Quantitative Quality Assessment of Coronary Artery Bypass Graft Surgery Using Ultrasound Images

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Introduction

Up to 9% of anastomoses performed during coroary artery bypass graft surgery are more than 50% stenosed due to surgical errors which can lead to unfavorable outcomes for the patient [1].
Epicardial ultrasound (EUS) has been suggested as an alternative approach for quality assessment of anastomoses and has shown promising results in ex-vivo and post surgery analysis studies. To use EUS during surgery a quantitative assessment of anastomotic stenotic rates (fig. 1) has to be made by automatic extraction of the area in the anastomotic sites from in vivo EUS sequences obtained on the beating heart.

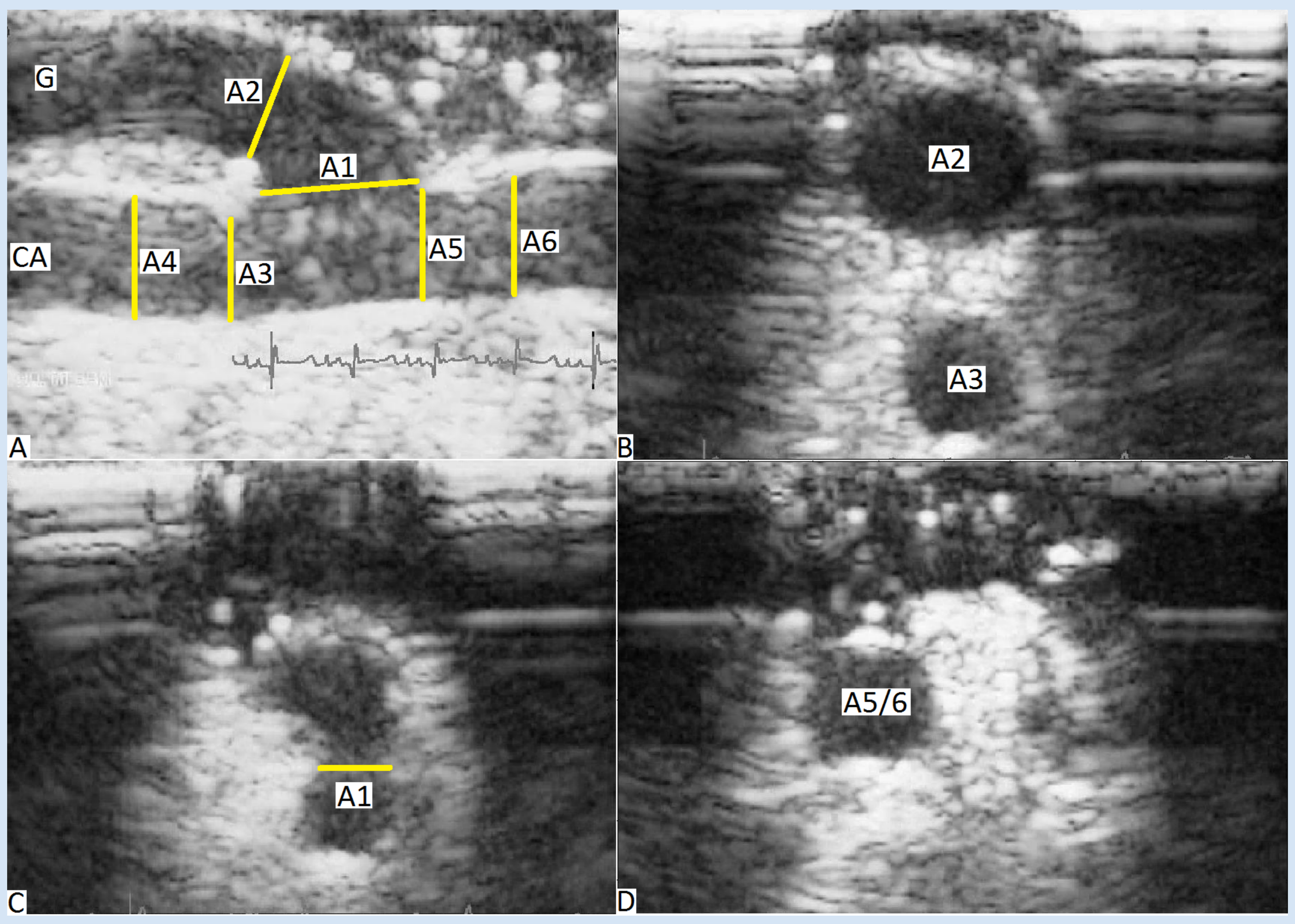

Fig. 1: EUS images of an anastomosis. (A) shows the anastomotic landmarks that has to be extracted in the longitudinal view. (B), (C) and (D) shows transverse views at the heel, midway heel/toe and toe site of the anastomosis.

The purpose of the study is to develop and test an algorithm for automatic segmentation of anastomotic structures in EUS sequences and use the segmented areas in the EUS sequences to estimate the area of the anastomotic sites.

Segmentation Algorithm

Currently an automatic anastomosis segmentation framework has been made using transverse images of the heel and toe sites of the anastomosis. It consists of a single frame vessel detection algorithm and vessel alignment, segmentation and quality control of the segmentations through the sequence (fig. 2).

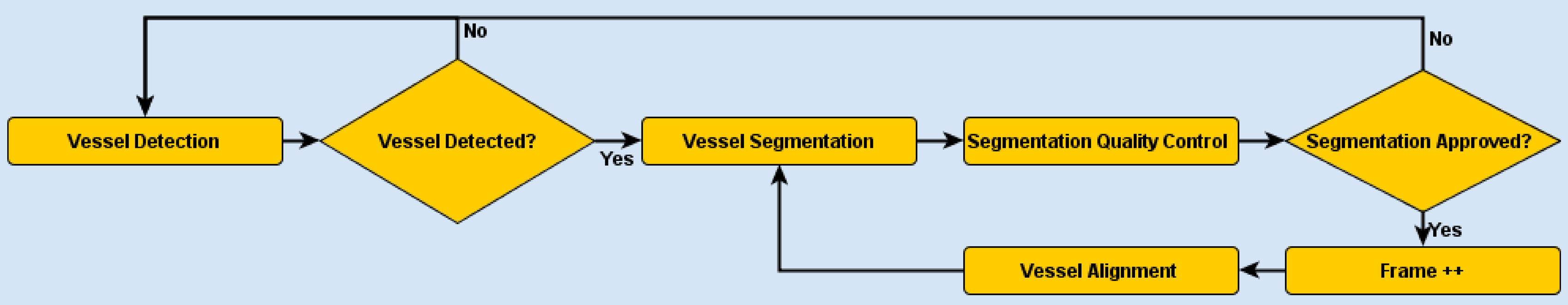

Fig. 2: Shows the flow of the segmentation algorithm.

Vessel detection:

- Initial vessel candidate segmentation.
  - Watershed.
  - Adaptive threshold.
- Vessel candidate classification (weighted voting classifier) of 8 extracted features from the vessel candidate segmentations.
  - Parzen Window Classifier.
  - Bayes Classifier.

Vessel alignment:

- Weighted centroid mean shift procedure (modification of [2]).

Vessel segmentation:

- Multi scale active contour using Gaussian low pass filters [3, 4].

Quality control:

- Contour gradient analysis in top, bottom, right, and left contour segments.

Data

Eight anesthetized pigs underwent coronary artery bypass graft surgery and one end-to-side anastomosis was performed on each pig. 10 independent in vivo EUS sequences, consisting of 40 - 112 frames, were obtained of the heel and toe site in each anastomosis using a GE Vivid 4 echo machine (General Electric) and a 13-MHz, i13L GE ultrasound transducer (General Electric, Schenectady, NY) mounted in a novel ultrasound transducer positioning device, Echoclip. The dynamic range was set to 70 dB, gain to 70 and imaging depth to 1 cm.

Preliminay Results

An 8-fold cross validation of the vessel detection classifier showed a mean sensitivity of 88.44%, specificity of 98.68%, and an overall accuracy of 92.82% in detecting vessels when defining regions with a vessel probabiliy >80% as a vessel region.
An a posterori visual validation has shown 78.51% of the vessel segmentations approved by the quality control were segmented correct.

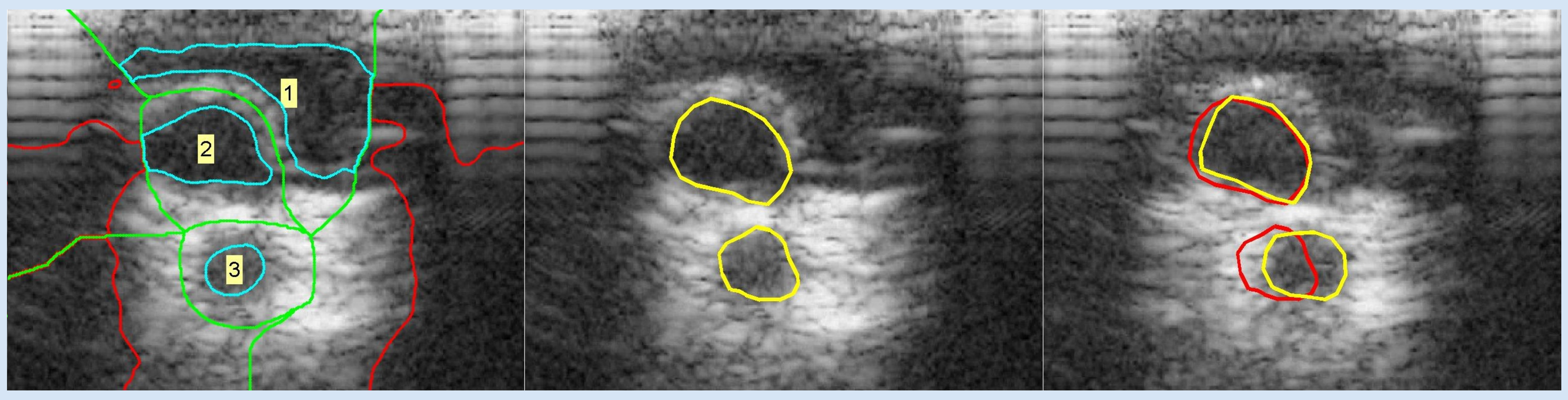

Fig. 3: Shows an example of the tracking and segmentation framework. (A) shows the vessel detection candidate segmentations in frame k. (B) shows the vessel segmentation of detected vessels in (A). (C) shows the result of the segmentations (yellow contour) in frame $k+1$. The red contours are the segmentations from frame k.

Discussion and Future Work

- The current algorithm has shown good preliminary results in healthy end-to-side anastomoses, however the performance in anastomoses with construction errors has yet to be determined.
- The specificity of the vessel detection may be improved by using more classifiers or use temporal information to ensure only vessel structures are detected in the EUS sequences.
- The quality control may be improved by including more features or it may alternatively be used as a parameter fitting tool for the active contour.
- The number of correct vessel segmentations may be improved by increasing the threshold for accepting segmentations. However that will cause an increased use of the detection algorithm during the sequences. Instead it may be more feasible to make the vessel segmentation more robust due to motion artifacts, missing vessel information and vessel branching by using more prior knowledge or temporal information to improve the segmentations.
- Anastomosis segmentation in longitudinal EUS sequences.
- Test of accuracy and reliability on simulated and human data.
- Area extraction algorithm.

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