Over the past decade, several anatomical plates have been introduced to improve the result of open reduction and internal fixation of the distal radius. Using 3-dimensional imaging techniques, the authors studied the accuracy and reproducibility of distal radius positioning using anatomical plates.

Distal radius fractures and the correction of these fractures were simulated with plastic bone models of radii. The authors simulated a defect by removing an arbitrary wedge shape from the artificial radius. Two surgeons corrected these fractures by placing 2 anatomical plate types according to the plate manufacturers’ instructions. The residual positioning errors of the distal segment in relation to the unaffected radii were determined using 3-dimensional imaging and were compared with naturally occurring bilateral radius differences in healthy individuals. In many cases, positioning does not agree with differences based on bilateral asymmetry in healthy patients.

This study indicated the accuracy of anatomical plates. Positioning an anatomical plate may lead to considerable residual errors in individual patients. Volar distal radius plate shapes differ among plate manufacturers. Therefore, one plate may perform better than another in an individual.
Fixed-angle volar distal radius plates provide stable fixation after radial fractures or corrective osteotomies of malunited fractures.1-4 The most recent variation of this type of plate is the anatomical plate, which is preshaped to optimally fit the contour of the distal radius. The anatomical plate is designed to bring the distal radius to its original anatomical position. A correlation exists between the accuracy of the anatomical reconstruction of a wrist and its function.5-7

Over the past decade, several anatomical plates have been introduced to improve the results of open reduction and internal fixation of the distal radius.8,9 The manufacturers of anatomical plates claim that no intraoperative adjustment in terms of bending of the plate is necessary because the shape of the plate is already adapted to the contour of the bone. The shape of the plate can be used as an intraoperative guide to determine the correct position of the dislocated distal radius segment.

However, the contour of the plate may not always optimally fit the distal volar radius profile. In a previous anatomical study, a statistically significant difference existed in the morphology of the distal radius in 55% of the study population.10 In these patients, plate application may lead to suboptimal plate positioning and a false distal radius segment position after plate fixation. In addition, shape differences exist between anatomical plates among manufacturers. Another anatomical study reported a considerable variation in ideal plate location among the anatomical plates from different manufacturers.12 It is sometimes unclear where to place the anatomical plate. Erroneous plate positioning can cause complications such as tendon ruptures and reduction loss.13,14

Based on these previous studies, the authors hypothesized that the results of distal radius segment positioning using an anatomical plate may vary due to anatomical variations in the morphology of radii, variations in anatomical plate contours between manufacturers, and subjective plate placement by surgeons. Although these parameters were studied separately in other studies, the relative importance of each factor is unclear.12-14 Therefore, the current authors investigated the accuracy and reproducibility of distal radius positioning using 2 anatomical plate brands—a 2.4-mm LCP distal radius plate, 04.110.440 (Synthes, Solothurn, Switzerland) and an Acu-Loc standard distal radius VDR plate, PL-DR50R (Acumed, Hillsboro, Oregon)—placed by 2 surgeons (J.C.V., S.D.S.) in multiple radii. The evaluation was performed with the help of 3-dimensional imaging techniques.15-21 The authors compared the residual errors observed in the current study with naturally occurring bilateral radius differences in healthy individuals.22

**Materials and Methods**

The authors simulated distal radius fractures and the correction of these fractures with plastic bone models of radii. To create artificial radii models with different morphologies, they obtained computed tomography (CT) scans of 5 healthy individuals (3 women and 2 men; average age, 23 years) with a Brilliance 64 CT scanner (voxel size 0.45×0.45×0.45 mm, 120 kV, 150 mAs, pitch 0.6; Philips, Cleveland, Ohio). The patients had no history of wrist injury or musculoskeletal disorders. The medical ethical committee of the authors’ institution approved this study, and informed consent was obtained from each patient.

From the CT scans, the authors segmented the right radius of each patient and printed acrylonitrile butadiene styrene models of the radii by additive manufacturing using a 3-dimensional printer (SST1200es 3D printer; Dimension, Inc, Eden Prairie, Minnesota). The resolution of the printer was 254 μm. Five radii models (models 1-5) were printed to investigate the effect of radius morphology on positioning, the differences between plates, and the interoperator plate positioning variability (Figure 1A). To

![Figure 1: Five artificial 3-dimensional radii with different morphologies (A). A defect was simulated by removing a wedge from the distal part of each radius (B). The affected radius was corrected with an Acumed plate (Acu-Loc standard distal radius VDR plate, PL-DR50R; Acumed, Hillsboro, Oregon) and fixated with cyanoacrylate glue shown from different angles (C, D).](image-url)
High-resolution CT scans were obtained of the models; they served as references for finding residual positioning errors after plate fixation. A defect was simulated by removing an arbitrary wedge shape from each of the 9 artificial radii (Figure 1B). Two surgeons corrected the affected radii by placing the anatomical plates according to the plate manufacturers’ instructions. The distal part of the plate was placed at the best possible position against the watershed line. The proximal part of the plate was placed in line with the shaft of the radius. This plate was fixated with cyanoacrylate glue (Figures 1C, D). The surgeons performed this procedure with a Synthes plate (2.4-mm LCP distal radius plate) and an Acumed plate (Acu-Loc standard distal radius VDR plate). All radii were corrected in random order.

After plate fixation, CT scans were obtained of the corrected physical models with the plate in situ, which allowed the residual positioning errors of the distal segment to be calculated in relation to the previously scanned unaffected artificial radii. The method of finding these residual positioning errors was reported by Dobbe et al.\textsuperscript{23} Using this method, the CT image containing the unaffected physical radius model was segmented to create a virtual 3-dimensional model of that radius. Subsequently, a distal part of this virtual bone model and a larger proximal part were selected and aligned with the CT image of the corresponding corrected radius using intensity-based image registration.

When the proximal segments were aligned, the residual positioning error was shown as the degree to which the positions of the distal segments differed. This allowed the authors to calculate the residual displacements ($\Delta x$, $\Delta y$, $\Delta z$) and rotations ($\Delta \varphi_x$, $\Delta \varphi_y$, $\Delta \varphi_z$; rotation sequence y, x, z) for aligning the corrected radius with each corresponding reference radius. To compare the positioning results between the radii of different morphologies, an anatomical coordinate system was aligned with the virtual radius of each reference radius in the same way (Figure 2)\textsuperscript{23}. Positioning parameters are expressed in terms of these anatomical coordinate systems. All image analysis steps were performed with custom software.

The residual errors in the current study were compared with naturally occurring bilateral radius differences in healthy individuals ($n=20$).\textsuperscript{22} When using 3-dimensional imaging techniques, which are often used in corrective surgeries, the...
contralateral radius is used as a reference for correcting the affected radius. No better reference is available. Therefore, the range of bilateral differences in healthy individuals is considered acceptable for comparison with the current results.

**Statistical Analysis**

Statistical analysis was performed nonparametrically. Differences in positioning due to morphological variation between radii were assessed with a Friedman test. Paired Wilcoxon signed rank test was used to assess whether differences existed in positioning between surgeons and between the Acumed and Synthes plates. The dataset of models 1 through 5 was used for all tests. The dataset of the models 1B through 1E was used to demonstrate a possible intraoperator variability of distal radius positioning. A P value less than .05 was considered statistically significant.

**RESULTS**

In the current study, the anatomical plates fit well on the radii surfaces. Figures 3 and 4 indicate that residual displacements along the axes of the anatomical coordinate system (Δx, Δy, Δz) are in the order of 0 to 2 mm, whereas rotations around the axes (Δϕx, Δϕy, Δϕz) can be up to 14° in individual cases (Δϕz1 in Figure 3). The reproducibility of positioning on the same bone morphology 5 times by both surgeons (Figure 3) and the variability in positioning on the distal radius segment of 5 individuals (Figure 4) are in the same order of magnitude but slightly smaller for the case of a repetitive plate placement with the same bone geometry (Figure 3).

According to the effect of morphology variety, a significant difference for positioning parameter Δy (P<.05) was only observed between the different physical

### Table:

**Comparison With Healthy Individuals**

<table>
<thead>
<tr>
<th>Positioning Parameter</th>
<th>Bilateral Difference in Control Group (n=20) (Average Range ± 2 SD)</th>
<th>Acumed (n=10)</th>
<th>Synthes (n=10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average Range</td>
<td>No. Cases Not in Range</td>
<td>Average Range</td>
</tr>
<tr>
<td>Δx, mm</td>
<td>−3.25-1.63</td>
<td>2</td>
<td>−0.60-3.41</td>
</tr>
<tr>
<td>Δy, mm</td>
<td>−1.29-1.27</td>
<td>5</td>
<td>−2.02-1.91</td>
</tr>
<tr>
<td>Δz, mm</td>
<td>−1.43-6.69</td>
<td>5</td>
<td>−4.90-3.56</td>
</tr>
<tr>
<td>Δϕx, deg</td>
<td>−1.87-2.13</td>
<td>7</td>
<td>−6.72-11.02</td>
</tr>
<tr>
<td>Δϕy, deg</td>
<td>−3.30-2.10</td>
<td>6</td>
<td>−9.32-7.33</td>
</tr>
<tr>
<td>Δϕz, deg</td>
<td>−9.47-10.53</td>
<td>0</td>
<td>−5.12-4.69</td>
</tr>
</tbody>
</table>

*The ranges of bilateral asymmetry in the control group represent the generally accepted ranges for the experiments. For the Acumed (Hillsboro, Oregon) and Synthes (Solothurn, Switzerland) plates, the results for both surgeons were considered for the physical models (models 1-5).
models (models 1-5). Positioning using an Acumed plate was statistically significantly different for parameter $\Delta \psi$ ($P<.05$) compared with positioning using a Synthes plate. No statistically significant differences existed in positioning parameters between the 2 surgeons.

The Table compares the results of residual positioning errors with naturally occurring bilateral differences in healthy individuals. These bilateral differences between the right and left radius were $-0.81 \pm 1.22$, $-0.01 \pm 0.64$, and $2.63 \pm 2.03$ mm for $\Delta x$, $\Delta y$, and $\Delta z$, respectively, and $0.13^\circ \pm 1.00^\circ$, $-0.60^\circ \pm 1.35^\circ$, and $0.53^\circ \pm 5.00^\circ$ for $\Delta \psi$, $\Delta \psi$, and $\Delta \psi$, respectively. The Table shows the 95% confidence interval (mean $\pm$ SD) as a generally accepted range because the contralateral side is the best reference available in corrective surgery. This allowed the authors to judge which cases were suboptimal. In many patients, positioning is less accurate compared with what can be achieved when the contralateral bone is used as a reference. The Table indicates how many cases were not in the accepted range.

**DISCUSSION**

The current authors investigated the accuracy and reproducibility of distal radius positioning using an anatomical plate. The hypothesis was that positioning may be influenced by different radii morphologies, different anatomical plate contours, and the subjective placement of the plate by the surgeon.

An anatomically shaped plate should facilitate adequate bone positioning for every patient. Because plates are designed for the average patient and differences between bone morphologies exist, positioning errors occur for individual patients. This study showed a large variation in positioning, mainly due to subjective placement by the surgeons. This explains why the authors could not establish the apparently smaller effect in malpositioning due to morphological differences for all parameters. However, a small but statistically significant difference existed for parameter $\Delta y$ ($P<.05$) between the radii.

When comparing the positioning parameters between the Acumed and Synthes plates, a difference ($P<.05$) existed for parameter $\Delta \psi$ (surgeon 1; Figures 3, 4). This can be explained by the visible shape differences between the Acumed and Synthes plates (Figure 5). Angle $\alpha$ is likely to influence parameter $\Delta \psi$, and angle $\beta$ is likely to influence parameter $\Delta \psi$. Different plates provide different ways of positioning. Differences in plate definition are likely due to differences in the underlying subpopulations used by the manufacturers. The large differences between subpopulations indicate larger differences between individuals. Therefore, an anatomical plate may perform well for 1 patient but be inadequate for another patient.

The large variability in positioning by both surgeons indicates subjectivity in plate placement. The authors found no statistically significant difference in placement between surgeons due to the high intraoperator spread (Figure 3).

In many patients, the residual positioning parameters of the current experiments fall out of the generally accepted range of bilateral differences in healthy individuals. When considering all 6 positioning parameters simultaneously for each experiment, all of the experiments have 1 or 2 positioning parameters that are not in the range seen in healthy patients.

In addition to the low statistical power, another limitation of this study was that the surgeons had a clear view of the whole radius. Intraoperatively, surgeons do not have a clear view of the radius, and more positioning errors may occur in a clinical setting than reported in this study. Moreover, surgeons can use the ulna as guide for positioning the distal radius along the bone axis intraoperatively. In performing the bone correction with the anatomical plate on the physical radius models, the surgeons did not have this reference. Therefore, parameter $\Delta \psi$ has no clinical relevance in this study.

Abnormal morphologies were not included in this study. Bone surface deformities, such as those seen with malunions, may not allow the anatomical plate to fit on the bone morphology. Using an anatomical plate for corrective osteotomies of the malunited distal radius will introduce higher positioning errors than were reported in this study.

**CONCLUSION**

This was an explorative study to determine the accuracy of anatomical plate positioning and the factors influencing the final positioning result. Future studies should be performed with more statistical power to more accurately quantify the effects of bone morphology and plate shape on positioning of the distal radius segment.

Nevertheless, positioning with an anatomical plate may lead to considerable residual errors for individual patients that
fall out of the generally accepted ranges in healthy patients, mainly due to plate placement uncertainty.

REFERENCES


