EPiC Series in Health Sciences
Volume 7, 2024, Pages 202–206
Proceedings of The 24th Annual Meeting of the International Society for Computer Assisted Orthopaedic Surgery

# Development and evaluation of a shape completion model for corrective osteotomy of distal radius malunion patients

Camiel J Smees[1,2], Judith olde Heuvel[1], Esmee D van Uum[2], Anne JH Vochteloo[1], Gabriëlle JM Tuijthof[2]
[1] OCON, Hengelo, the Netherlands
[2] University of Twente, Enschede, the Netherlands
c.smees@ocon.nl

**Abstract**

3D planning of a corrective osteotomy of a radius malunion requires a healthy reference which is not always available. A shape completion model could create a reference bone based on the unaffected part of the malunited bone. The aim of this study is to develop and validate a shape completion model for clinical use.

A statistical shape model (SSM) was developed based on CT scans of 80 healthy radii. This SSM was expanded into a shape completion model to predict the distal 12% of the radius, based on the proximal 88%. Nine other CT scans were used to validate this model and to set hyper parameters that dictate factors of the available data. Finally, eight more CT scans were used to test the performance of the shape completion model.

The average accuracy of the shape completion model, measured through a root mean square difference, was 0.42mm (SD 0.10) and the average Hausdorff distance was 3.57mm (SD 1.09). The predicted radii were comparable to the actual radii, with the differences mainly found at the radial styloid, Lister tubercle and the sigmoid notch. The radiocarpal articular surface was often well predicted.

In conclusion, the current shape completion model showed to predict clinically useable models that have error margins that are comparable with previous models described in literature. Future research should compare the use of the shape completion model to the use of the contralateral radius to find what technique works more optimal.

## 1 Introduction

A symptomatic distal radius malunion is often treated with a corrective osteotomy. The malunion usually requires a multiplanar correction. This is difficult to achieve free-hand, and 2D X-rays give insufficient information to plan this correction [1]. Therefore, planning of radius osteotomies are increasingly performed in 3D, after which 3D printed patient specific (saw and drilling) guides are designed.

The 3D planning is performed by mirroring and aligning the healthy contralateral CT-based radius over the affected radius. However, this method has a few drawbacks. First, it depends on the accessibility of a healthy contralateral radius, which is not always available due to bilateral deformity [2]. Additionally, studies have showed that intra-patient bilateral shape differences are present, which means that the contralateral radius may not be a perfect representation of the pre-fracture situation [3]. These drawbacks demonstrate the need for an alternative way of obtaining a healthy representation of the affected radius.

Such an alternative might be the use of a statistical shape model (SSM). A SSM determines the statistical shape variations in a dataset of healthy radiuses. It creates an average shape, accompanied with principal components. Principal components are groups of shape variations that are present in the input dataset, which can be dialed to represent specific representations of the variation. An advanced version of a SSM is a shape completion model; the healthy part of the affected radius is used to determine the settings for the different principal components. The average shape, combined with the settings of the principal components then represents the healthy version of the affected radius.

The aim of this study is to develop a shape completion model and to validate this model for clinical use.

# 2 Methods

A total of 97 patients with a distal radius malunion and a healthy contralateral arm were retrospectively included. The CT scans of the healthy arms were extracted and converted into 3D models. 80 scans were allocated to build the SSM, 9 to validate the model and to set hyper parameters of the shape completion model. To test the outcome of the shape completion model 8 scans were used.

## 2.1 Statistical shape model

Building the SSM was done using the scripting library for statistical shape modeling and model-based image analysis Scalismo (University of Basel, Graphics and Vision Research Group).

The SSM was built similar to the study of Mauler et al. [4]. The 80 scans were placed into correspondence through a combination of scaling, rigid and non-rigid iterative closest point matching. Next, a generalized Procrustes analysis was used to create an average radius shape. This is then used in a principal component analysis (PCA). This creates a summary of all shape variations, with a rating of importance of each variation. The average radius shape together with the PCA form the SSM.

The performance of the SSM was evaluated with three variables. The compactness showed that 4 principal components are needed to capture 95% of the variability within the population. The found generalization was a root mean square error of 0.33 mm. The specificity was found to be 1.12mm (SD: 0.27) over 10 sampled meshes. These were all deemed acceptable for use in the shape completion model.

## 2.2 Shape completion model

The SSM was expanded into a shape completion model. First, correspondence between the 9 validation models and the reference model was obtained. The distal 12% of the 9 models was cut off, which roughly corresponds with the position of a distal radius fracture. The proximal 88% of these models are used to determine the settings for the PCA though a Gaussian process regression. This Gaussian process assumes a certain degree of normally distributed uncertainty for each point, represented by a triple; the reference point, the corresponding deformation vector and the level of noise.

The most likely shape (the predicted radius) is the combination of all points and per point the most likely location.

The Gaussian process has a set of hyperparameters that dictate factors in the data. The validation set was used to find the best settings for these hyperparameters. The optimal settings were sigma: 150, scale factor: 5 and noise: 20.

The performance of the model was evaluated by the accuracy and the Hausdorff distance of the shape completion compared to the 3D models of eight scans.

# 3 Results

The results of the test set are represented in table 1. The average accuracy found was 0.42mm (SD 0.10) and the average Hausdorff distance was 3.57mm (SD 1.09).

| | Accuracy (mm) | Hausdorff distance (mm) |
|---|---|---|
| Radius 1 | 0.39 | 3.14 |
| Radius 2 | 0.43 | 2.78 |
| Radius 3 | 0.34 | 3.36 |
| Radius 4 | 0.32 | 2.43 |
| Radius 5 | 0.57 | 4.07 |
| Radius 6 | 0.53 | 4.37 |
| Radius 7 | 0.45 | 5.69 |
| Radius 8 | 0.31 | 2.68 |
| Average | 0.42 (SD 0.10) | 3.57 (SD 1.09) |

Table 1: The found accuracy in root mean square error per radius and the Hausdorff distances. Also, the averages are given.

In figure 1, the comparison between the predicted radii and the original radii is represented. The most apparent differences are seen in the radial styloid, Lister tubercle and the sigmoid notch. Additionally, a length difference is observed in radius 5.

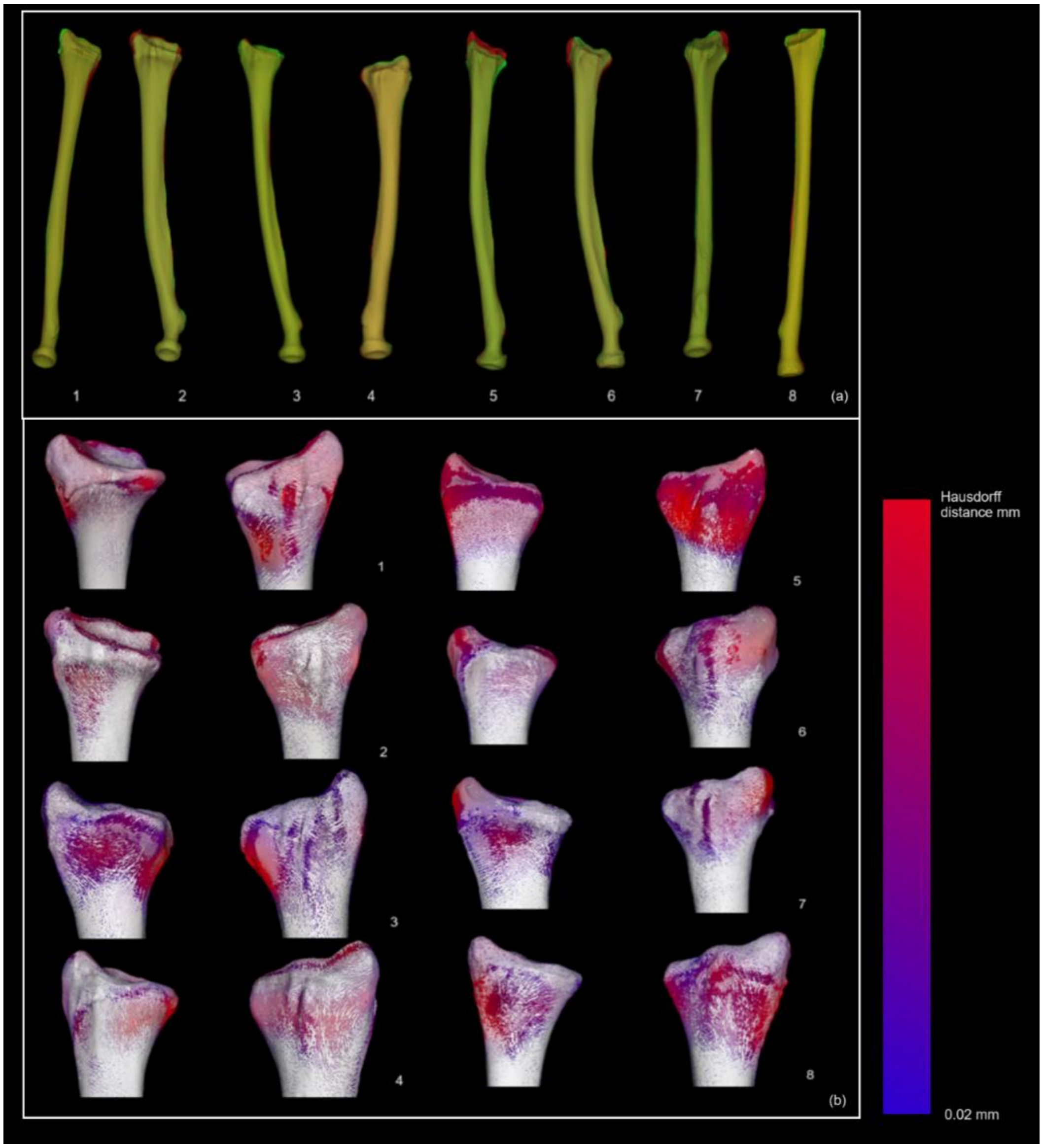


Figure 1: A) All predicted radii of the test set (red), with the corresponding original radii (green). B) The distal part of the radii is shown with the original radii (white), and the colored arrows depicting the amount and direction of deformation from a point to the predicted location. The colors range from the 0.02 to the Hausdorff distance of the specific radius.

# 4 Discussion

This study showed a SSM of the radius with a good generalization, consecutively building an accurate shape prediction model. Differences between predicted and the original distal radius were mainly found at the radial styloid, Lister tubercle and the sigmoid notch.

The accuracy of the current model (distance 0.42mm) is better than what was described by Mauler et al. 0.71 mm (SD 0.10) and Oura et al. 0.93 mm (SD 0.39) [4-5]. We expect that this is caused by the larger portion of proximal bone used to predict the distal section.

Studies have shown that bilateral differences of the distal radius can be as large as 4.10 mm. [6] The average Hausdorff distance found in this research was slightly smaller than this 4.10 mm. The mean accuracy of contralateral planning was 0.49 mm, which is less accurate than the found accuracy in this research, indicating that the model performs better in this area than contralateral based planning. The results show that the model could outperform the contralateral based planning. Future research should compare the use of the shape completion model to the use of the contralateral radius to find what technique works more optimal.

In conclusion, this preliminary shape completion model already showed to be able to predict clinically relevant models, with error margins that are on par with previous models described in literature.

# References

[1] Smees CJ, van Es EM, Tuijthof GJM, Colaris JW, de Graaff F, Vochteloo AJH. A comparison of 3-D CT and 2-D plain radiograph measurements of the wrist in extra-articular malunited fractures of the distal radius. Journal of Hand Surgery (European Volume), 2023. 0(0).

[2] Ekblom AG, Laurell T, Arner M. Epidemiology of congenital upper limb anomalies in Stockholm, Sweden, 1997 to 2007: application of the Oberg, Manske, and Tonkin classification. Journal of Hand Surgery (American Volume), 2014. 39(2):237-48.

[3] Vroemen JC, Dobbe JG, Jonges R, Strackee SD, Streekstra GJ. Three-dimensional assessment of bilateral symmetry of the radius and ulna for planning corrective surgeries. Journal of Hand Surgery (American Volume), 2012. 37(5):982-8.

[4] Mauler, F., et al., Prediction of normal bone anatomy for the planning of corrective osteotomies of malunited forearm bones using a three-dimensional statistical shape model. Journal of Orthopaedic Research, 2017. 35(12):2630-6.

[5] Oura, K., et al., Prediction of forearm bone shape based on partial least squares regression from partial shape. The International Journal of Medical Robotics and Computer Assisted Surgery, 2017. 13(3):e1807.

[6] Hong, E., D.A.-O.X. Kwak, and I.A.-O. Kim, Morphological symmetry of the radius and ulna-Can contralateral forearm bones utilize as a reliable template for the opposite side? PLOS ONE 16(10): e0258232.