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Fully Automatic Analysis of Posterosuperior Full-Thickness Rotator Cuff Tears from MRI

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Abstract

Rotator cuff tears (RCT) are one of the most common sources of shoulder pain. Many factors can be considered to choose the right surgical treatment procedure. Of the most important factors are the tear retraction and tear width, assessed manually on preoperative MRI.

A novel approach to automatically quantify a rotator cuff tear, based on the segmentation of the tear from MRI images, was developed and validated. For segmentation, a neural network was trained and methods for the automatic calculation of the tear width and retraction from the segmented tear volume were developed.

The accuracy of the automatic segmentation and the automated tear analysis were evaluated relative to manual consensus segmentations by two clinical experts. Variance in the manual segmentations was assessed in an interrater variability study of two clinical experts.

The accuracy of the tear retraction calculation based on the developed automatic tear segmentation was 5.3 mm ± 5.0 mm in comparison to the interrater variability of tear retraction calculation based on manual segmentations of 3.6 mm ± 2.9 mm.

These results show that an automatic quantification of a rotator cuff tear is possible. The large interrater variability of manual segmentation-based measurements highlights the difficulty of the tear segmentations task in general.

1 Introduction

Rotator cuff tears (RCT) are the most common source of shoulder pain. The tear thickness (partial vs. full), tear retraction and tear width, tear shape, and muscle quality, as evaluated on preoperative image data, are important considerations for treatment planning. Currently, the assessment of full-thickness RCT is described by Davison et al. in [1]. The retraction of the tendon in the coronal MRI and the width of the tear in sagittal MRI are measured as straight lines from tendon footprint to tendon stump.

Recently, Shim et al. presented a deep learning based method for automatic classification of RCTs from coronal MRI [2]. The algorithm categorises RCTs into five classes: none, partial, small, medium, Large-to-Massive. They use a class activation map to provide an estimated region of the tear location with a heatmap. However, to date, no method for automatic quantifying RCT retraction and width has been described.

In this study we propose a two-step algorithm for fully automatic analysis of posterosuperior full thickness RCTs, including deep learning-based segmentation of the tear for automatic tear size quantification.

2 Methods

For automatic segmentation of the tear, a 2D and 3D-full-resolution nnUnet [3] was trained with manual segmentations created by consensus of two clinical expert. The training data included 79 coronal proton-density- (N=72) and T2-weighted (N=7) MRIs with full-thickness posterosuperior RCTs. All patients underwent surgery in the same clinic; however, the MR images were acquired from different MRI scanners in different institutes and therefore showed a high variance in resolution, field strength and pulse sequence parameters.

For automatic quantification of the tear, an algorithm which calculates in each segmented coronal slice the distance between the most distant points on the segmentation border, was developed. The tear retraction is defined as the largest encountered distance along all slices. The tear width is calculated by the multiplication of the number of slices containing a tear segmentation times the slice thickness of the MRI sequence.

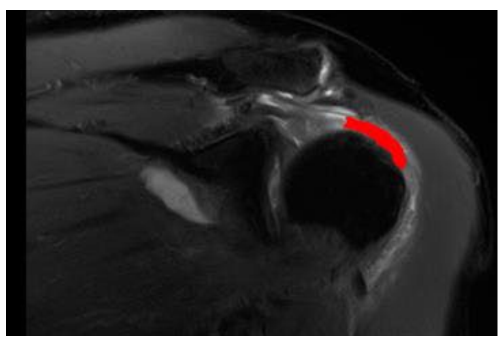

Figure 1: Segmentation (red) of the tear region in a coronal MRI

3 Results

The networks were trained in a five-fold cross validation against manual consensus segmentation (N=79). The 3D networks outperformed the 2D networks and achieved a Dice coefficient of 0.56 while an inter-rater variability Dice coefficient between one clinical expert and the consensus segmentation (N=35) was 0.54.

For evaluation of the entire proposed pipeline, the automatic segmentations from the 3D networks and the manual segmentations were analyzed by the second algorithm to compare the extracted tear retractions and tear widths.

The mean absolute tear retraction error calculated based on the automatic tear segmentation compared to the results from the consensus segmentations was 5.3 mm ± 5.0 mm and 5.8 mm ± 5.4 mm for the tear width. The absolute inter-rater variability of the tear retraction was 3.6 mm ± 2.9 mm and 7.9 mm ± 6.0 mm for the tear width.

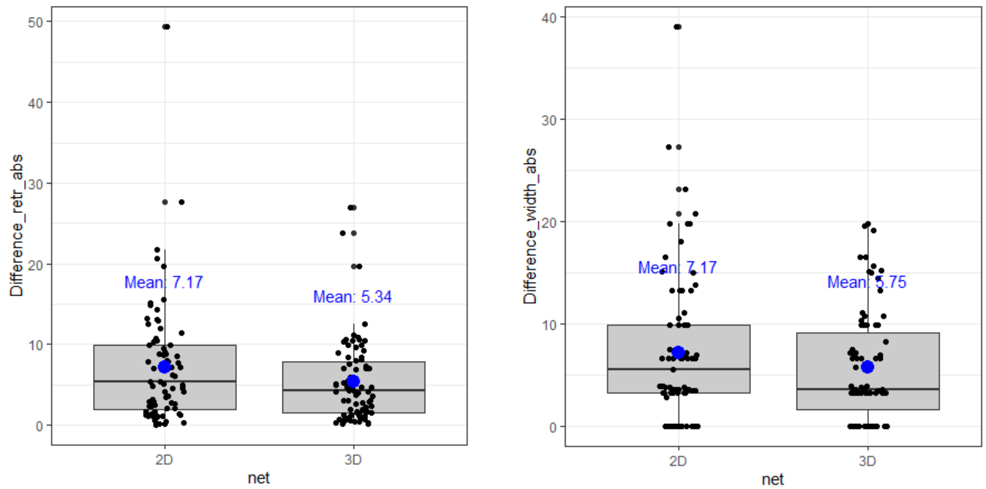

Figure 2: Absolute difference of the extracted tear retraction and tear width measurements between automatic and manual consensus segmentation.

4 Discussion and Conclusion

In this study we present a method for automatic RCT retraction and width measurement from MRI data. This algorithm allows a fast quantitative analysis of the tear of the Rotator Cuff Tendons and therefore builds the basis for further automated analysis on larger datasets to investigate better predictive metrics for rotator cuff repair outcome from 3D image data. The presented algorithms would also allow an efficient automated, user independent diagnosis of RCTs which can be used to determine the optimal reattachment site, the number of anchors and the need for a patch during surgery.

The high inter-rater variability observed in this study aligns with previous reports. Lippe et al. [4] showed a moderate inter-rater agreement by three board-certified shoulder surgeons classifying full-thickness tears from MRI into Patte categories [5].

Some torn tendons leave an empty gap between the footprint at the humeral head and the retracted tendon and therefore show a clearly visible tear region in the coronal MRI. However, the majority of the torn tendon stumps are frayed and show decreasing tendon quality from healthy tendon at the musculotendinous junction towards the footprint. These tears lead to the high inter-rater variability observed in this study because these tears do not show clearly visible tear region borders at the tendon side in coronal MRI.

The current algorithm analyses the tear width in the low-resolution direction of the coronal MRI while the manual tear width measurement in the clinical routine is usually done in sagittal MRI data. An additional segmentation algorithm for sagittal MRI should therefore be trained to assess the tear width in high resolution and with higher accuracy.

Additional segmentations of other tissue such as bone, muscle and tendons in the shoulder MRI would allow more sophisticated retraction and width measurement from the segmentation and facilitate tear classification.

5 References

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