Ruptures of the distal biceps brachii tendon are generally treated operatively due to their loss of supination and flexion force. A mechanical impingement at the insertion of the tendon at the radial tuberosity is discussed to play a role in the etiology of this injury. The aim of this study was to present a detailed, three-dimensional anatomical analysis of the radioulnar space at the radial tuberosity. A total of 166 imprints of the radioulnar space in neutral rotation and pronation from 84 cadaveric specimens of both arms using silicone impression material were produced for this study. Imprints were cut in slices of 3 mm and digitally measured after picture acquisition using a high-resolution digital camera. Distances were grouped into a proximal, central, and distal groups and used for correlation to morphometric data at the elbow (radial head diameter, ulna and radius length) as well as volume calculation. The mean radioulnar distance was 8.8 ± 4.0 mm in neutral rotation and 7.8 ± 3.9 mm in pronation. In pronation, the central zone was the smallest whereas in neutral rotation the proximal zone was the smallest. The volume of the radioulnar space did not reduce significantly during pronation. Little space is provided for the insertion of the distal biceps brachii tendon especially during pronation. This could play a role in the etiology of distal biceps brachii tendon ruptures and should be considered in the fixation after rupture of the tendon. Clin. Anat. 33:661–666, 2020. © 2019 Wiley Periodicals, Inc.

Key words: radius; ulna; elbow; tendon injuries; anatomy

INTRODUCTION

Ruptures of the distal biceps brachii tendon occur with an incidence of about 2.55/100,000 (Kelly et al., 2015). The mechanism of injury is usually characterized by excessive eccentric loading of the biceps brachii with flexion of the elbow (Safran and Graham, 2002). As a rupture of the distal biceps brachii insertion is typically associated with a significant loss of supination and flexion force, operative treatment is advocated in most cases (Morrey et al., 1985; Chillemi et al., 2007; Freeman et al., 2009; Miyamoto et al., 2010). Risk factors for such ruptures that are described in the literature are male sex, smoking, steroid intake, and obesity (Safran and Graham, 2002; Kelly et al., 2015). Most ruptures of the distal biceps brachii tendon occur close to its insertion at the radial tuberosity. The etiology of these injuries, however, is still under debate. Apart from a proposed hypovascular zone that could impair tendon repair mechanisms at this location, a mechanical impingement is discussed as cause for distal biceps brachii tendon ruptures (Seiler et al., 1995).
Anatomically, the distal biceps brachii tendon is believed to consist of two separate bundles inserting at the radial tuberosity (Eames et al., 2007). The tendon widens from 5.3 mm at the distal part of the tendon to 19.4 mm at the anatomical footprint (Kulshreshtha et al., 2007). Furthermore, several studies investigated the bony anatomy of the radial tuberosity and the insertion of the distal biceps brachii tendon (Athwal et al., 2007; Eames et al., 2007; Kulshreshtha et al., 2007; Mazzocca et al., 2007; Forthman et al., 2008; Hutchinson et al., 2008; Cucca et al., 2010; Cho et al., 2011). The radial tuberosity is described as a 24.2 x 12 mm large elevation of the radial shaft (Hutchinson et al., 2008). Hutchinson et al. classified the radial tuberosity in two subtypes with a more common semilunar and a less common oval footprint (Hutchinson et al., 2008). However, although detailed knowledge of the distal biceps brachii tendon and the radial tuberosity is available, the dimensions of the radio-ulnar space have not been studied in detail. More detailed knowledge of this space could be valuable in the understanding of a possible mechanical impingement at this region.

Therefore, the aim of the present study was to present a detailed, three-dimensional anatomical analysis of the radio-ulnar space and its variability. We hypothesized that a significant variation of this region can be found between individuals. Additionally, the study was based on the assumption that the width of the radio-ulnar space is dependent of forearm rotation.

**MATERIAL AND METHODS**

Eighty-six formalin-fixed elbow specimens were available for this study. The mean age of the specimens at death was 83.5 ± 9.0 years (range, 62–101 years). There were 22 female and 20 male specimens. After careful removal of the surrounding soft tissues at the proximal 15 cm of the forearm, the radial tuberosity was exposed. The remaining soft tissues at the distal forearm were left intact with the exception of the styloid process of the ulna and the radius. The insertion of the distal biceps brachii tendon was then thoroughly removed from the radius. Great care was taken not to injure the radial tuberosity.

To quantify the radio-ulnar distance three-dimensionally, imprints of the radio-ulnar space were taken. For this purpose, the radio-ulnar space was filled with a commercially available silicone impression material combined with an activator (Optosil P plus and Universal activator, Kulzer, Hanau, Germany) in pronation and neutral rotation of the forearm with the proximal and distal radio-ulnar joint strictly aligned. To standardize the position of pronation, we used 80° as the standard position as used before by Bhatia et al. (Bhatia et al., 2017). The imprints were then removed from the radio-ulnar space by dislocating the proximal radio-ulnar joint. Two imprints were excluded due to damaged material, leaving a total of 166 imprints that were generated using this technique.

The imprints were then cut into slices of 3 mm, starting at the neck of the radial head to the radius distal of the tuberosity using a custom-made cutting machine providing standardized cut-thickness. The orientation of the slices was oriented at 90° to the forearm axis. All slices covering the radial tuberosity were then positioned on scaled millimeter paper (Fig. 1). Standardized pictures of the slices were taken in a right angle to the surface using a high-resolution single-lens reflex camera (EOS 5D, Canon, Tokyo). To prevent distortion of the images, we used a 50 mm prime lens. Width of the slices was then measured using the...
ImageJ digital image analysis software (http://imagej.net [Rueden et al., 2017]). For width-measurement, two standardized lines oriented along a line connecting the most dorsal and the most ventral imprint of the radius and the ulna were created. Width of the slides was then measured parallel to this line in steps of 3 mm and grouped into three zones: (a) proximal, (b) central, and (c) distal (Fig. 2). The surface area of each slide was also measured (Fig. 3). For validation of the measurements, the width was measured using a digital caliper on two slides showing a matching of the digital measurements within 0.1 mm.

To correlate the radioulnar distance to patient-specific parameters, we additionally measured the ulnar length, the radial length, and the smallest as well as the largest diameter of the radial head by using a measuring tape or a digital caliper in all specimens, respectively.

The volume of the radioulnar space at the radial tuberosity was calculated by using the measured distances. For each parameter (e.g., radioulnar distance, radioulnar volume) the mean, minimum and maximum, and standard deviation (SD) were calculated. To compare the smallest distances at each height of the radial tuberosity, means of the smallest height of

![Fig. 3. Digital measurement of the radioulnar distance. The radioulnar distance was measured in 3-mm steps. The surface of each slide was measured using a polygone-line.](image)

![Fig. 4. Three-dimensional graph of the radioulnar distance at the radial tuberosity in (a) neutral rotation and (b) 80° pronation. The x- and z-axis are oriented along the proximal-distal radius (x-axis) and the anterior–posterior radius (z-axis). The y-axis shows the mean distances at each level throughout all specimens. The color of each field is determined by the number of specimens where this coordinate was available. [Color figure can be viewed at wileyonlinelibrary.com]](image)

| TABLE 1. Radioulnar Distances at Different Levels of the Radial Tuberosity |
|---------------------------------------------------------------|
| Radioulnar distance | Neutral rotation mean distance (SD) | Pronation mean distance (SD) | P-value |
| Mean distance (mm) | $8.8 \pm 4.0$ mm (range, 0.1–24.0 mm) | $7.8 \pm 3.9$ mm (range, 0.0–25.0 mm) | <0.0001 |
| Proximal zone (mm) | $8.3 \pm 3.6$ mm (range, 0.5–20.9 mm) | $7.6 \pm 3.5$ mm (range, 0.0–21.6 mm) | <0.0001 |
| Central zone (mm)  | $8.6 \pm 4.2$ mm (range, 0.1–22.6 mm) | $7.5 \pm 4.0$ mm (range, 0.0–25.0 mm) | <0.0001 |
| Distal zone (mm)   | $9.7 \pm 4.0$ mm (range, 0.5–24.0 mm) | $8.4 \pm 4.2$ mm (range, 0.0–22.8 mm) | <0.0001 |

| TABLE 2. Difference of the Radioulnar Distance According to Side of the Arm and Sex |
|---------------------------------------------------------------|
|                      | Left arm | Right arm | P-value   |
|----------------------|----------|-----------|-----------|
| Mean distance (SD)   |          |           |           |
| in neutral rotation  | $8.8 \pm 3.9$ mm | $8.8 \pm 4.1$ mm | 0.977     |
| in pronation         | $7.8 \pm 2.2$ mm | $7.8 \pm 4.0$ mm | 0.663     |
| Female               | $8.5 \pm 4.0$ mm | $9.3 \pm 4.0$ mm | <0.0001   |
| Male                 | $7.8 \pm 4.2$ mm | $7.8 \pm 3.6$ mm | 0.4838    |
each group were calculated and compared. The study was approved by the Ethics Commission of Cologne University’s Faculty of Medicine (registration number: 18–112).

RESULTS

The mean radioulnar distances throughout all specimens in neutral rotation and pronation were 8.8 ± 4.0 mm and 7.8 ± 3.9 mm, respectively. The mean distance was significantly smaller in pronation (P-value: <0.05) (Fig. 4). The mean radioulnar distances at the proximal, central, and distal zone are depicted in Table 1. When comparing between the mean distance of each zone (proximal, central, distal) the proximal distance was significantly smaller than the central or distal distance in neutral rotation (mean 8.3 ± 3.6 mm, P-value: <0.05) whereas the central distance was the smallest in pronation (7.5 ± 4.0 mm, P-value: <0.0001).

The mean volume of the radioulnar space at the height of the radial tuberosity was 2,261 mm³ in neutral rotation and 2,120 mm³ in 80° pronation. The mean difference in the volume of the radioulnar space between pronation and neutral rotation was 141 ± 1,141 mm³ (range: −1,343 to 1,841). The difference did not reach significance (P-value: 0.0555). The radioulnar distance in neutral rotation was significantly larger in male specimens. However, in pronation no significant difference between sex could be found. No significant difference in mean distances in neutral rotation and pronation could be found between the left and right arm (Table 2).

Correlation of the smallest radioulnar distance to morphometric measurements of the radial head, the ulna and the radius revealed only a weak correlation to the smallest radial head diameter (Table 3).

DISCUSSION

Based on the presented data, we conclude that the distance between the radius and the ulna at the radial tuberosity is significantly smaller in pronation, although the volume of the radioulnar space does not decrease significantly. We could show that the smallest distance at the level of the tuberosity can be found at the central third of the radial tuberosity. Moreover, the smallest distance does not correlate with anatomical measurements close to this region such as the radius length, indicating a missing relation to the patients’ height. To the best of our knowledge, this is the first study to investigate the three-dimensional radioulnar space on a large scale.

The radioulnar space at the proximal forearm is specifically important for the distal biceps’ brachii footprint at the radial tuberosity as a narrow space could result in a mechanical impingement during pronation (Seiler et al., 1995). This mechanism has been discussed to influence the surgical reattachment that could also be relevant for distal biceps brachii tendinitis. There are only sparse investigations in the literature dealing with this anatomical region (Seiler et al., 1995; Krueger et al., 2014; Bhatia et al., 2017). The radial tuberosity and the footprint of the distal biceps brachii are generally believed to be of highly individual anatomical variability with two types of tendon insertions: semilunar (Type I), oval shape (Type II), and a variably present axial ridge or osteophytes (Hutchinson et al., 2008). Seiler et al. were the first to investigate the radioulnar space by 1.5 cm-cross sections of six frozen specimens in pronation, supination, and neutral rotation on axial and longitudinal slices (one for each orientation and rotational position) as well as computer tomography (CT) of 10 volunteers in maximal supination, pronation, and neutral rotation (Seiler et al., 1995). They found an average change from supination to pronation of 3.85 mm in CT and a mean distance of 3.97 mm in pronation (range, 2.1–6.0 mm) (Seiler et al., 1995). They did not describe the anatomy in a three-dimensional manner and at different levels of the tuberosity.

The narrowness of the radius and the ulna at the distal biceps’ brachii footprint could be problematic after fixation of the distal biceps brachii tendon. Krueger et al. investigated the available radioulnar space in different fixation techniques of the distal biceps brachii tendon (Krueger et al., 2014). They found that the available radioulnar space was significantly decreased in all fixation techniques compared to the native insertion. Therefore, fixation techniques resulting in a more reduced radioulnar space could expose the patient to a larger risk of impingement after repair (Krueger et al., 2014). Bhatia et al. found the highest decrease of the radioulnar distance at the lowest level of the radial tuberosity during pronation with a mean of 3.9 mm (45%) (Bhatia et al., 2017). The results of these studies are emphasized by the presented results as this study highlights the decrease of the smallest distances...
during pronation although we found the smallest distance at the central portion of the radial tuberosity. A mechanical impingement of the radioulnar space could not only be a significant risk factor in the etiology of distal biceps brachii tendon ruptures in general but in particular for an impingement after repair of the distal biceps brachii tendon. Such an impingement following a reconstruction might lead to and explain re-ruptures of the repaired tendon. On other anatomical regions such as the shoulder joint, the association between a mechanical impingement and a higher incidence of tendon injuries has long been discussed (Oh et al., 2010). The impingement of the distal biceps brachii tendon has been first described by Davis and Yassine (Davis and Yassine, 1956). Although re-ruptures of the distal biceps brachii tendon have only been shown to occur in only 1.6% of the cases, a mechanical impingement could explain recurring pain after repair of the tendon or whether commonly occurring heterotopic ossifications become symptomatic (Beks et al., 2016).

Especially in individuals with a narrow radioulnar space, fixation techniques with a lower risk of a mechanical impingement might therefore be of importance. Biomechanical studies investigating the reattachment site of the distal biceps brachii tendon have been focused on whether the tendon is inserted at a location more anterior or posterior of the radial tuberosity. While these studies could show the best supination torque after reattachment at the anatomical site or dorsal thereof, biomechanical effects of variations of the insertion height on the radial tuberosity have not been studied (Henry et al., 2007; Schmidt et al., 2010).

Several techniques for fixation of the distal biceps brachii tendon to the radial tuberosity are described using suture anchors, cortical buttons, interference screws, or bone tunnels through a single- or double-incision technique (Miyamoto et al., 2010; Savin et al., 2017). The technique with the least reduction of the radioulnar distance compared to the native insertion are techniques with an excavation of the radial tuberosity although they might reduce the supination torque (Krueger et al., 2014; Schmidt et al., 2014).

The present study has several limitations. Formalin fixation generally leads to shrinking of the tissue, posing a possible limitation due to an alteration in the anatomy. However, shrinkage of calcified bone is typically not an issue in formalin-embedded specimens (Docquier et al., 2010). A further limitation might be that variation at the radial tuberosity could also be reflected in the variation of the biceps brachii tendon at the footprint, hence individuals with a narrow radioulnar distance could also have a comparably small tendon at the footprint. This was not analyzed in the present study and the limitation could only have been overcome if the distal biceps brachii tendon would have been measured simultaneously. Moreover, all studies describing the radioulnar space only measure distances in static positions of the forearm. With muscle forces such as those from the biceps brachii acting on the forearm, distances could also change. Especially in active flexion of the elbow, the biceps brachii might pull the radius upward and increase the radioulnar distance.

In conclusion, the radioulnar space provides only small room for the insertion of the distal biceps brachii tendon, especially during pronation. This could play a role in the etiology of distal biceps brachii tendon ruptures. Therapeutically, this should be considered in the fixation after rupture of the tendon, as a repair usually leads to an increase in the cross-sectional area of the repaired tendon, which might be due to a shortening of the distal biceps brachii stump and augmentation with heavy sutures. Future studies could reveal specific risk factors such as certain anatomical variations that are of risk for a mechanical impingement that could benefit from decompression of this space during repair of the distal biceps brachii tendon.

**CONFLICT OF INTEREST**

None declared by the authors.

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