4 Design Considerations in Radial Head Arthroplasty

Shawn W. O'Driscoll

Outline

In this chapter, we will study three sets of issues that affect design considerations for radial head arthroplasty:

1. *Functional anatomy and biomechanics of the radial head*
2. *The prosthesis*
3. *Instruments and technique*

Functional Anatomy and Biomechanics of the Radial Head

The radial head plays an important role in axial load bearing across the elbow as well as being an important constraint to valgus instability [1–5]. The radial head bears approximately 60% of the axial load across the elbow; however, the effect of forearm rotation has been controversial with different methods having found different results [1, 4].

Radial head excision shortens the moment arm resisting valgus torque on the elbow and therefore concentrates stressors on the lateral ulnohumeral joint and increases stress in the medial collateral ligament as shown in Fig. 4.1. This eventually leads to erosion of the bone in the lateral ulnohumeral joint as shown in Fig. 4.2. Multiple studies have shown that radial head excision substantially alters elbow kinematics, load bearing, and articular contact stressors [6–13]. Long-term studies after radial head excision document radiographic changes of arthritis, bone loss in the lateral ulnohumeral joint, and valgus drift (pseudolaxity) due to that bone loss [8]. Whether or not these long-term changes can be prevented by radial head replacement is not known yet, but biomechanical studies of radial head arthroplasty show that these disturbances in elbow kinematics, laxity, and load bearing can be corrected or prevented by prosthetic radial head replacement [7, 14, 15]. These biomechanical and clinical factors render a compelling argument in favor of radial head replacement, provided that the long-term safety and efficacy of this type of arthroplasty can be confirmed.

The three-dimensional shape and orientation of the radial head have a number of unique features. The radial head is elliptical in shape, not round, and is offset from the axis of rotation of the forearm such that there is a cam effect during rotation of the radial head. The radial head is also tilted (angulated) with respect to the neck of the radius. This is to accommodate a change in alignment of the long axis of the radius that occurs

S. W. O'Driscoll (✉)
Department of Orthopedic Surgery, Mayo Clinic and Mayo Foundation, Rochester, MN, USA
e-mail: odriscoll.shawn@mayo.edu

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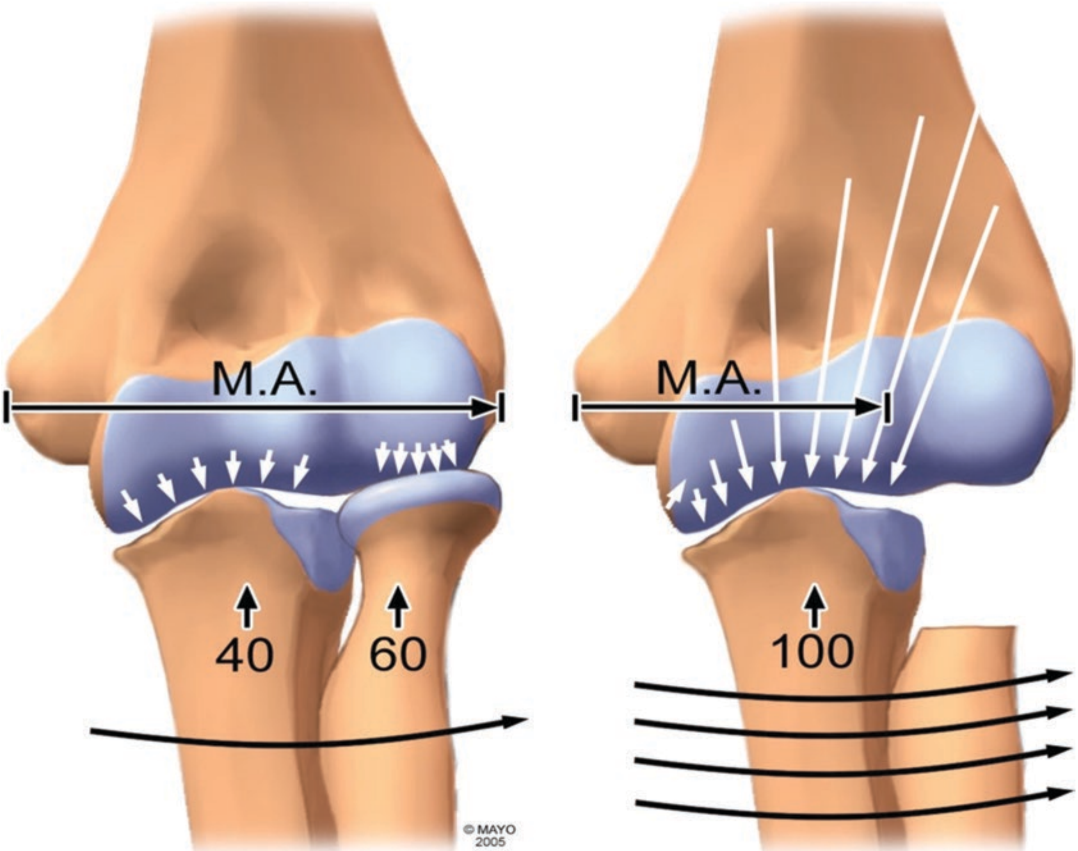

Fig. 4.1 Radial head excision increases valgus torque on the elbow due to the shortened moment arm. This increases joint surface contact pressures in the lateral ulnohumeral joint and stress in the medial collateral ligament. (By permission of Mayo Foundation for Medical Education and Research (https://www.mayoclinic.org/copyright).

during forearm rotation. As the distal radius crosses over the ulna at the wrist during pronation, the valgus alignment of the radius with respect to the humerus decreases. In other words, the radius does not rotate about its online axis, but rather about a long axis that passes through the radial head proximally and the ulna distally. The resulting crossover type of motion creates a windshield wiper motion of the radial head on the capitellum with forearm rotation.

As we consider these various anatomic, biomechanical, and functional aspects of the radial head, design specifications must take into consideration the needs for the radial head to [1] bear load, [2] articulate correctly, and/or [3] compensate for incorrect articulation. In theory, achievement of the first two design specifications would require a prosthetic radial head to be designed anatomically and positioned correctly by the surgeon. If this was thought not to be possible or feasible, then specification number 3 might be accomplished a number of different ways. For example, constraint within the prosthesis itself can be decreased through the use of a bipolar articulation. Constraint at the prosthetic-bone interface can be decreased with loose-fitting smooth stems. Finally, constraint at the prosthetic-joint surface interface can be reduced by altered shape (geometry) of the head itself.

Fig. 4.2 Increased valgus stress eventually leads to erosion of the bone in the lateral ulnohumeral joint. (By permission of Mayo Foundation for Medical Education and Research (https://www.mayoclinic.org/copyright). All rights reserved)

Design Considerations of the Prosthesis

Design considerations relating to the prosthesis itself can be grouped into three categories:

- The head
- The stem
- The head-stem connection

The Head

The head is the most obvious critical part of the prosthesis, since it articulates with the capitellum and ulna. Three features of the head are important or potentially important design considerations:

- Shape
- Position and orientation in 3-D space
- Material

Shape of the Radial Head

Since the prosthetic radial head will articulate with the capitellum, lateral trochlear ridge, and radial notch of the ulna, the ideal shape of the prosthetic head would either replicate native anatomy or be designed to compensate for any potential deleterious effects resulting from differences in shape. In this section we will focus on native radial head, which has been studied on cadaveric elbows, MRI images, and CT scans [16–19].

In the majority of native elbows, the outer surface of the radial head is asymmetrical in shape, representing an oval (or an ellipse) more than a circle (Fig. 4.3). King et al. measured cadaveric radial heads and found that the main difference between the maximum and minimum outer diameters (i.e., long axis vs. short axis) was 2 mm, ranging from 0 to 3 mm [16]. In other words, the radial head is not generally round, but it can be for those at one end of the spectrum.

The portion of the radial head that articulates with the capitellum is referred to as the "articular dish" (Fig. 4.3). The articular dish is generally round and symmetrical, but offset anterolaterally along the long axis of the radial head when the forearm is positioned in neutral rotation. This results in a cam effect such that the articular dish moves laterally and medially on the capitellum during forearm rotation [14]. The articular dish has an average depth of 2.3–2.4 mm, depending on the diameter of the head [16, 17]. The depth of a radial head prosthesis is a very important parameter, as it affects radiocapitellar contact area and peak stresses [20]. The depth of the prosthetic articular dish should probably be within 0.5 mm of that of the native radial head.

The radial head is also tilted (angulated) with respect to the neck of the radius. This is to accommodate a change in alignment of the long axis of the radius that occurs during the forearm rotation. As the distal radius crosses over the ulna at the wrist during pronation, the valgus alignment of

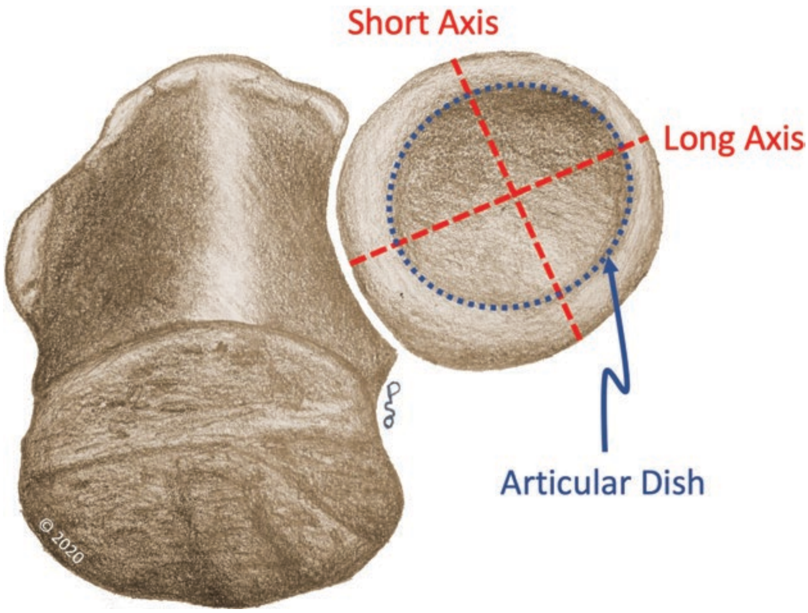

Fig. 4.3 The native radial head is oval, with maximum and minimum outer diameters (i.e., long axis vs. short axis) that differ by about 2 mm. (By permission of Pierre S. O'Driscoll. All rights reserved)

the radius with respect to the humerus decreases. In other words, the radius does not rotate about its online access, but rather about a long axis that passes through the radial head proximally and the ulna distally. The resulting crossover type of motion creates a windshield wiper motion of the radial head on the capitellum.

To this point we have focused on geometric parameters describing the overall shape of the radial head (Fig. 4.4). There are several more aspects that relate to the surface contours specifically that are relevant to prosthetic design. We already described the fact that the articular dish is offset anterolaterally along the long axis of the radial head. A close look at the surface of the radial head will reveal two things about the rim, which forms the transition from the articular dish to the side of the radial head. First, it is broad posteromedially and narrow anterolaterally. The broad crescent-shaped rim posteromedially has a variable radius of curvature that articulates with the lateral trochlear ridge of the humerus and is an important load-bearing structure. In fact, load bearing in this region functions much like a "truss effect," the way a roof truss bears the load of a roof (Fig. 4.5). Radial head prostheses vary greatly in the extent to which they mimic this aspect of the articulation (Fig. 4.6) [14].

The second feature of the rim of the radial head to notice is that it is not generally in a single plane but undulates up and down (Fig. 4.7). These undulations are not symmetrical. This is quite noticeable during elbow arthroscopy while observing the rim calculating against the capitellum during pronation/supination. Although the functional importance of this feature has not yet been clarified, it likely confers some degree of optimization of either radiocapitellar contact or radiocapitellar stability, or a combination of the two.

Position and Orientation of the Radial Head in 3-D Space

The radial head is offset from the axis of the intramedullary cavity of the radial neck as well as from the axis of rotation of the forearm such that there is a cam effect during rotation of the radial head. The radial head is also tilted (angulated) with respect to the neck of the radius. Replicating the position and orientation of the native radial head with a prosthetic radial head requires precisely defining the intramedullary axis of the neck (or proximal shaft in the case of a long-stem prosthesis) and the orientation and position of the head with respect to that axis. That could be done mechanically as illustrated

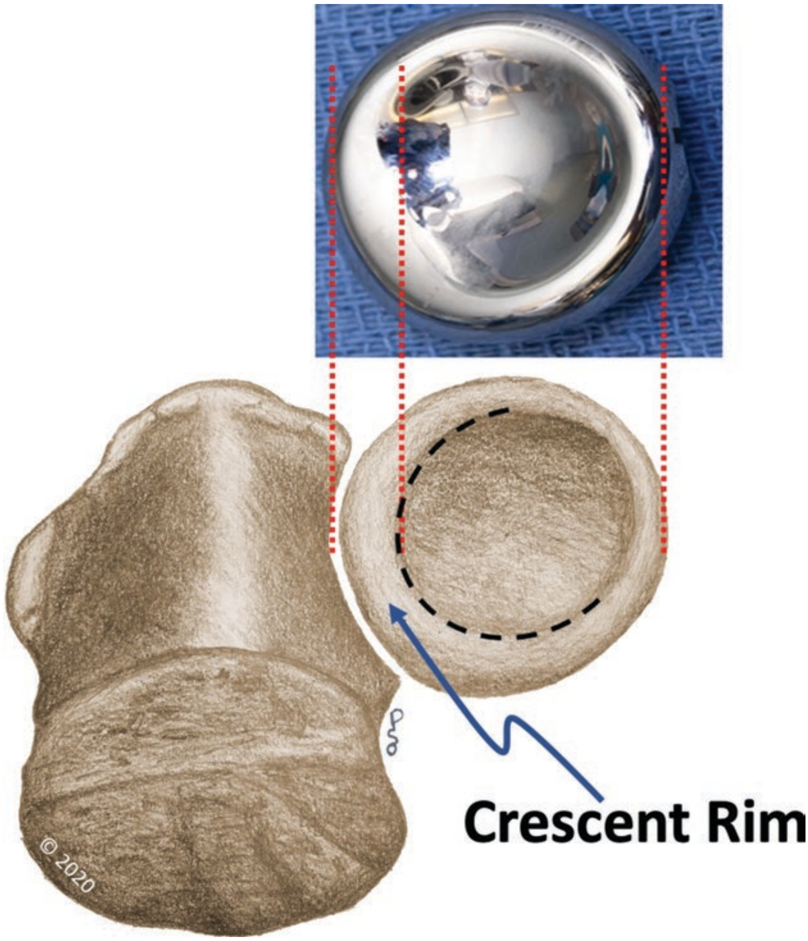

Fig. 4.4 The articular dish is offset anterolaterally along the long axis of the radial head. The broad crescent-shaped rim posteromedially has a variable radius of curvature that articulates with the lateral trochlear ridge of the humerus and is an important load-bearing structure. (By permission of Pierre S. O'Driscoll. All rights reserved)

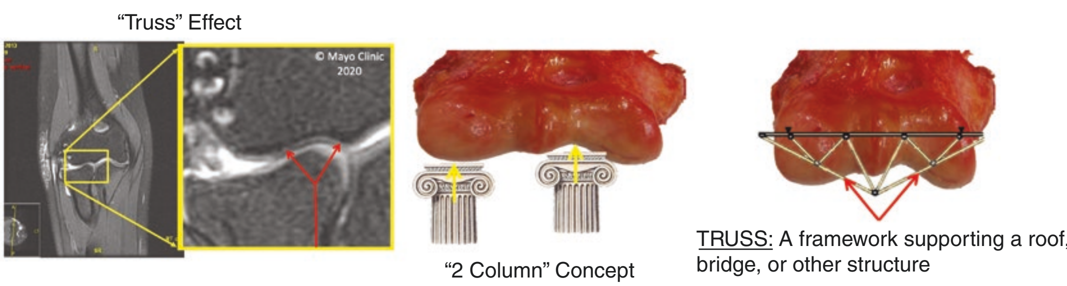

Fig. 4.5 The load bearing in the broad crescent-shaped rim of the posteromedial radial head that articulates with the lateral trochlear ridge has a "truss" effect in the way it bears load – the way a roof truss bears the load of a roof. (By permission of Mayo Foundation for Medical Education and Research (https://www.mayoclinic.org/copyright). All rights reserved)

in Fig. 4.8, in which the intramedullary canal was reamed to determine its central axis. The angle between that intramedullary rod and a rigid plexiglass sheet fitted onto the rim of the head can be used to determine the head/neck angle. A long-stem prosthesis going into the radial shaft is more complex to design. For determining the spatial relationship between the

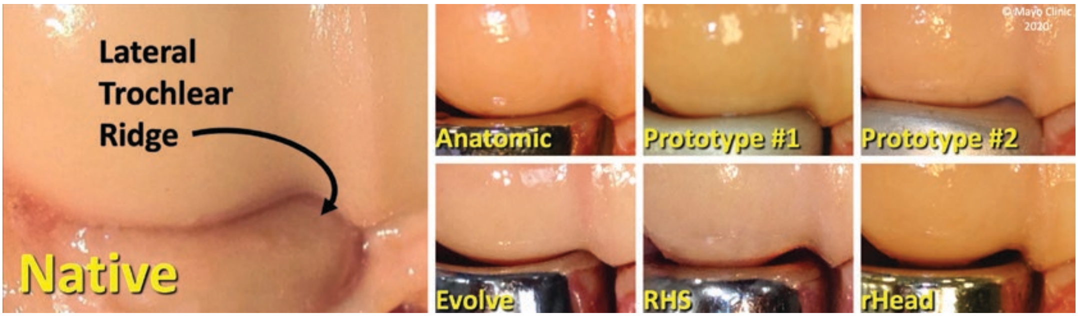

Fig. 4.6 Radial head prostheses vary greatly in the extent to which they mimic the crescent rim that articulates with the lateral trochlear ridge (LTR). (By permission of Mayo Foundation for Medical Education and Research (https://www.mayoclinic.org/copyright). All rights reserved)

Fig. 4.7 The rim of the radial head goes up and down, not lying in a single plane. (By permission of Mayo Foundation for Medical Education and Research (https://www.mayoclinic.org/copyright). All rights reserved)

head and intramedullary axis of the shaft of the radius, the engineering concept of a free body diagram is a valuable tool.

Getting the position and orientation of the head in 3-D space correct is important because incorrect placement will cause edge loading and therefore increased stress on the capitellar articular cartilage and subchondral bone. Additionally, increased or abnormal translational movement of the prosthesis across the capitellum will exacerbate any such wear.

The Material

A discussion of the prosthetic material is included in the section related to the design of the head itself, although it is relevant to the stem as well. Various materials that have been employed in commercially available radial head prosthesis can be grouped according to whether they are nonmetallic or metallic. Nonmetallic materials have included silastic (silicone), PMMA (polymethyl methacrylate), and pyrocarbon. Metallic processes have been made of titanium, stainless steel, cobalt-chrome, or combination of titanium and cobalt-chrome.

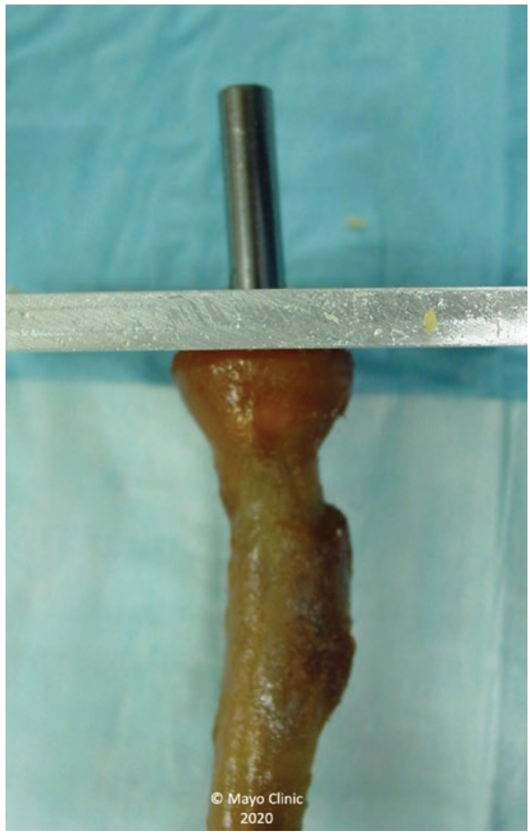

Fig. 4.8 The radial head/neck junction is angulated in two planes. (By permission of Mayo Foundation for Medical Education and Research (https://www.mayoclinic.org/copyright). All rights reserved)

Silastic has fallen out of favor because of the potential for erosive destructive silicone synovitis that can occur over 2–3 decades as the soft silicone material breaks down and causes an inflammatory reaction in the synovium. PMMA use is not FDA approved for this use in the USA but has limited use in Europe. Pyrocarbon has lower hardness and stiffness compared to metal, which might confer a theoretical benefit with respect to decreasing cartilage wear on the distal humerus. That said, pyrocarbon is still orders of magnitude stiffer than native articular cartilage; any potential advantage of pyrocarbon over metal would almost certainly be less than the deleterious effects of poor radiocapitellar contact due to the shape or the orientation/position of the radial head. Marked increases in contact stresses that are known to be dangerous to articular cartilage and capable of eroding the subchondral bone can be expected with certain deviations from anatomic shape or orientation/position of the radial head.

Metallic radial heads currently in use generally have a cobalt-chrome head component. Solid titanium has been used in the past, but it has generally been realized that titanium is not a good bearing surface due to the possibility of developing titanium particulate debris and the associated osteolysis and soft tissue reaction.

The Stem

The three main features related to the stem are:

- Fixed vs. loose-fitting (and cemented vs. uncemented if fixed)
- Length
- Shape

Fixed Versus Loose-Fitting

Stems are either fixed or loose-fitting. Fixed stems can be either cemented or press-fitted for bone ingrowth. Fixed stems for bone ingrowth are made of titanium and have a porous surface that is plasma sprayed or grit-blasted, although other options may become available in the future such as coating with titanium beads, hydroxyapatite, or porous metal such as tantalum. Stems designed for cemented use are not porous coated although some surgeons prefer to cement non-cemented stem designs, hoping to diminish problems of loosening.

Loose-fitting stems are generally undersized, with the hope that leaving a little bit of mobility of the stem inside the canal might compensate for any incorrect articulation of the head against the capitellum [21]. Loose-fitting stems are smooth, are polished, and made from cobalt-chrome or stainless steel, to diminish the shedding of metal particles that can cause metallosis and osteolysis. They should not be made from titanium, as titanium particles cause more biologic reaction than cobalt-chrome or stainless steel.

Each of these design concepts has advantages and disadvantages. Porous-coated stems that achieve bone ingrowth will likely remain stable over decades. However, failure of bone ingrowth with loosening and osteolysis is being reported much more commonly than I have experienced, and it is a very real clinical concern. The reasons for this are not yet completely clear. One factor is that bone ingrowth requires a very tight initial press fit with less than 100–200 microns of micromotion, which means that the radial canal must be carefully prepared and the prosthesis hammered into the bone [22]. Surgeons have concern about fracturing the radius, especially if the neck is comminuted, and therefore may be hesitant to insert a big enough stem. Fortunately, single, non-propagating hoop-stress fractures do not affect press-fit stability of porous titanium stems [23]. Nevertheless, fear of fracturing the radial neck does lead some surgeons to choose a suboptimal stem diameter, which may lead to loosening, pain, and osteolysis from titanium debris. Pain in the proximal radial forearm is pathognomonic for a loose prosthetic radial stem (Fig. 4.9).

To prevent loosening, some choose to cement the stem. If ingrowth does occur, stress shielding commonly occurs. Bone loss from stress shielding can be distinguished from that due to loosening, since stress shielding causes periosteal bone loss whereas loosening causes endosteal bone loss as seen in Fig. 4.10 [24]. One potential option to diminish stress shielding is to limit the porous texture to the proximal portion of the

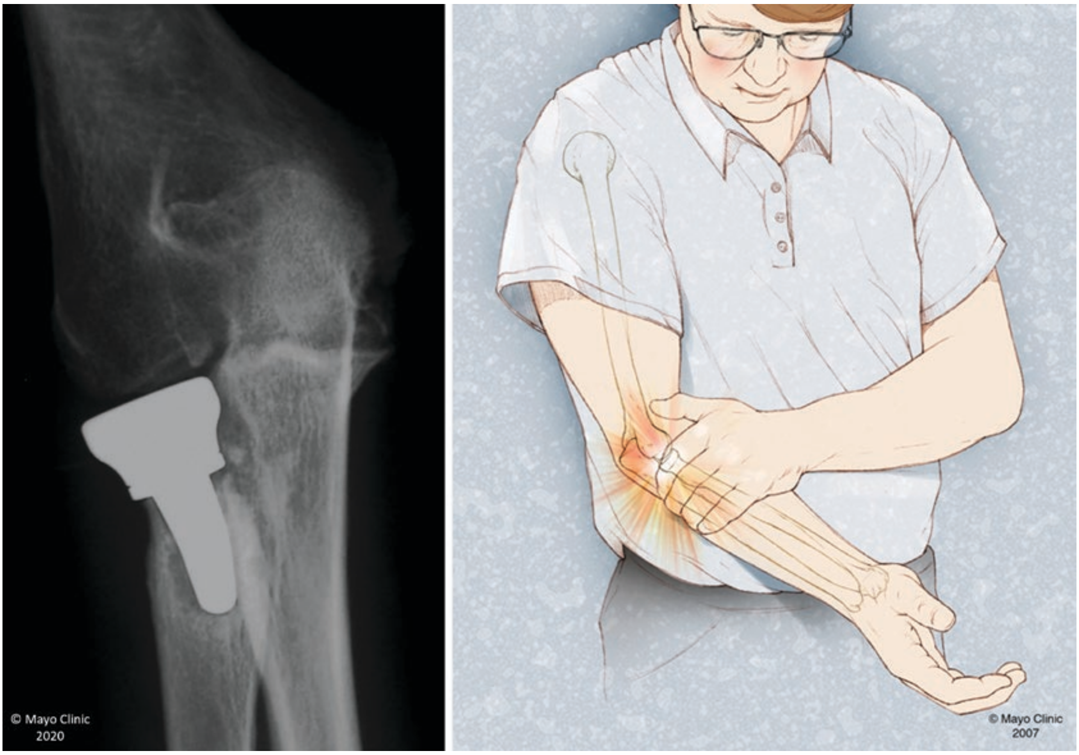

Fig. 4.9 Pain in the proximal radial forearm is pathognomonic for a loose prosthetic radial stem. (By permission of Mayo Foundation for Medical Education and Research (https://www.mayoclinic.org/copyright). All rights reserved)

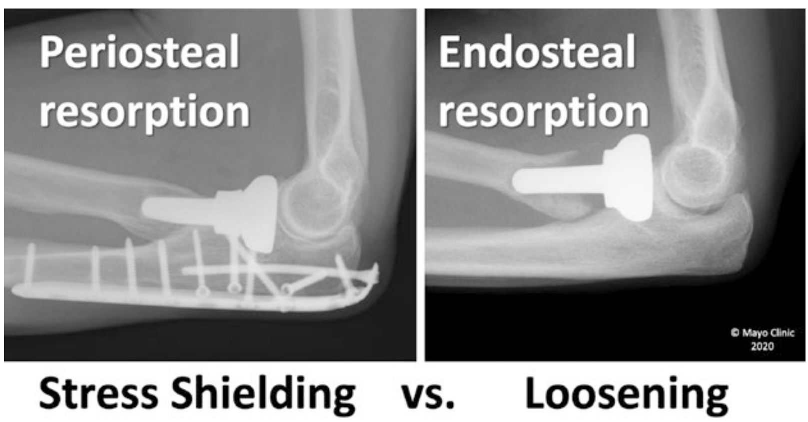

Fig. 4.10 Bone loss from stress shielding causes periosteal bone loss, whereas loosening causes endosteal bone loss. (By permission of Mayo Foundation for Medical Education and Research (https://www.mayoclinic.org/copyright). All rights reserved)

stem. Doing so with grit-blasted stems does not seem to affect initial micromotion of the stem [25]. Future efforts to reduce stress shielding might focus on reducing the stiffness of the implant stem.

Ingrowth titanium stems are available in plasma spray and grit-blasted configurations. It would seem intuitive that a plasma spray surface would have a greater initial press-fit stability than a grit-blasted stem, but one biomechanical study showed no difference in micromotion between the two stem designs [26]. Whether or not there is a clinical difference in successful bone ingrowth is not known. However, removal of a well-fixed

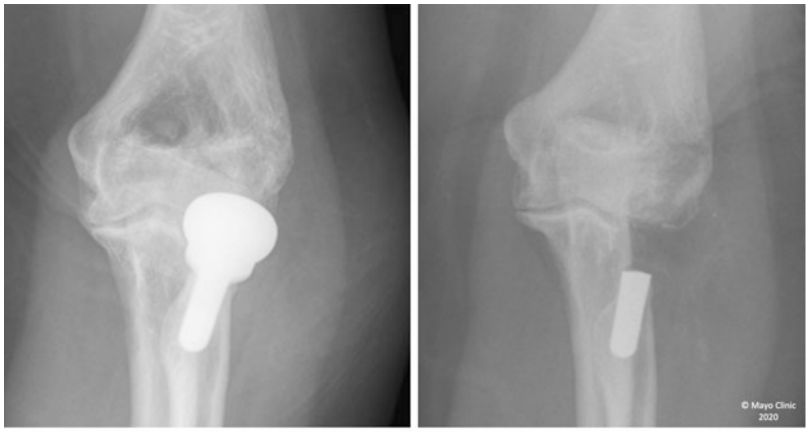

Fig. 4.11 Removal of an ingrown plasma spray stem is difficult and sometimes impossible. In such circumstances, the stem may need to cut with a carbide burr. (By permission of Mayo Foundation for Medical Education and Research (https://www.mayoclinic.org/copyright). All rights reserved)

plasma spray stem is exceedingly difficult and sometimes impossible (Fig. 4.11), whereas ingrowth grit-blasted stems seem to be able to be hammered out of the bone with less difficulty.

Cemented long stems have been reported to have little tendency to loosen, but data for cemented short stems remains limited [27]. The main disadvantage of cemented stems is the possible need to remove the cement in the case of infection or malpositioning. This is very difficult in the proximal radius. Another concern is the potential for osteolysis if the stem loosens.

Loose-fitting stems have the advantage of simplicity of insertion and a theoretical capacity to accommodate for small imperfections in alignment (or shape) of the radial head with respect to the capitellum. The latter has not been proven. However, they have the disadvantage that the stem remains loose and may not be capable of providing the same load transfer to the capitellum as a well-fixed stem. Loose-fitting designs originated as temporary "spacers" implanted into unstable fracture dislocations of the elbow with the intention of removing them once soft tissue (and any other bony) healing had occurred [28, 29]. Due to the fact that removal of the spacer required subluxating the elbow, some surgeons stopped removing them, as they appeared to be well tolerated if left in place [28]. The loose fit is associated with a frequent occurrence of mild (sometimes moderate) proximal radial forearm pain ranging from 1 to 5/10, although removal is not often required. In fact, removal of press-fitted porous stems is reported more commonly than removal of loose-fitting smooth stems, since loose titanium ingrowth stems seem more likely to cause pain and osteolysis. Radiographic follow-up typically reveals endosteal lucencies and tilting of the stem (Fig. 4.12) [30–32].

Whether or not one stem interface with the bone will turn out to be superior to the others is not yet known. Stem fixation of prostheses in other joints has evolved toward a preference for non-cemented porous ingrowth stems. Loose-fitting stems in the hip, shoulder, and knee have essentially disappeared from clinical use.

Stem Length

Stems can be separated into short and long, depending on whether or not the tip of the stem extends distally past the bicipital tuberosity into the shaft of the radius (Fig. 4.13). The reason that this distinction is so important is that the axis of the intramedullary canal of the radial neck does not line up with that of the shaft. Some prosthetic designs have an intermediate stem length. The problem with an intermediate stem length is that the long axis of the stem may not line up with either the intramedullary canal of the neck or the shaft, depending on how long the proximal radius is. Initial stability of a porous-coated, cementless titanium stem is related to the length of the stem

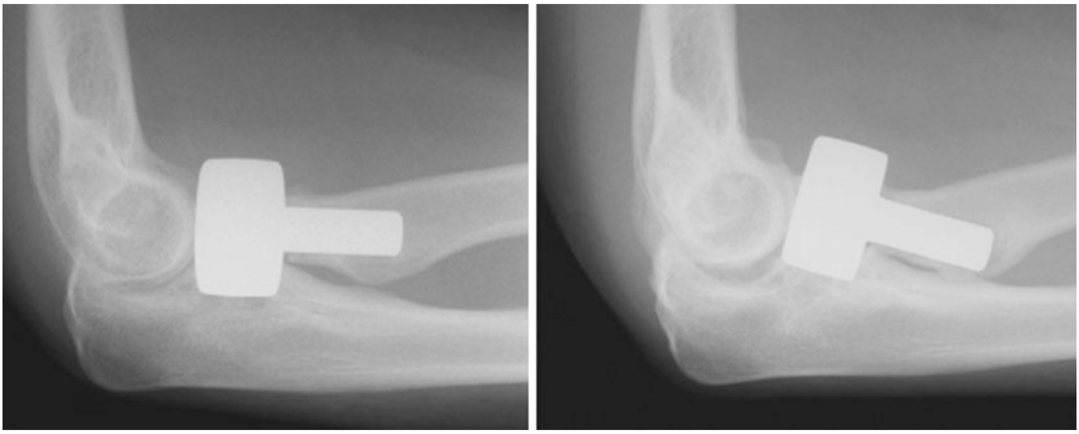

Fig. 4.12 Radiographic lucencies are common with loose-fitting stems, which sometimes tilt in the canal. (Reprinted from O'Driscoll and Herald [45], Copyright 2011, with permission from Elsevier)

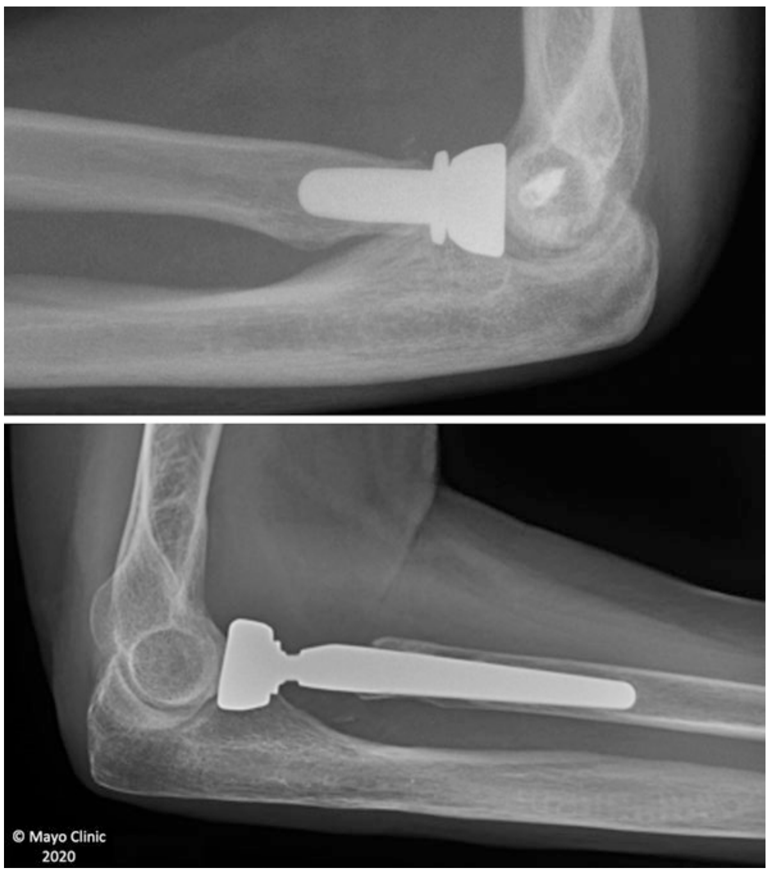

Fig. 4.13 Stems can be short (top) or long (middle), depending on whether or not the tip of the stem extends distally past the bicipital tuberosity into the shaft of the radius. (By permission of Mayo Foundation for Medical Education and Research (https://www.mayoclinic.org/copyright). All rights reserved)

within the bone and the level of the cut (amount of radial neck resected) [33]. The cantilever quotient, defined as the ratio of combined head and neck length to total implant length, must be 0.4 or greater to ensure secure fixation (Fig. 4.14) [34]. As a generality, if the combined head and neck length is 15 mm or less, a short-stem design is appropriate. If the combined head and neck length is 18 mm or more, a long-stem design should be used.

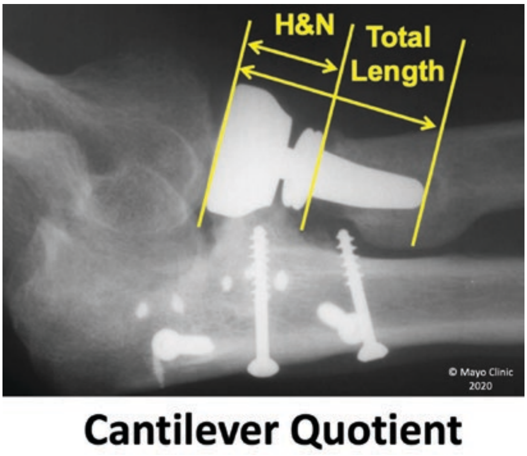

Fig. 4.14 Stability, and therefore the likelihood of bone ingrowth, of a cementless stem is inversely related to cantilever quotient, defined as the ratio of combined head and neck length (*H&N*) to total implant length (*total length*). (By permission of Mayo Foundation for Medical Education and Research (https://www.mayoclinic.org/copyright).

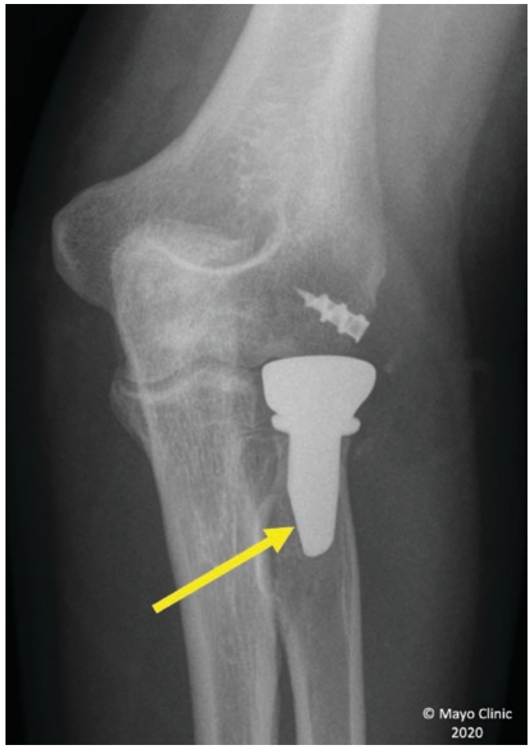

Fig. 4.15 Example of a stem with a beveled tip (arrow), which has two theoretical benefits. (By permission of Mayo Foundation for Medical Education and Research (https://www.mayoclinic.org/copyright).

Stem Shape

As has been found with prosthetic stems in other joints, straight stems are preferable over curved stems. One of the problems with curved stems is that the preparation of the canal must perfectly match the shape and placement of the final component or there will be loosening. High loosening rates preceded withdrawal from the market of a radial head prosthesis which had a curved stem that also was relatively short (high cantilever quotient). No data yet exist to recommend whether the stem should be cylindrical or tapered. The exception would be a long-stem component going down into the shaft, because the intramedullary cavity of the proximal radius has a definite taper to it. Some stems have a bevel near the tip, which has two theoretical benefits (Fig. 4.15). One is that if the stem goes down past the bicipital tuberosity, the bevel might prevent bottoming out on the cortex distal to the tuberosity and fracturing the proximal radius. However, that does not seem to be a clinical problem reported with any stem design. The second theoretical advantage has to do with ease of insertion, but this is not a true advantage because once the non-beveled portion of the stem engages the intramedullary canal of the radial neck, it is mandatory that the stem be lined up with the long axis of the canal. It is not the first half of the stem that is difficult to insert correctly, but the final half of the stem, because it is during that phase when the head must clear the capitellum (assuming the head had been coupled onto the stem prior to insertion). By that point, it's no longer an option to have the stem angulated in the canal. Some designs try to get around this problem by having an in situ mechanism for coupling the head onto the stem, but each of these has its own potential problems as discussed below. Finally, the presence of a bevel might actually have some potential to compromise stem stability and therefore bone ingrowth. This is due to the fact that the broaches and reamers used to prepare the canal do not have a bevel, and therefore they leave a void between a portion of the stem and the bone.

The Head-Stem Connection

Three aspects of the head-stem connection merit consideration:

1. Monopolar vs. bipolar
2. Coupling mechanism
3. Angle(s) and offset(s)

Monopolar Versus Bipolar Connection

Bipolar connections have the theoretical advantage of compensating for any inaccuracies in alignment of the articulating head with the capitellum [35]. However, there are also some disadvantages. The primary disadvantage of a bipolar design is that any translation of the radial head with respect to the capitellum under axial load causes the bipolar component to tilt. As a result, the contribution of concavity compression to radiocapitellar stability is lost when the bipolar head tilts (Fig. 4.16) [36]. This also creates a tendency for the radial head to translate posteriorly with respect to the capitellum and therefore subluxate (Fig. 4.17). This can actually cause chronic attenuation of the lateral collateral ligament complex with tardy posterolateral rotatory instability (PLRI).

A bipolar radial head design has a UHMWPE bearing surface between the head and the stem and therefore has a potential for polyethylene particulate debris which can lead to osteolysis. Since radial head prostheses are generally implanted for trauma and post-traumatic conditions, rather than degenerative or inflammatory arthritis, the patients are often relatively young and high demand. Therefore, a radial head prosthesis should ideally have many decades of longevity. This is a concern for a polyethylene bearing surface.

Additionally, bipolar heads can partially or completely disengage. The mechanism for this disassembly is a force couple caused by an edge-loading compressive force on one side of the bipolar radial head and a distraction force on the other side caused by scar tissue surrounding the bipolar radial head. Complete dissociation requires reoperation. Partial disengagement can occur due to deformation or wear of the polyethylene. When this happens, the repeated partial coupling/uncoupling tends to cause further polyethylene wear and reactive synovitis (Fig. 4.18).

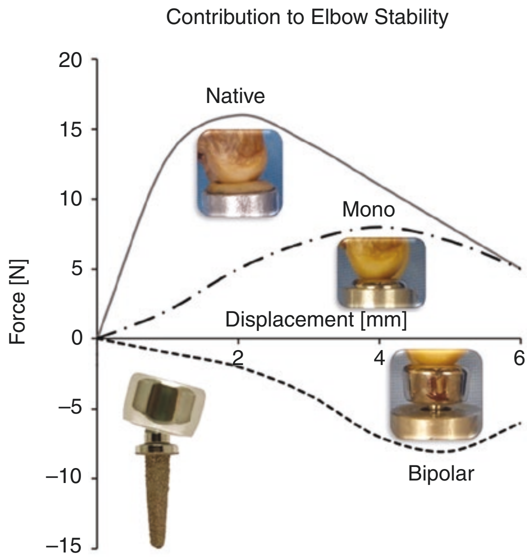

Fig. 4.16 A bipolar radial head will tilt when subluxated, which diminishes the force resisting subluxation. If this same bipolar radial head is made to behave like a monoblock (Mono) prosthesis by locking it into place with a washer so it can no longer tilt, it is then able to resist subluxation in a manner similar to the native radial head. (By permission of Mayo Foundation for Medical Education and Research (https://www.mayoclinic.org/copyright). All rights reserved)

Head-Stem Coupling Mechanism

The traditional Morse taper has functioned well in radial head arthroplasty, although it typically requires that the head and neck be coupled prior to insertion. This is not a problem in the acutely unstable elbow, which can be subluxated to get a straight shot down the canal and readily deliver the prosthesis over the capitellum. However, if the elbow is not unstable, or if the radial head prosthesis is being used for reconstruction in the post-traumatic setting, the lateral collateral ligament may need to be released in order to subluxate the elbow and insert the prosthesis. In situ couplers have been developed to secure the Morse taper, but these have proven bulky and difficult to use.

For this reason, a number of designs have attempted to permit coupling of the prosthesis in situ, typically with a slide on mechanism. The concept is valid, but two potential problems can occur (Figs. 4.19, 4.20, and 4.21). First, a coupling mechanism can come apart and dissociation can occur, requiring revision. Second, the

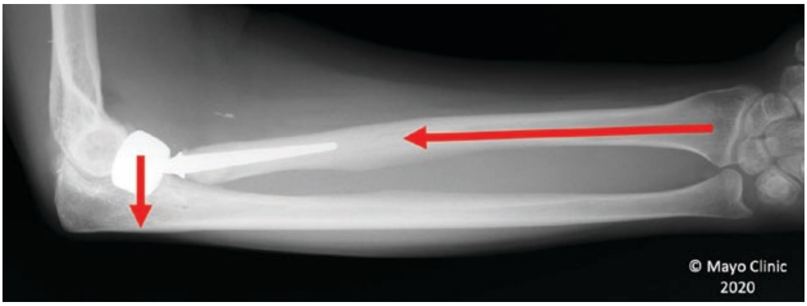

Fig. 4.17 Bipolar radial heads have a tendency for the radial head to translate posteriorly with respect to the capitellum and therefore subluxate. This can actually cause chronic attenuation of the lateral collateral ligament complex with tardy posterolateral rotatory instability (PLRI). (By permission of Mayo Foundation for Medical Education and Research (https://www.mayoclinic.org/copyright). All rights reserved)

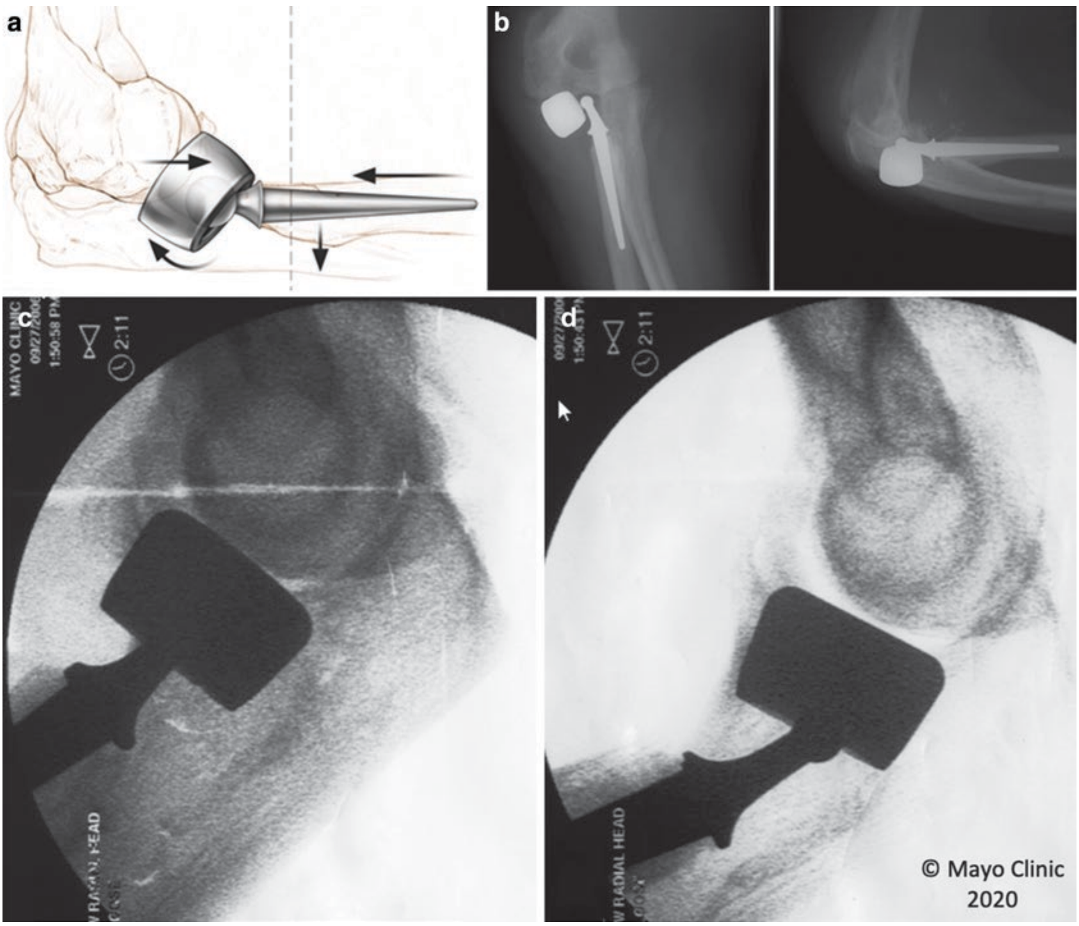

Fig. 4.18 Bipolar heads can partially or completely disengage. The mechanism for this disassembly is a force couple caused by an edge-loading compressive force on one side of the bipolar radial head and a distraction force on the other side caused by scar tissue surrounding the bipolar radial head (**a**). Complete dissociation requires reoperation (**b**). Partial disengagement can occur due to deformation or wear of the polyethylene (**c**, **d**). When this happens, the repeated partial coupling/uncoupling tends to cause further polyethylene wear and reactive synovitis. (By permission of Mayo Foundation for Medical Education and Research (https://www.mayoclinic.org/copyright). All rights reserved)

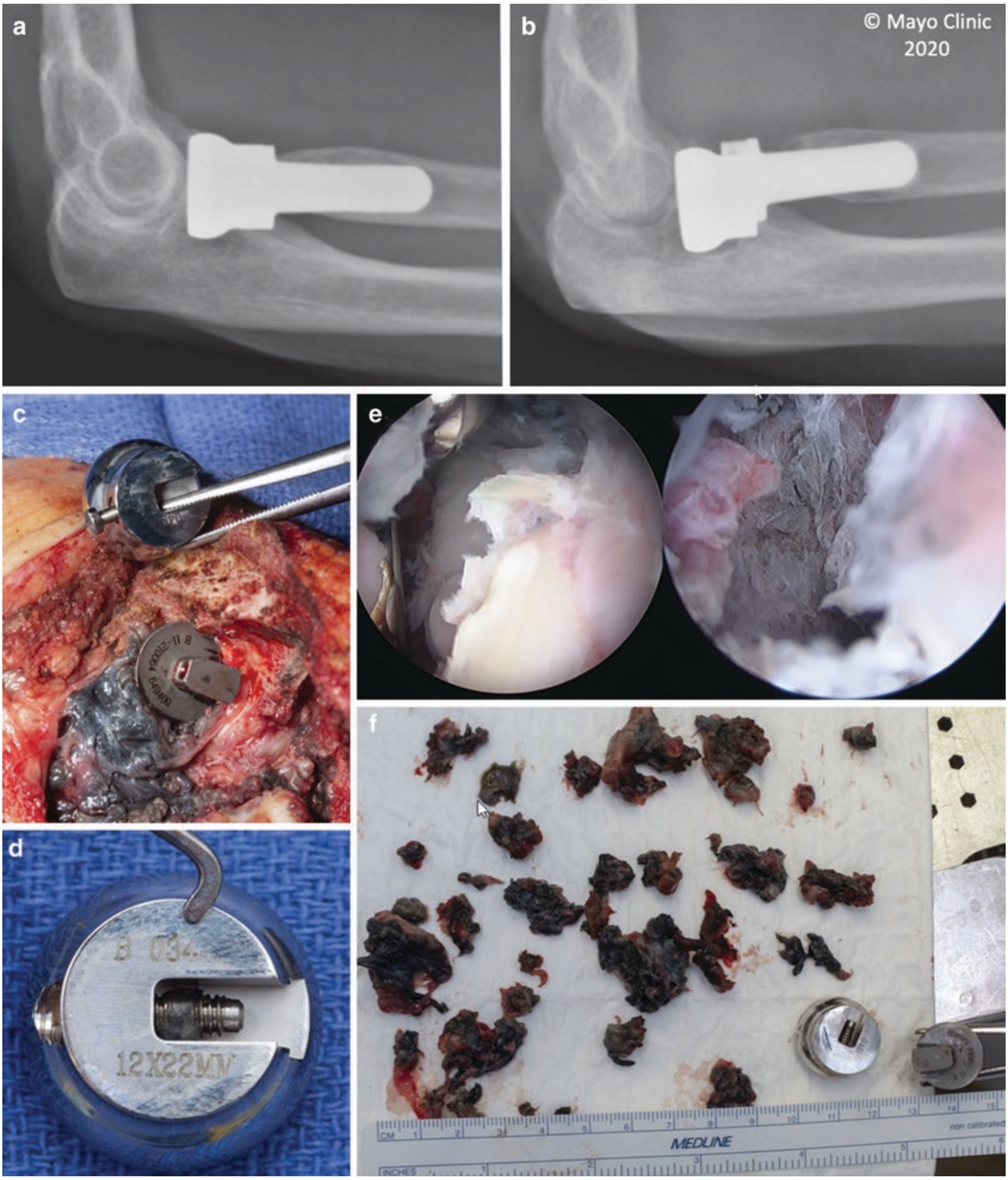

Fig. 4.19 (**a**) Side-loading head with bolt locking mechanism engaged. The head lines up with the neck. (**b**) The bolt has loosened (not seen) and the head partially disengaged from the neck, with which it is no longer aligned. (**c**, **d**) Metallosis caused by abrasion of the head on the stem, as evidenced by worn laser markings. (**e**) Arthroscopic views showing titanium synovitis. (**f**) Metallosis due to the release of metal particles. (By permission of Mayo Foundation for Medical Education and Research (https://www.mayoclinic.org/copyright). All rights reserved)

Fig. 4.20 Examples of disengagement of a three-part Slide-Loc torsional locking mechanism. (**a** and **c**) Short and long stems assembled in situ. (**b** and **d**) The same prostheses disengaged, as evidenced by tilting (**b**) or translation (**d**) of the head/neck on the stem. (By permission of Mayo Foundation for Medical Education and Research (https://www.mayoclinic.org/copyright). All rights reserved)

Fig. 4.21 Example of disengagement of an adjustable angle locking mechanism using a bolt. (**a**) Positioning the elbow for comparison lateral X-rays in flexion and hyperflexion. (**b**) Lateral view in flexion. (**c**) Hyperflexion causes the head to tilt on the neck, indicating that the locking mechanism is no longer working, but causing metal-on-metal abrasion. (**d** and **e**) Arthroscopic reviews of the head/neck junction showing that it can be tilted. (**f**) Arthroscopic view showing synovitis. (**g** and **h**) Excoriations at the head/neck junction due to failed locking mechanism, explaining the surrounding titanium synovitis. (By permission of Mayo Foundation for Medical Education and Research (https://www.mayoclinic.org/copyright). All rights reserved)

locking mechanism can loosen and permit subclinical micromotion without apparent dissociation. This occurs regardless of whether the head is locked in place with a locking bolt or with a rotational torque. Micromotion at the head-stem interface causes abrasion and the release of metal particles that can lead to metallosis, synovitis, and osteolysis. It is not known at this point whether or not the types of problems that are seen with "trunnionosis" in the hip will be seen with these coupling mechanisms.

Angle(s) and Offset(s)

The native radial head is angled in two planes with respect to the intramedullary canal of the radial neck. At the bicipital tuberosity, the intramedullary canal takes another change in direction such that there is angulation between the

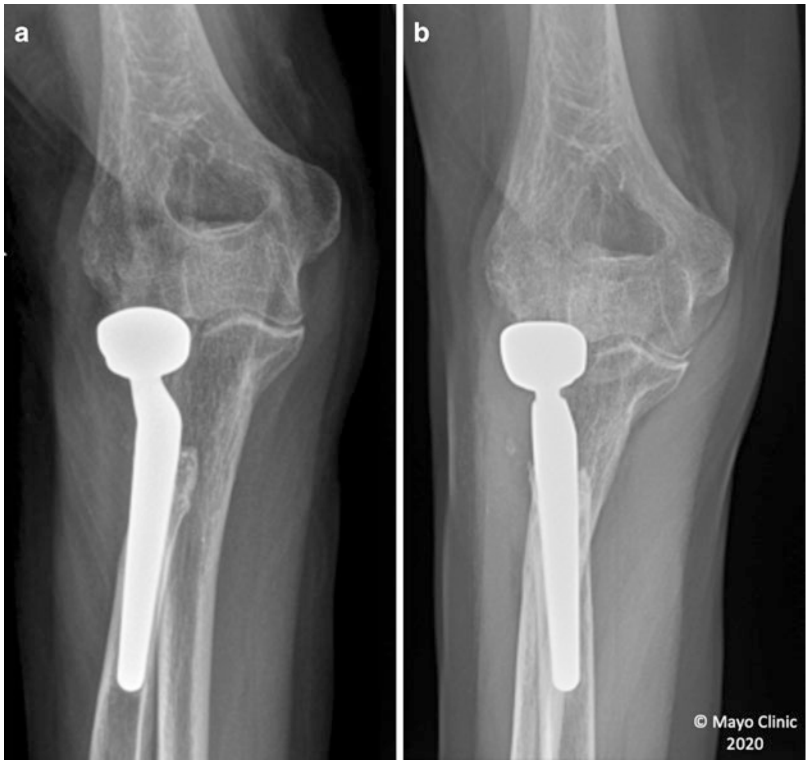

Fig. 4.22 Long-stem prostheses need to take into consideration the angle between the neck and the proximal radial shaft **(a)**. By mimicking the complex bi-planer, angulated anatomy of the radial head and proximal radius, adequately designed long-stem prosthesis can permit the biceps tendon and its insertion on the bicipital tuberosity to clear the ulna during pronation and supination **(b)**. (By permission of Mayo Foundation for Medical Education and Research (https://www.mayoclinic.org/copyright). All rights reserved)

intramedullary axis of the radial neck and of the proximal radial shaft. This complex anatomy permits the biceps tendon and its insertion on the bicipital tuberosity to clear the ulna during pronation and supination (Fig. 4.22). In addition to the normal radial bow, this complex arrangement of head/neck and neck/shaft angles makes it possible for the radius to cross over the ulna during pronation. Standard stem length radial head prostheses need to take into consideration the angulation between the head and the neck. Long-stem prostheses also need to take into consideration the angle between the neck and the proximal radial shaft.

Instruments and Technique

As with any prosthetic replacement, reliable precise instruments and reproducible technique are essential. Some aspects of the technique are more critical than others, but four key elements of radial head replacement merit discussion:

- Height (length)
- Stem diameter
- Head diameter
- Head rotation (for anatomic designs) and tilt

Height (Combined Head and Neck Length)

Getting the height correct is one of the two most important technical variables [37–41]. Overstuffing is the term that has generally been used to mean lengthening of the radius by inserting a combined head and neck length that exceeds the bone and cartilage resected. Lengthening the radius by more than 2 mm causes increased radiocapitellar contact pressures resulting in cartilage necrosis and subchondral bone erosion (Fig. 4.23).

Instruments and a method for measuring the correct height of the radial head and neck are essential (Fig. 4.24). This is best done using a set of feeler gauges and an adjustable height gauge.

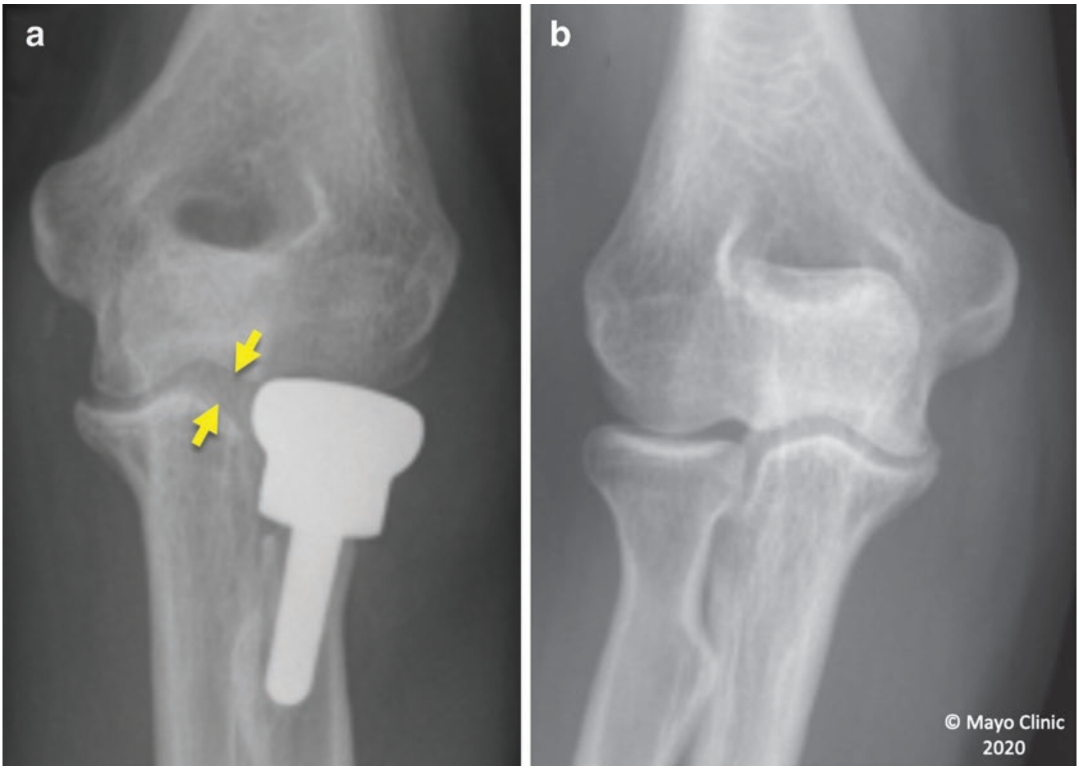

Fig. 4.23 Lengthening the radius by more than 2 mm (overstuffing) causes increased radiocapitellar contact pressures resulting in cartilage necrosis and subchondral bone erosion. These radiographs show an increased ulnohumeral gapping (**a, arrows**) as compared to the contralateral elbow due to the radius being overlengthened/overstuffed (**b**). (By permission of Mayo Foundation for Medical Education and Research (https://www.mayoclinic.org/copyright). All rights reserved)

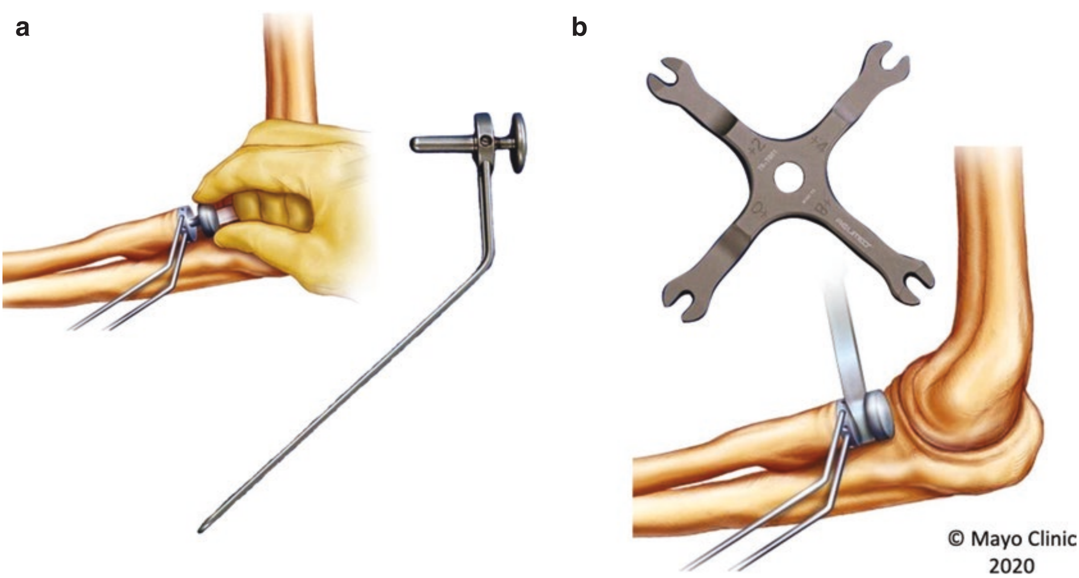

Fig. 4.24 Instruments are required for measuring the correct height of the radial head and neck. Example of feeler gauges (**a**) and an adjustable height gauge (**b**). (By permission of Mayo Foundation for Medical Education and Research (https://www.mayoclinic.org/copyright). All rights reserved)

A critically important step in measuring height is to ensure that the ulnohumeral joint is reduced while performing the measurement. This can be done by placing the elbow at 90 degrees and applying a firm compressive force on the olecranon in line with the long axis of the humerus.

Stem Diameter

Getting the stem direct diameter correct is essential to prevent loosening of a porous ingrowth stem. Some systems have broaches that are hammered in and others have reamers that are twisted. When using broaches, a "rule of thumb" is that if you can push it in with your thumb during surgery, you'll be able to pull it out with your finger and thumb at the time of revision. In other words it will not have adequate initial press-fit stability to permit bone ingrowth. Broaches and the final stem must be hammered into the canal to ensure reliable ingrowth [23].

Head Diameter

The native radial head is asymmetrical and oval shaped, with a long axis that is generally about 2 mm longer than a short axis. Most systems rely on templating the excised radial head in a series of wells to determine head diameter. The excised head must fill the well tightly. If the well is bigger than the head, the prosthetic head will be bigger than the excised native head. If this happens, the next smaller size should be chosen. With some radial head systems, downsizing the implant by 2 mm further improves radiocapitellar contact [42–44]. A circular radial head should be sized according to the short axis, whereas an anatomic radial head should be sized according to the long axis.

Head Rotation (For Anatomic Design) and Tilt

There is currently only one anatomic radial head implant design on the market. Head rotation is determined by lining up the laser marking on the head with a cautery mark on the lateral side of the radial neck placed at the midpoint of the neck with the forearm in neutral rotation. This also lines up with the Lister's tubercle at the wrist. No special instruments are needed.

The tilt is predetermined in all but one prosthesis on the market currently. That particular implant design requires the head to be locked onto the stem at the chosen tilt angle determined by the surgeon intraoperatively. There are no specific instruments provided to accomplish this.

Summary and Future Considerations

The function and structure of the radial head is a much more complex than may be generally recognized. Prosthetic replacement design is still in the early stages and more scientific research is needed. As with replacement of other joints, the multiplicity of designs will likely diminish over time as clinical experience and scientific research shed light on which design features are the most important and successful. It is highly probable that certain features will have less tolerance for error than others. For example, a 3 mm (lengthening) error in radial height is almost certainly worse than a 3 mm error in rotational positioning of an asymmetric anatomic radial head. The former will have a deleterious effect on radiocapitellar contact pressures and lead to cartilage loss, whereas the latter represents a 15° malrotation, which studies in our laboratory show as well tolerated. The key priorities currently requiring attention include symptomatic loosening and osteolysis around ingrowth stems, cartilage and bone erosion due to nonanatomic radial head shapes on press-fitted stems, failure of head-stem coupling mechanisms, and the question of whether or not a loose-fitting stem in the canal truly functions as a prosthetic replacement and provides functional benefit over radial head excision in the long term.

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