Operative treatment of displaced and comminuted radial head fractures involves internal fixation with plates and screws in cases where reconstruction is possible and replacement with a radial head prosthesis when comminution renders the radial head unreconstructable. The purposes of this study were to evaluate the morphometry of the radial head using a modern technique and to compare the findings with several commercially available radial head prostheses.

Computed tomography scans of 30 cadaveric elbows and 3-dimensional reconstructions were used to analyze the morphometry of the proximal radius. Results were compared with the manufacturer data of several radial head prostheses. Mean diameter of the radial head at the level of the fovea was 19±1.58 mm (range, 15.82-21.81 mm) in the anteroposterior plane and 18.62±1.78 mm (range, 15.48-22.21 mm) in the radioulnar plane. Mean diameter of the radial head at its widest part was 23.15±1.94 mm (range, 19.45-26.49 mm) in the anteroposterior plane and 22.44±1.73 mm (range, 19.64-25.44 mm) in the radioulnar plane. Mean diameter of the radial head at the level of the head–neck junction was 15.42±1.59 mm (range, 11.80-18.46 mm) in the anteroposterior plane and 14.75±1.39 mm (range, 12.32-17.31 mm) in the radioulnar plane. Statistically significant sex differences existed in the maximum diameter of the radial head, the diameter at the level of the head–neck junction, and the length of the radial head. Currently available radial head prostheses cover the range of sizes encountered. Products with a choice of head and stem sizes in any combination are preferable. In unstable elbow fractures, correct implant size is an important factor to avoid subluxation of the radial head (Mason type IV fractures) if collateral ligaments are sufficient.
Fractures of the radial head and neck are one of the most common fractures about the elbow, comprising 33% of all elbow fractures and 1.5% to 4% of all fractures in adults. A common mechanism of injury is a fall on an outstretched hand with an extended and pronated forearm. Operative treatment of displaced and comminuted radial head fractures involves open reduction and internal fixation with plates and screws in cases where reconstruction is possible and replacement with a radial head prosthesis when comminution renders the radial head unreconstructable.

In 1954, Mason classified the displacement of radial head fractures. This classification was subsequently modified by Broberg and Morrey in 1987 and Hotchkiss in 1997. In Hotchkiss type III fractures, resection or replacement of the radial head with a prosthesis may be necessary. However, these implants may not always precisely recreate the complex anatomy of the proximal radius.

The purpose of this study was to evaluate the morphometry of the radial head using a modern technique and compare the findings with several commercially available radial head prostheses.

**Materials and Methods**

Thirty cadaveric elbows preserved using Thiel’s embalming method were examined in the supine position using a 64-slice Siemens Somatom Sensation computed tomography system (0.6 mm contiguous axial slices) (Siemens Medical Solutions USA, Inc, Malvern, Pennsylvania). Digital Imaging and Communications in Medicine raw data sets were reconstructed using Mimics 3-dimensional software (Materialise, Leuven, Belgium). Extremities with severe arthrosis, evidence of trauma, or other pathological changes were excluded from the study. Mean age of the donors at death was 72.5 years (range, 59-98 years). Fourteen elbows were from male donors and 16 were from female donors. Sixteen elbows were right elbows and 14 were left elbows. The results were recorded on Excel 2003 software (Microsoft Corp, Redmond, Washington). Two-sample \( t \) test was used for calculating sex differences. A \( P \) value of .05 or less was considered statistically significant.

To the authors’ knowledge, no published standardized methods for measuring the radial head exist. Therefore, the following points of reference were used to describe the geometry of the radial head and neck for the purposes of this study.

The first 4 points were set on the most proximal projections of the fovea of the radial head to measure the anteroposterior (AP) and radioulnar (RU) diameters (Figure 1). The radial head is slightly barrel shaped and widens before narrowing again to join the radial neck. Measurements were performed in the AP and RU planes between points set at the widest part of the radial head to quantify its maximum diameters (Figure 2). Four more points were set at the head–neck junction as determined by the vertex of the curve of the neck as it joins the shaft in the AP and RU planes. The vertex was defined by the point of the curve that is farthest from a line between the beginning and end of the curve (Figure 3).

Two pairs of points 5 mm distal to those at the head–neck junction on the periosteal surface of the radial shaft in the AP and RU planes were chosen and labeled \( \text{shaft} \) (Figure 3). The head–shaft angle was calculated between the points \( \text{max head, junction, and shaft} \) at each of the measurement points for the anterior, posterior, ulnar, and radial sides (Figure 3).

To determine the lengths of the anterior, posterior, radial, and ulnar aspects of the radial head, the distance between each of the 4 fovea points and the corresponding junction point was measured (Figure 3). To quantify the flexion between the radial head and neck in the sagittal plane, a circle was constructed using 3 points on the coverture. The radius of this constructed circle was measured (Figure 4). The dimensions of various radial head prostheses are shown in Table 1.

**Results**

Mean diameter of the radial head at the level of the fovea was \( 19 \pm 1.58 \text{ mm} \) (range, 15.82-21.81 mm) in the AP plane and \( 18.62 \pm 1.78 \text{ mm} \) (range, 15.48-
22.21 mm) in RU plane. Mean diameter of the radial head at its widest part was 23.15±1.94 mm (range, 19.45-26.49 mm) in the AP plane and 22.44±1.73 mm (range, 19.64-25.44 mm) in the RU plane. Mean diameter at the level of the head–neck junction was 15.42±1.59 mm (range, 11.80-18.46 mm) in the AP plane and 14.75±1.39 mm (range, 12.32-17.31 mm) in the RU plane.

Because the differences between the mean AP and RU diameters were marginal, the radial head was assumed to be circular, mean AP and RU measurements at each level (labeled diameter) were used. Mean diameter of the fovea was 19.15±1.54 mm in male donors and 18.50±1.66 mm in female donors. This difference did not reach statistical significance (P=.28). However, for the widest part of the radial head, sex-dependent differences were observed (men, 23.81±1.58 mm; women, 21.90±1.37 mm; P<.01). Similar results were observed at the head–neck junction (men, 15.76±1.39 mm; women, 14.49±1.12 mm; P=.01). No statistically significant difference existed between the right and left radial head measurements (P=.49).

Mean radial head length on each side (anterior, 11.81±1.57 mm; posterior, 11.77±1.41 mm; radial, 11.89±1.52 mm; ulnar, 11.72±1.42 mm) was compared between male and female donors, resulting in significant differences (men, 12.41±1.7 mm; women, 11.26±0.83 mm; P<.01). Mean radius of the curvature was 8.76±2.50 mm, with no significant difference between the sexes (P=.59). Mean angle between the radial head and shaft was 158.8° (Table 2).

Comparing this study’s results with the dimensions of commercially available radial head prostheses is demanding because different controversial concepts exist regarding radial head displacement.

The Acumed Anatomical Radial Head System (Acumed, Hillsboro, Oregon) is a metal implant with a free combinable head and cementless stem components. Head diameter options are 20, 22, 24, 26, and 28 mm, which is more than the average head diameter in the current study. With a preset 4° ventral and 4° ulnar
angulation, right and left implants are needed.

Ascension Orthopedics (Austin, Texas) offers a metal modular radial head implant and a pyrocarbon radial head implant with 3 head sizes (20, 22, and 24 mm) and 4 stem sizes (each with a standard or a long collar) that can be implanted without cement.

The Liverpool Radial Head Replacement (Biomet, Inc, Warsaw, Indiana) has a shaft angulation of 10°, two head diameters, and 13 different stems. The stems are bond-coated, which should provide a better fixation. The ExploR Radial Head by Biomet can be cemented or press-fit. Three different head sizes (20, 22, and 24 mm), 5 different head lengths, and 5 different stems are offered.

The Radial Head metal (CoCrMo) implant (Corin Group PLC, Cirencester, United Kingdom) is coated with hydroxyapatite and titanium. Three head sizes (18, 21, and 25 mm) and 3 different stems are offered.

Another radial head prosthesis is the rHead implant (Small Bone Innovations, Inc, Morrisville, Pennsylvania), which is offered in a lateral version (head can be loaded from lateral using a less invasive approach) and a recon version (bipolar head with the ability of a free angulation up to 20°). The implants are made of metal (CoCr) and feature a fully coated stem. The shaft angulation is 12°. Three head

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**Table 1**  
Dimensions and Specifications of Radial Head Prostheses

<table>
<thead>
<tr>
<th>Prosthesis</th>
<th>Diameter (Length), mm</th>
<th>Special Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anatomic Radial Head System(^a)</td>
<td>20</td>
<td>6 (25) Chirality (different implants for right/left arms); head-socket +0, +2, +4, +6, and +8</td>
</tr>
<tr>
<td>Carbon Modular Radial Head(^b)</td>
<td>20</td>
<td>4 stem sizes each in long version Pyrocarbon</td>
</tr>
<tr>
<td>ExploR Radial Head(^c)</td>
<td>20</td>
<td>5 stem sizes</td>
</tr>
<tr>
<td>Liverpool Radial Head Replacement(^d)</td>
<td>16</td>
<td>(6-18, step 2) 10° angulation; bond-coated stem</td>
</tr>
<tr>
<td>Radial Head metal (CoCrMo)(^e)</td>
<td>18 (9, 13)</td>
<td>10 (28) 15° angulation; neck lengths: 5, 6.5, 8, 10 mm</td>
</tr>
<tr>
<td>rHead(^f)</td>
<td>18 (7.2)</td>
<td>6.4 (16) Recon version</td>
</tr>
<tr>
<td>Solar Radial Head(^g)</td>
<td>Small</td>
<td>8</td>
</tr>
<tr>
<td>CRF II Jude(^h)</td>
<td>19</td>
<td>6.5 Bipolar</td>
</tr>
<tr>
<td>MoPyC(^i)</td>
<td>18 (9)</td>
<td>7 (40) Pyrocarbon neck; 15° angulation;</td>
</tr>
<tr>
<td>Evolve Proline(^j)</td>
<td>18</td>
<td>4.5-9.5 +2 and +4 head</td>
</tr>
<tr>
<td>Swanson(^k)</td>
<td>19</td>
<td>27-32 Not modular combinable</td>
</tr>
</tbody>
</table>

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\(^a\)Acumed, Hillsboro, Oregon.  
\(^b\)Ascencion Orthopedics Inc, Austin, Texas.  
\(^c\)Biomet, Inc, Warsaw, Indiana.  
\(^d\)Corin Group PLC, Cirencester, United Kingdom.  
\(^e\)Small Bone Innovations, Inc, Morrisville, Pennsylvania.  
\(^f\)Stryker, Kalamazoo, Michigan.  
\(^g\)Tornier, Saint-Ismier Cedex, France.  
\(^h\)Wright Medical Technology, Inc, Arlington, Tennessee.
sizes (18, 21, and 24 mm) and 4 stems sizes with 2 collar lengths are available. The Solar Radial Head implant by Stryker (Kalamazoo, Michigan) has a cemented stem and features 2 head sizes with 5 different stems.

Tornier (Saint-Islmier Cedex, France) offers different radial head prostheses. The commonly used CRF II implant was introduced approximately 2 decades ago. It features a shaft angulation of 15°, a head range of motion of 35°, and is made of metal (CrCo). Two head sizes (19 and 22 mm) and 2 cementable stems (6.5 and 8 mm) are available. The newer MoPyC implant is made of pyrocarbon and offers the same shaft angulation and a cementless press-fit implantation. Its smaller head sizes (18, 20, and 22 mm) are comparable with the sizes found in the current study. Four neck sizes and 4 shaft sizes are free combinable.

Wright Medical Technology, Inc (Arlington, Tennessee), offers 2 radial head implants. The Swanson Titanium Radial Head Implant is available in 5 head diameters (19-23 mm). The stem size depends on the head, and the components are not combinable. A Silicon Head version is also offered. The modular Evolve system is offered with 6 head diameters (18, 20, 22, 24, 26, and 28 mm), lengths of 11, 13, or 15 mm, and 6 stem sizes, each with a standard neck, a 2-mm neck, and a 4-mm neck. Many combinations are possible.

**Discussion**

Operative treatment of radial head and neck fractures consists of open reduction and internal fixation when a stable, reliable fixation can be achieved. In fractures where comminution renders the fracture unreconstructable, the fragments are excised and a metal radial head prosthesis is inserted.

Some biomechanical studies have emphasized the importance of correctly sizing the radial head prosthesis at the time of implantation. A short, small prosthesis can lead to valgus instability, whereas a long implant has the potential to overstuff the radiocapitellar joint. Some authors have suggested that a difference of no more than 2 mm from the patient’s native anatomy is tolerated. In unstable elbow fractures, correct implant size is an important factor to avoid subluxation of the radial head (Mason type IV fractures) if collateral ligaments are sufficient. In the current authors’ opinion, posterior subluxation can occur in cases of insufficient medial collateral ligaments.

Tejwani and Mehta reported that 60% of the axial load from the forearm is transmitted through the radiocapitellar joint, particularly with the elbow flexed and the forearm pronated. The highest loads were recorded with the elbow extended and forearm pronated. Itamura et al reported discrepancies between the anatomy of the radial head and available radial head prostheses. Beredjiklian et al used magnetic resonance imaging to investigate the morphology of the radial head and reported results similar to those of the current study. They measured the minimum (22 mm) and maximum (23 mm) diameter of the radial head at the level of the convexity, comparable with the maximum diameter of the radial head in the AP (23.15 mm) and RU (22.44 mm) planes. Mean radial head length (12 mm) in the study by Beredjiklian et al was similar to the mean dorsal, ventral, radial, and ulnar length (11.8±1.19 mm) in the current study.

Using the Poli SKY II coordinate measuring machine (Quality Control Technology Ltd, Nottingham, United Kingdom) and ProENGINEER software (PTC, Needham, Massachusetts), Swieszkowski et al examined 16 radial heads and reported a mean diameter of 23.36±1.14 mm. In a biometric study, Captier et al measured 96 radial bones using a vernier caliper and goniometer and found the fovea to be elliptical (more than 1 mm difference between AP and RU diameters) in 57% of bones; mean AP diameter was 21.6±2.9 mm and mean RU diameter was 21±2.7 mm. Compared with the current study’s results, Captier et al measured a slightly smaller diameter in both planes. They
also reported a mean radial head length of 15.3 mm, whereas in the current study it was 11.80 mm. This may be due to the use of dry bones as opposed to fresh. Captier et al detected a relationship between the angle of the axis of the radial neck and diaphysis and the shape of the fovea. They reported a mean angle of 166.75°±3° in specimens with a circular fovea and 168.62°±3.2° in specimens with an oval-shaped fovea. They postulated that pronation is facilitated due to deviation of the radial tuberosity by 2 mm from the incisura.

Popovic et al scanned 51 proximal radii using computed tomography and compared their measurements with those of a commercially available radial head prosthesis. They reported results for radial head diameter (22.8±1.9 mm maximum and 21.8±1.9 mm minimum) comparable to the current study and described sex-dependent differences in radial head size. They showed that the smaller 19-mm implant is too small for most adults, whereas the 22-mm implant should fit in most cases. They also recommended that the shaft and head of the implant should be used in any combination because no correlation seemed to exist between head size and intramedullary neck diameter.

Itamura et al examined 22 elbows using computed tomography with the forearm placed in different positions and reported a maximum diameter of 22.3±2.4 mm and a minimum diameter of 20.9±1.9 mm, comparable with the measurements in the current study (Table 3). However, their mean radial head length measurement (11.8±1.19 mm) differed from those of the current study because different measurement points were used.

Numerous radial head prostheses from a variety of manufacturers are available on the market (Table 1). Most implants come in several head sizes covering the anatomical range demonstrated by the current study’s measurements, but not all products offer the possibility of fully interchangeable head and shaft sizes.

New isoelastic (pyrocarbon) prostheses should offer better gliding ability without wear. First results from animal studies and retrospective clinical studies show advantages of pyrocarbon prostheses compared with metal prostheses. Recent case series on the use of bipolar radial head prostheses report good functional results. In a cadaveric study, Moon et al reported that a bipolar prosthesis was unable to resist subluxation as well as the native radial head or a monopolar prosthesis.

Summarizing the aforementioned studies, reliable, comparable values were found for small and large radial head diameters, whereas radial head and neck length and head-diaphysis angle measurements are difficult to compare in the absence of well-defined landmarks.

In unstable elbow fractures, correct implant size is an important factor to avoid subluxation of the radial head (Mason type IV fractures) if collateral ligaments are sufficient. Measurement of the contralateral side is a valid option to determine the size of the fractured radial head and to choose the correct implant size. Currently available radial head prostheses cover the range of sizes encountered in the current study. Implants with a choice of head and stem sizes in any combination are preferable. Several prosthesis design features cannot be easily compared, but anatomic ovoid implants affect kinematics more physiologically.

<table>
<thead>
<tr>
<th>Study</th>
<th>Head Size</th>
<th>Length</th>
<th>Head–Diaphysis Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current study</td>
<td>23.15</td>
<td>11.89</td>
<td>153°-165°</td>
</tr>
<tr>
<td>Beredjiklian et al</td>
<td>23</td>
<td>12</td>
<td>N/A</td>
</tr>
<tr>
<td>Popovic et al</td>
<td>22.8</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Itamura et al</td>
<td>22.3</td>
<td>15.3</td>
<td>N/A</td>
</tr>
<tr>
<td>Swieszkowski et al</td>
<td>23.36</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Captier et al</td>
<td>21.6</td>
<td>15.3</td>
<td>167°-169°</td>
</tr>
</tbody>
</table>

Abbreviation: N/A, not available.

### References


