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Automatic Friedman's Axis placement via the use of deep learning algorithms

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Abstract

Reference axis based on Friedman's approach is widely recognized as an anatomic landmark from which to measure and compare implant parameters within preoperative planning software for total shoulder arthroplasty. Equinoxe Planning Application (ExactechInc.) offers 3D measurements techniques for glenoid version and inclination requiring meticulous placement of trigonum and glenoid center. We propose as automatic determination of this reference axis, based on deep learning that shown a median error of less than 1°.

1 Introduction

Preoperative planning and surgery guidance of total shoulder arthroplasty (TSA) based on use of 3D computed tomography (CT) reconstruction, has proven effective in increasing surgery success. These technologies give the user better understanding of patient's pathology (Wanner, Maslow , & Byram, 2019) and increase accuracy of final implant placement (Schoch, et al., 2020). Preoperative planning allows surgeons to virtually choose implant, set its location and orientation against a reference axis (RA) created following the widely accepted Friedman technique (Friedman, Hawthorne, & Genez, 1992).

Creating the 3D scapular reconstruction needed for preoperative planning software is a time intensive semi-manual process. As well, the trigonum and glenoid center (GC) points necessary for the RA are placed manually on the 3D model, which are prone to error and both intra- and inter-observer variability. The added time and resources necessary to these steps increase the total cost of the procedure and increase the amount of time needed between the patient's CT scan and the TSA procedure. This study seeks to examine the accuracy of automated RA placement using a convolutional neural network (CNN) pipeline without manual point selection.

2 Material and methods

2.1 Data

This study includes a total number of 11745 shoulder CT scans from TSA cases. Each scan followed a specific protocol to ensure consistency in spacing, voxel sizing, and resolution. The RA was constructed by internally trained experts and reviewed. The cases were split in 4 subsets:

- Training (8220 cases) as training basis of CNN architectures.
- Validation (2345 cases) for CNN architectures assessment.
- Test (1170 cases) to assess the final pipeline architecture's performances
- Comparison (10 cases) composed of 5left and 5right cases where the RA was constructed 3 times, by 3 experts for a total of 9 RA axes constructed per case. This subset allowed comparison of the inter and intra-observer variability, and comparison against the pipeline prediction errors.

2.2 Prediction pipeline architecture

The prediction pipeline (PP) was divided into 2 stages. A two-stage approach was used to allow the use of reasonably sized CNNs to reduce computational hardware requirements, while reaching the required accuracy for surgery planning. 1st stage computed a gross prediction of the 3D-coordinates of trigonum and GC, letting to build volumes of interest. These volumes are given to the second stage, providing a well-balanced amount of spatial information, whilst restricted to local areas around the landmarks. The second stage computes the refined landmark location with the expected accuracy.

2.3 Evaluation of results

Evaluation of the validation and test subsets was performed by statistically assessing the GC prediction error as a 3D distance and the RA prediction error as a 3D angle. Ground truth is referred as the landmarks placed by internal experts, during the original segmentation process. The validation and test subsets were used to conduct a statistical accuracy assessment, while the comparison subset was used to compare the PP results against the intra- and inter-observer positioning variability.

3 Results

3.1 Validation and test subsets

Table 1 presents distribution of landmark prediction errors against ground truth for validation and test subsets. Median RA errors were 0.68° and 0.63° in the validation and test datasets, respectively.

	Validation dataset (n=2345)		Test dataset (n=1170)	
	Glenoid center error (mm)	Ref axis error (°)	Glenoid center error (mm)	Ref. axis error (°)
5%	0.31	0.18	0.31	0.17
25%	0.59	0.43	0.92	0.41
50% (median)	**0.88**	**0.68**	**0.63**	**0.65**
75%	1.29	1.04	1.31	1.11
95%	2.61	1.96	3.12	2.62

Table 1: GC prediction and RA angle error distributions against validation and test subset

3.2 Comparison dataset

For the 10 cases in the comparison dataset, the landmark prediction was computed from the PP. Figure **1** displays the error compared to the ground truth created by the experts and the PP.

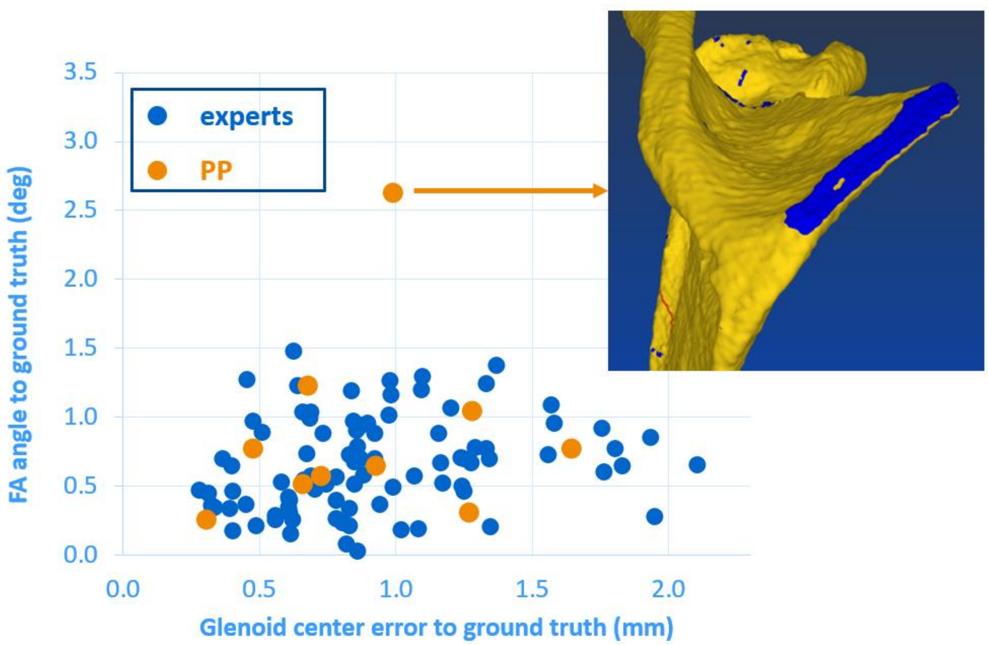

Figure 1: Predicted RA angle with ground truth (in degrees) vs GC distance to ground truth (in mm). Blue point series represent the error to the ground truth calculated for each of the 90 expert reconstructions. The orange point series represent the pipeline prediction error. Mesh of outlier PP prediction is shown on right.

For 9 out of the 10 cases, error to the ground truth demonstrated by the PP was equivalent or lower than the error demonstrated by the experts. GC error was lower than 1.7mm and the RA angle error was lower than 1.3°.

For the outlier case, the distance of predicted GC to the ground truth was acceptable (<0.5mm), but the RA angle error was greater than 2.5°. In this particular case, the CT scan did not include the full scapula bone, altering the trigonum region. This caused a significant error in placement of trigonum landmark and resulted in an increased angular error for this case.

4 Discussion

Results indicate that equivalent accuracy can be reached for RA construction from automatic PP computation. Over a cohort of 2345 cases, the median axis angle error was 0.68°. However, a change in the crop volume of the scan can significantly impact the algorithm accuracy, whereas a trained expert can easily discern and adjust for such cropping. Put alongside the previously developed automated scapula segmentation (Schmitt, Greene, Polakovic, Davis, & Bertrand), this algorithm is expected to reduce both time and resources involved in CT scan preparation for preoperative planning. It should reduce time and reconstruction processing time and surgery planification delay. Finally, we expect the algorithm developed in this study to lead to more consistent RA construction and better agreement with surgeon measured axes. This latter point has been identified critical for surgery success, yet limited agreement has been established in the literature (Erickson, et al., 2021). Moreover, as the RA serves as the basis for subluxation calculation methods, the increased consistency shown in this study may continue to reduce variability of these metrics in the future (Masten & Hsu, 2021).

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