROM to let damaged tissue's healing undisturbed [14].

A very special case in which this sequence can be used is to manage in the early postoperative stage a subluxation or dislocation of an unlinked elbow prosthesis. After 3 weeks of immobilization, cast will be substituted with a hinged brace with an extension block [3].

In case of unsatisfactory ROM recovery, in this case as we told after about 6 weeks from

surgery, the use of *mobilization braces* to recover the deficient movement plan is allowed. They induce a prolonged, low-load soft tissue elongation in the plane we want to regain, usually flexion, alternated with rest moments. These braces can be *static* or *dynamic***.** The first ones use creep loading by the use of a constant force and have to be worn up to 12 h/day, but don't ensure a plastic deformation is achieved during each session. Results are therefore variable, and pressure sores and skin breakdown are possible.

Dynamic braces have a sort of elastic mechanism built into them to allow some movement of the elbow while being stretched the rest of the time. The principle underlying their action is stress relaxation, that is, displacement is constant, but force varies. These lead to plastic deformity more quickly and reliably. The *static progressive splint* is a specialization of the dynamic splint where a constant tension is used (e.g., a turnbuckle) [15] (Fig. 29.14).

We have found static progressive splints to be the most effective especially because patient can wear them for the requested time being less painful and aggressive than others: it is the patient that controls the amount of force applied and the length of time that it's applied. Dynamic ones are used above all for pronation/supination recovery [14].

A very important thing that patient has to understand is the correct use of these splints: it should be tight enough to feel some stretch and discomfort but no pain at all and has to be clear that is unlikely to see any effect until worn for at least 1 or 2 weeks. The splint is applied (or an alternate direction splint is used) repetitively throughout the day until the night. Tension has to be adjusted after a few minutes of wearing to allow that stress relaxation of the tissues takes place. The splint has to be removed every 3–4 h and the elbow freely used for about 1 h. Splinting is continued until no ROM improvement is noted over approximately 6 weeks. This is to contrast

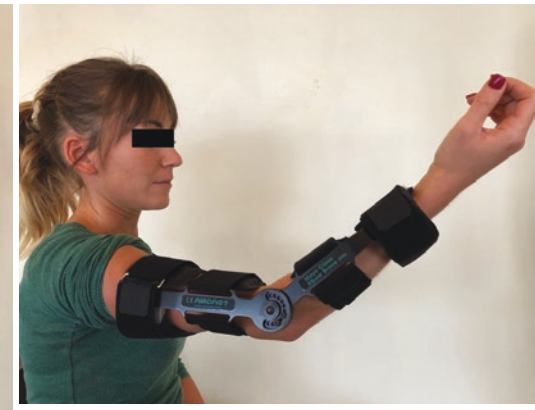

Fig. 29.14 Static-progressive splint that apply torque to the elbow to hold it in its end range position in order to increase range of motion. As tissue length changes, patient is easily able to readjust tension to new maximum tolerable length

the rebound effect in which motion loss can take place if it's dismissed too quickly.

Muscular gentle strength recovery starts at about the eighth week and only if the elbow has achieved a wide enough ROM of about 70–80° but always with the limits of 2 kg.

The muscles that pass across the joint provide compressive forces to the articulation and have been shown to play an important role in stabilizing the elbow [3].

Further, we have to remember that most of the muscles that originate from the elbow epicondyles cross the wrist so any dysfunction will involve both the elbow and the wrist joints function; our rehabilitation program therefore has to involve the wrist and the fingers every time.

Finally, it has been hypothesized that anconeus muscle, whose contraction is associated with that of the triceps one, plays a role as varus stress joint stabilizer, so don't forget to recover it too.

Patient can start with gentle isometric and isotonic wrist flexion/extension and elbow flexion strengthening, but biceps should be reinforced with elbow supported (Fig. 29.15). Initially we'll work on each single plane of elbow movement separately and then progressing to composite movements as appropriate.

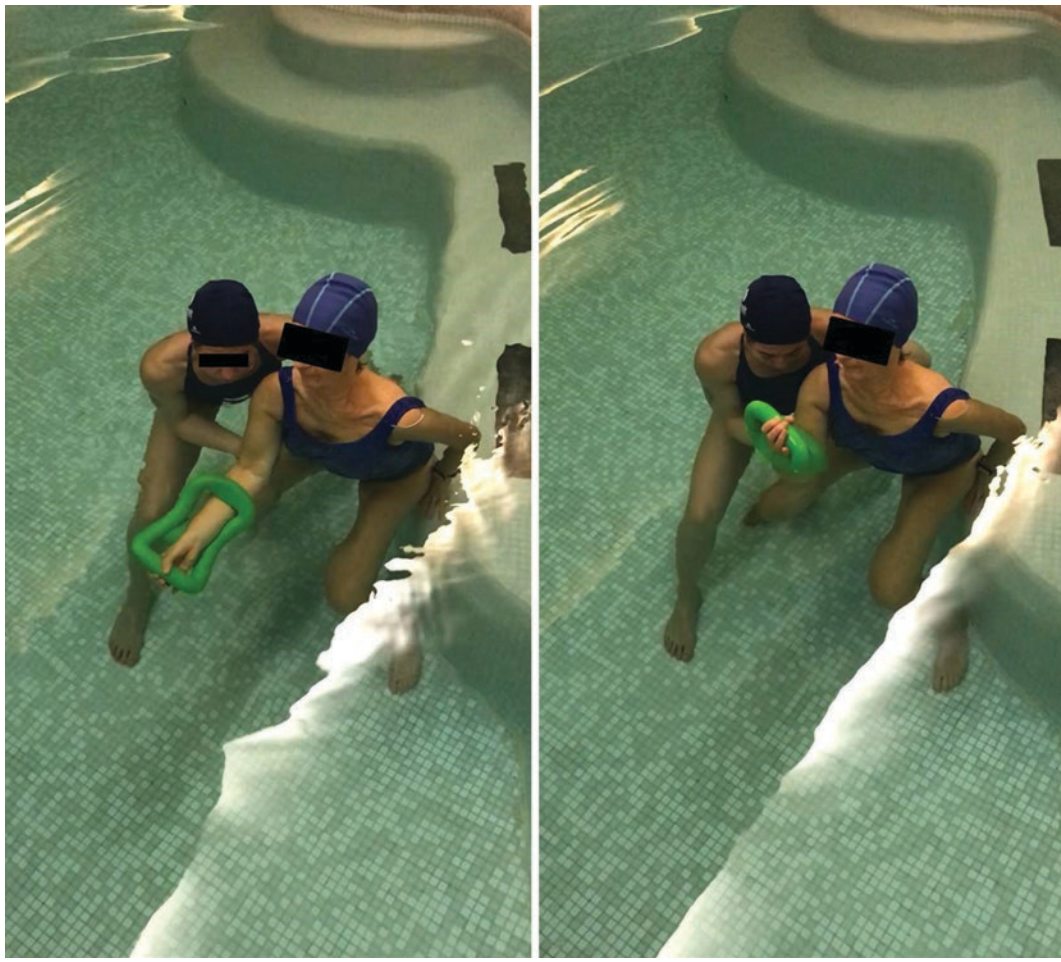

Fig. 29.15 Example of analytic gentle isometric and isotonic elbow flexion strengthening with elbow supported by therapist hand. Working in water at low speed makes muscular work even sweeter and makes this environment optimal to quickly start this rehabilitation phase

Later, at about the tenth week, in addition to going on isotonic reinforcement, we may add antigravity active extension but with no resistance (until weeks 12–13), start muscular gentle recovery with an ergometer but at very low resistance, and introduce stronger, sub-maximal isotonic exercises for shoulder to promote the generally upper limb conditioning taking care not to exceed with the rotational exercises as not to stress too much the elbow in varus/valgus. Even manual opposed exercises in the different movement planes are performed in this period, initially in an analytical modality, according to the proprioceptive neuromuscular facilitation method (PNF), with an accommodating contrast and diagonal directions (Fig. 29.16a, b).

Use of weights for strengthening, as already mentioned, must be very cautious and never superior to 2 kg but this, for the lifetime.

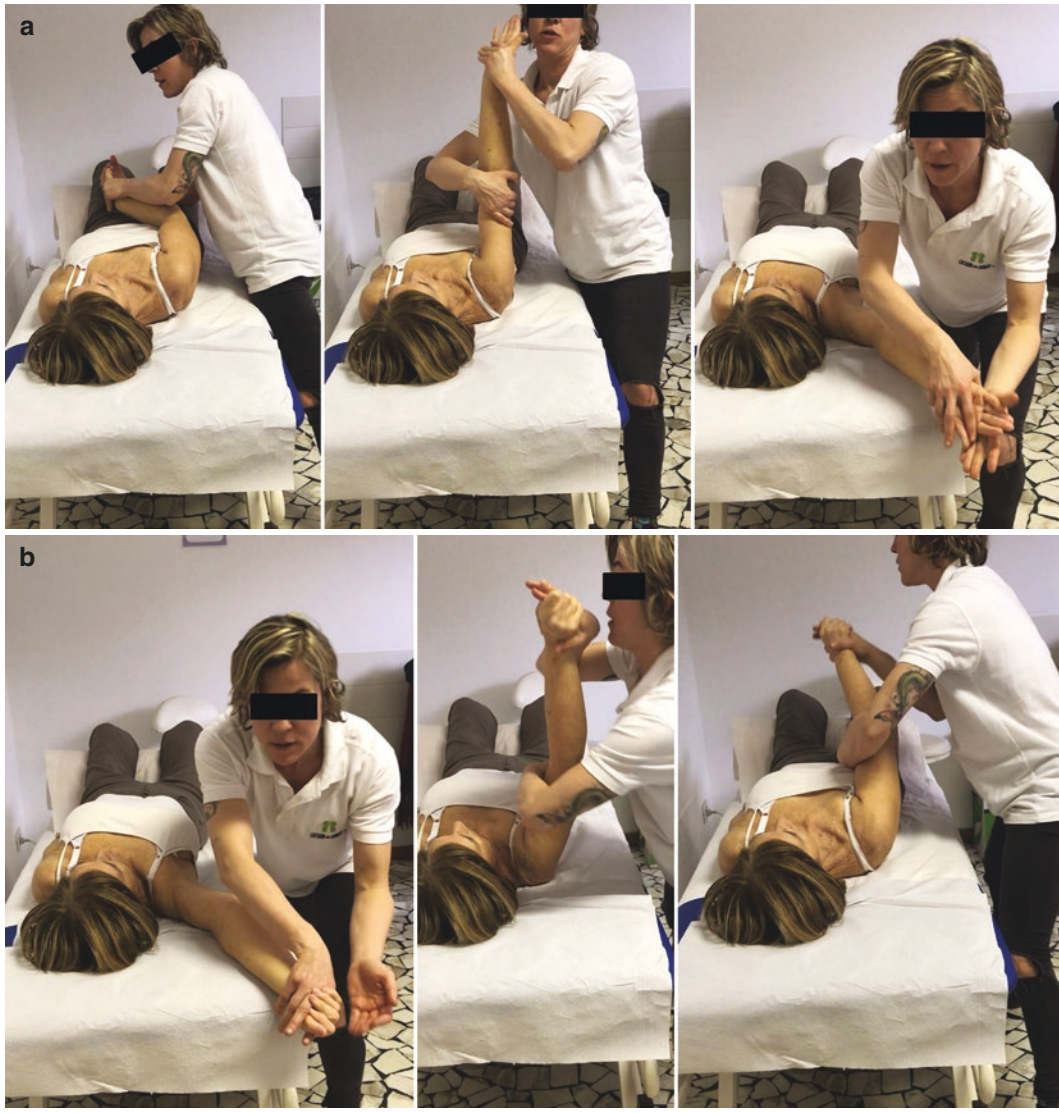

Fig. 29.16 (**a**, **b**) Proprioceptive neuromuscular facilitation method (PNF) applicated to the elbow in a diagonal pattern

We can change exercise intensity even varying the execution speed: at higher velocity indeed, forces acting upon the joint are reduced.

In patients with unlinked prosthesis, active extension-supination strength exercises have to be avoided during the muscular strengthening phase because they could induce a prosthesis subluxation.

What has to be always clear to the patient and to the therapist is that a vigorous strengthening program is never appropriate following total elbow arthroplasty because we have to avoid doing too much too quickly!

The last goal of the rehabilitation program is the whole upper limb function recovery. To obtain this, apart from recovering all the elbow-connected joints if needed and taking advantage of the therapeutic exercises that promote the interaction of the upper limb with the external world, we have to focus our attention on proprioceptive awakening.

Studies show that proprioception in elbows after total arthroplasty was significantly compromised compared with the contralateral side and a healthy population [16].

Patients who have undergone arthroplasty present with high movement perception latency at the joint. Probably it depends on capsule and ligaments sectioning and on the modification of soft tissue tensioning caused by surgery reconstruction, fibrosis, and mechanical load absorption by the hinge of the prosthesis which compromise the recruitment of residual receptors [17].

Therefore perceptive and proprioceptive stabilizing exercises have greater sense of being proposed if the patient has an unlinked prosthetic implant. Proprioceptive rehabilitation starts when the elbow reaches a wide and not painful motion. Exercises are done in traction, suspension, and compression using either closed or open kinetic chain (CKC and OKC); difficulty of the exercises increases progressively as well as tools instability.

Perceptive and proprioceptive work is completed with postural realignment, performed according to global techniques and associated to respiratory control to recover the core stability.

When "formal" rehabilitation is considered finished, patients are discharged from the rehabilitation service with a home exercise program to perform 2–3 times per week focused on maintaining a pain-free arc of motion and a good strength and efficiency of the entire upper limb.

Whenever possible, we use hydrotherapy from the moment the wound is completely healed up until the last phases of the program. With the qualified staff support, we can successfully reach a lot of treatment aims [18].

Water therapist can assist the patient with passive mobilizations of the elbow while avoiding any compensatory movement onset in the other joints (Fig. 29.17).

To gain ROM and to perform symmetric stretching or muscle reinforcement exercises, use of sticks is very useful and effective (Fig. 29.18): the healthy limb is used to facilitate the movement of the operated one in all plans of the space. Gloves, paddles and speed change exercises are responsible for both a facilitated (Fig. 29.19a) and a contrasted (Fig. 29.19b, c) work inducing a variable and accommodating resistance by water and allowing an alternating activation of the agonists and antagonist muscles of the limb. Using tables or tubes is possible to carry out a lot of proprioceptive exercises (Fig. 29.20).

Moreover, the fact that the exercises are carried out in a more amusing environment should not be underestimated. Furthermore, water facilitates movement making some gestures that are not possible or too difficult in the air environment, simpler. It is a motivational stimulus that greatly enhances the patient compliance, and this is very useful for rehabilitation purposes.

Specific and age-appropriate sports will be selected on the basis of the patient desires; among the recommended sports are yoga and oriental disciplines, gymnastics in water, and dance (see Sect. 29.2).

Finally, occupational therapy can be a great help to encourage the people's ability in the daily life activities, social integration, and personal satisfaction.

Fig. 29.17 Therapist assists the patient with passive mobilizations of the elbow using his own body and pool walls to avoid compensatory movement of other joints

Fig. 29.18 Example of stick use to reinforce pronation and supination muscles

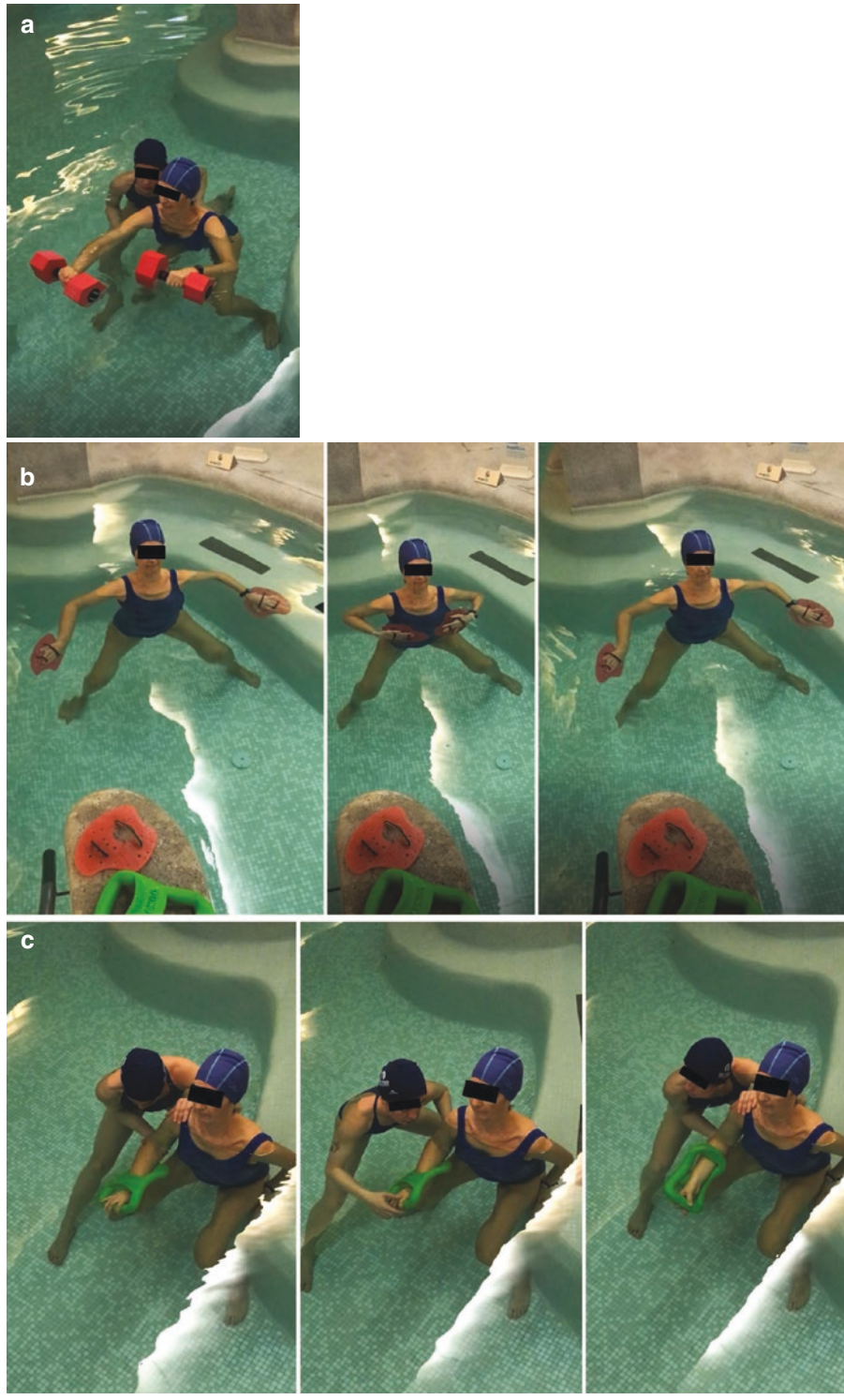

Fig. 29.19 (**a**–**c**) Use of floating dumbbells to facilitate the elbow flexion-extension movement recovery (**a**), paddles use to reinforce simultaneously both the pronator-supinator and the flexor-extensor muscles of the elbow in protected modality using low speeds (**b**), tool to perform a pronation-supination contrasted movement

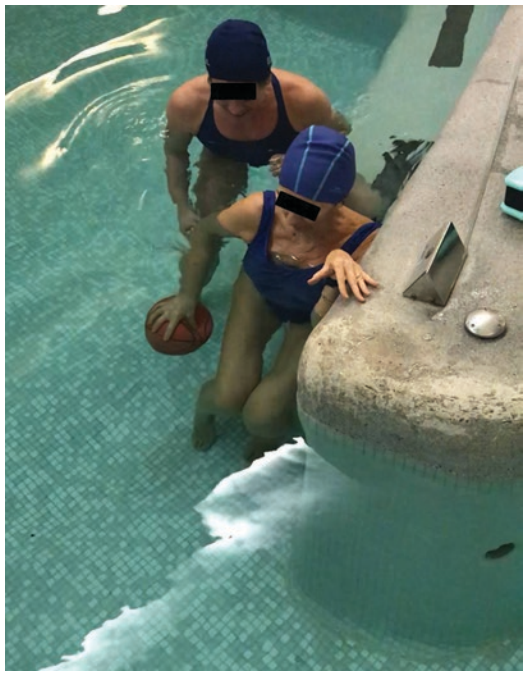

Fig. 29.20 Example of proprioceptive exercise using a common basketball

29.2 Conclusions

Total elbow replacement is a surgical procedure to replace the elbow joint's damaged surfaces to relieve pain and disability caused by severe degenerative problems or particular fracture patterns above all in elderly patients with low physical demands to improve function and, therefore, quality of life.

This procedure is not for everyone; in fact it's contraindicated for patients who are unable or unwilling to comply with postoperative activity restrictions and, in general, should be avoided in younger patients: the success and rate of patient's recovery highly depend on their commitment and adherence to the physiotherapy program. The latter plays a rather important role to reach the goal for which the prosthesis was implanted.

To plan a good and effective rehabilitation program, communication between surgeon, physiatrist, therapist, and the patient is fundamental because patient management will vary depending on a lot of variables (type of implant, management of the triceps and collateral ligaments, status of ulnar nerve, and overall elbow stability assessed during surgery) that is imperative to know.

Rehabilitator role is important not only for the hands-on treatments that are limited in this type of surgery or to teach exercises but above all to provide education to patients. Among these indications, there are also precautions and functional restrictions that the patient has to know and respect for all his future life.

First of all it must be clear to the patient that he will never lift more than 2 kg weights with the operated limb and therefore he will also be proscribed heavy labor or that usual ADL that may put the prosthesis at risk of loosening. This is the reason why other procedures requiring the subsequent use of crutches has to be discussed seriously. Patients have to remember an appropriate antibiotic prophylaxis whenever he needs to undergo further surgery even minors.

The concept of sport in our opinion has to be very restricted: we prefer to talk about recreational activities rather than real sports with patients.

So we recommend soft gym but never with weights nor with "quadruped" positions to be kept, preferring swimming or water gym. In fact, remember that the group gymnastics courses that gyms often offer, even those so-called sweet for the elderly, are actually designed for healthy people and therefore may not be appropriate for our patients, however sweet they may be!

Patient should avoid vibratory or wrenching-type movements (e.g., hammering) as these may loosen the joint with time.

However, we also have to remember that, despite our repeated recommendations, often the patient will lead his life as he wants and then the real limits of these prostheses are not so clear nowadays!

Let's teach the patient to always listen to his symptoms: if a particular movement or activity causes pain, there is usually a reason for it!

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30 Mobilization Under Anaesthesia in Stiff Prosthetic Elbow: Is It Still an Option?

Paolo R. Rolla and Tony Mangano

30.1 Introduction

Despite worldwide accepted as a useful and safe technique in the management of a stiff knee after partial or total arthroplasty [1], mobilization under anaesthesia (MUA) is not currently considered as a therapeutic option in case of stiffness after arthroplasty in other anatomical districts. And this is especially true when dealing with elbow arthroplasty, where the risk of iatrogenic damages could easily overcome the benefits eventually deriving from the procedure.

Referring to the normal biomechanics of the joint, elbow stiffness is defined as a pathologic condition associated with functional arc of flexion-extension less than 100° and forearm rotation less than 100° [2]. It represents a well-noted postoperative complication after elbow arthroplasty, in the setting of radial head reconstruction and both partial and total elbow substitution. If heterotopic ossifications and soft tissue retraction could be involved to some extent in the etiopathogenesis of this condition, issues specifically related to the implant itself should always be taken into account as well, in the diagnostic and therapeutic work-up.

30.2 Prevention of Postoperative Elbow Stiffness

When dealing with complications after radial head prosthesis, elbow stiffness is frequently described in the literature, giving reason of more than 35% of all the causes of failure and/or reintervention [3, 4]. Duckworth et al. described 29 out of 105 cases of revision. The causes of revision were identified as follows: stiffness (12 cases), painful loosening (5 cases), isolated pain (4 cases), subluxation (3 cases), synovitis (2 cases), ulnar neuropathy (2 cases) and infection (1 case) [3]. Ha et al. [5] described radiographic causes of failures in 62 out of 258 implants: heterotopic ossification (53.2%), stiffness or pain due to tension and thickening of the synovial or capsular tissue (43.5%) and infection (3.2%). Oversizing the prosthetic radial head as well as overstuffing the joint with excessive lengthening of the radius could contribute to the onset of pain and stiffness in the postoperative period: such technical errors are actually recognized as the first cause of failure and implant revision after radial head replacement in the published series [6]. Attention should be paid by the operators to the surgical technique, and few surgical key

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points should be kept in mind when dealing with radial head replacement:

- A correct sizing of the prosthetic radial head (i.e., a smaller size with respect to the removed radial head).
- A correct placing of the implant (i.e., achieving a good match between the height of the prosthetic head and the sigmoid notch of the ulna).
- The check and eventual recovery of the integrity of the radial ligamentous complex.
- The adequate dimensioning of the prosthetic stem in order to achieve a good primary stability.

Of note, the full respect of these technical criteria is useful to avoid the above-mentioned complications and can lower the revision rate of radial head replacement to 10% or less also in the medium- to long-term follow-up [7].

Similarly, in the setting of distal humeral hemiarthroplasty (DHH) and total elbow arthroplasty (TEA), motion restrictions should be prevented as possible with a correct surgical technique, dealing with both implant positioning and soft tissue management [8, 9]. Despite this complication is described in the published series, it is generally reported as a low-frequency complication. In the systematic review from Dunn and coworkers [8], results and complications were described about 133 patients receiving DHH for fracture (116) and non-fracture (17) diagnosis. Eighty-five patients in the fracture group and seven patients in the non-fracture group experienced at least one complication. Postoperative elbow stiffness gave reason of 5.9% and 54.6% of complications in the fracture group and in the non-fracture group, respectively. Of note, rheumatoid arthritis (RA) accounted for 59% of cases of non-fracture use of DHH, and cases of elbow ankylosis (haemophilia-related in at least one case) accounted for 12%. Reconstruction after tumour resection and osteomyelitis represented the remaining preoperative diagnoses in this group. The authors conclude that while most patients undergoing DHH for non-fracture indications have tolerable functional results, most of the patients do not gain functional range of motion. In this group, patients reached an average 62° of flexion-extension and 117° prono-supination. Both of these were significantly less than the fracture cohort ($p < 0.005$). They hypothesize that both inability to complete physical therapy because of secondary medical comorbidities and severe preoperative restrictions of range of motion such as in ankylosis cases may contribute to this finding.

In a comprehensive review of the literature upon series of linked and unlinked TEA published between 1993 and 2009, Voloshin and coworkers [9] did not find elbow stiffness to be present between the commonly reported complications. However, in a more recent work, the same authors take into account this problem and state that cases with preoperative substantial motion restriction, as often seen in rheumatoid patients and/or preoperative ankylosis cases, should be considered at risk for postoperative stiffness after total elbow arthroplasty [10]. In such cases, an aggressive capsular resection is warmly suggested at the time of the implantation and a sufficient depth of insertion as well. The trial reduction is essential in order to identify and avoid the potential problem. Finally, a static adjustable splint is suggested by several authors to be used in the early postoperative period in order to gain and maintain motion, together with a pharmacologic prophylaxis against heterotopic bone formation.

30.3 Treatment of Postoperative Elbow Stiffness

Due to the complexity of the problem and the multiplicity of possible causes, cases of postoperative elbow stiffness after arthroplasty should be managed through a complete diagnostic work-up, followed by a therapeutic programme involving the medical or surgical treatment of the eventually identified causal factors. The main risks deriving from the MUA procedure encompass prosthetic mobilization, periprosthetic fractures and peripheral nerve damages, i.e., the same complications most commonly described in the published series, especially in case of partial or total elbow arthroplasty [9]. The above mentionned are major com-

plications this kind of prosthetic implant is commonly prone to, despite some improvements in prosthetic design, materials and surgical technique. In particular, when considering loosening after TEA, it is of note the improvement semiconstrained implants (i.e., including some play or laxity at the bushing) represented with respect to linked implants. Furthermore, the anterior flange of the Mayo-modified Coonrad device absorbs the load applied to the humerus, thus limiting stresses on the prosthesis-cement-bone interfaces: this is a key issue, when considering the resultant force vector is up to three times body weight during dynamic flexion and extension at the elbow [10]. Together with improvements in the cementing technique, all these factors coworked in lowering the rate of loosening of TEA, especially on the humeral component side. The ulnar component still represents the weak side of the implant, both due to small dimension and complex fixation. The MUA procedure could easily exert a sort of "extractor effect" on this prosthetic component and majorly on the forced extension, finally determining its mobilization (Fig. 30.1).

Fig. 30.1 (**a**) Semiconstrained TEA: the ulnar component is smaller with respect to the humeral one and lacks a stress dispersion system similar to the anterior flange of the humeral component; the ulnar component fixation represents the weak side of the implant. (**b**) Simulation of semiconstrained TEA implantation with plastic tubes. (**c**) Forced flexion with an anterior elastic element at the level of the hinge, with final *extractor effect* on the prosthetic components. (**d**) Forced extension with a posterior elastic element at the level of the hinge, with possible olecranic impingement and final *extractor effect*, mainly exerted on the ulnar prosthetic component

Despite the literature is lacking of works directly dealing with MUA in case of postoperative prosthetic elbow stiffness, the risk of the above-mentioned complications is not able to justify nor counterbalance, in our mind, the eventual gain of few degrees of range of motion.

A common sense-driven guideline should be taken into account both in case of radial head replacement and DHH or TEA:

- In patients with elbow stiffness after a technically incorrect prosthetic surgical treatment, a revision surgery should be immediately scheduled, in order to fix the error through implant exchange.
- In patients with elbow stiffness after a technically correct prosthetic surgical treatment, we suggest, as a first-line approach, to modify the rehabilitation programme with more active assisted exercises addressed at relaxing the antagonist muscles with the active isotonic contraction of the agonist muscles. If the patient has no contraindication, it is helpful a further oral therapy with prednisone (25 mg/day for 10 days, followed by 20 days at 12.5 mg/day).
- In cases with persistent stiff elbow after a correct radial head replacement and failure of the conservative approach, we suggest to perform an arthroscopic debridement and arthrolysis, always associated with mini-open ulnar neurolysis.
- In cases with persistent stiff elbow after a correct DHH or TEA and failure of the conservative approach, an open surgical revision should be considered, addressed to extensive periarticular soft tissue release and eventual heterotopic bone removal.

In conclusion, mobilization under anaesthesia should not be considered a still standing option in case of postoperative prosthetic elbow stiffness. The eventual risks of the procedure, and mainly the forced component mobilization through the *extractor effect*, do not counterbalance the possible benefits. A surgical revision is needed in case of incorrect or correct prosthetic implant with persistent stiffness after conservative treatment, and surgery should be strictly addressed at the causal factors. Surgeons should be aware of the possible causes of elbow stiffness after radial head replacement or DHH or TEA, and all the efforts for prevention of the problem are warmly recommended.

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