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● *Original Contribution*

AN IMPROVED ALGORITHM FOR CORONARY BYPASS ANASTOMOSIS SEGMENTATION IN EPICARDIAL ULTRASOUND SEQUENCES

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Abstract—Epicardial ultrasound (EUS) can be used for intra-operative quality assessment of coronary artery bypass anastomoses. To quantify the anastomotic quality from EUS images, the area of anastomotic structures has to be extracted from EUS sequences. Currently, this is done manually as no objective methods are available. We used an automatic anastomosis segmentation algorithm to extract the area of anastomotic structures from *in vivo* EUS sequences obtained from 16 porcine anastomoses. The algorithm consists of four major components: vessel detection, vessel segmentation, segmentation quality control and inter-frame contour alignment. The segmentation accuracy was assessed using *m*-fold cross-validation based on 830 manual segmentations of the anastomotic structures. A Dice coefficient of 0.879 (±0.073) and an absolute area difference of 16.95% (±17.94) were obtained. The proposed segmentation algorithm has potential to automatically extract the area of anastomotic structures. (E-mail: asj@hst.aau.dk) © **2016 World Federation for Ultrasound in Medicine & Biology.**

Key Words: **Epicardial ultrasound, Vessels, Segmentation, Coronary artery bypass surgery, Quality assessment.**

INTRODUCTION

Coronary artery bypass graft surgery (CABG) is used to treat patients with severe cases of coronary heart disease. Mack et al. (1999) reported that up to 9% of the anastomoses contain stenoses >50% post-surgery. This can lead to poor long-term graft patency or can be fatal if not discovered. Intra-operative anastomosis quality assessment can disclose technical errors, enabling revision during the primary surgery (Mack 2008). The current gold standard for intra-operative quality assessment is coronary angiography, which is not available in many operating rooms (Mack 2008), and the stenosis assessment is associated with significant inter-observer variability (Beauman and Vogel 1990). Instead, ultrasound-based methods such as transit time flow measurement and epicardial ultrasound (EUS) have been proposed as they can easily be used in the operating room. Transit time flow measurement (TTFM) provides a functional assessment of anastomotic quality by measuring the flow through the anastomosis. However, it can only reliably detect stenoses >75% and cannot provide an exact location or cause of a stenosis (Jaber et al. 1998).

Epicardial ultrasound (EUS) can be used to visualize anastomotic structures to locate technical errors within the anastomosis, and the results for intra-operative quality assessment have been promising (Budde et al. 2005; Di Giammarco et al. 2014; Hol et al. 2007; Tjomsland et al. 2003). Additionally, dynamic information on the anastomotic structures during the cardiac cycle may be obtained by recording *in vivo* EUS sequences on the beating heart (Staalsen et al. 2011). Visualization of the anastomotic structures allows the surgeon to determine the stenotic rates within an anastomosis as a quantitative measure of anastomotic quality (Fig. 1). To determine the stenotic rates of an anastomosis, the area of the vessel lumen has to be extracted from various locations of the anastomosis (Fig. 1). Currently, no objective methods are available to extract the area of anastomotic structures from EUS sequences. Therefore, determination of anastomotic quality is subjective, and surgeons have to be trained to interpret EUS images or use peer reviews from a radiologist. Additionally, extracting the area of the anastomotic structures from *in vivo* EUS sequences

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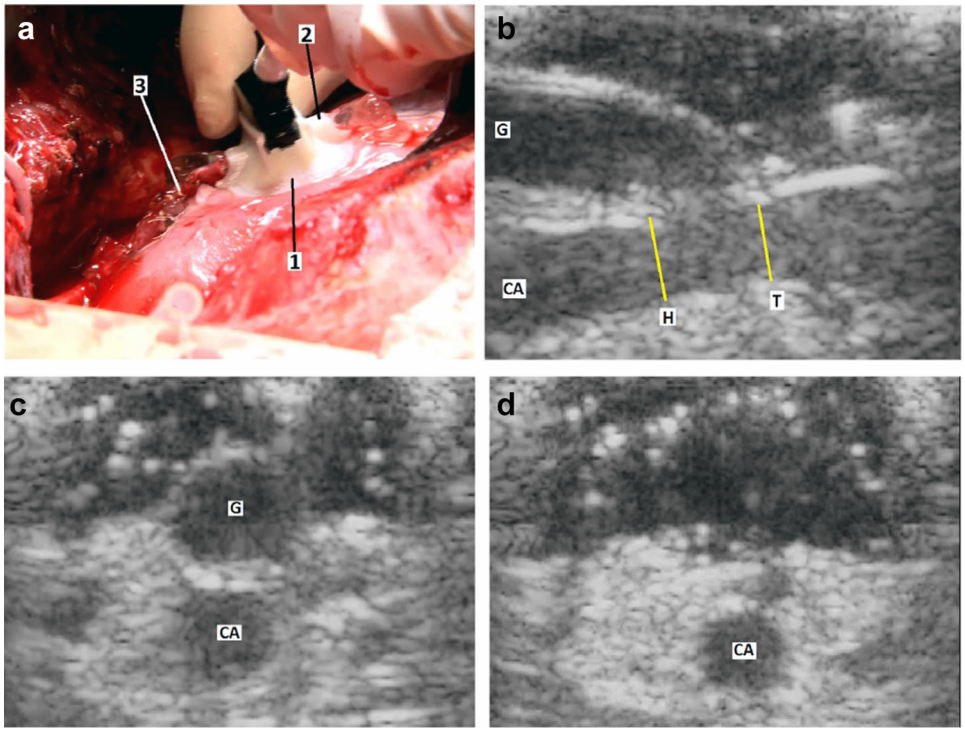

Fig. 1. (a) Acquisition of epicardial ultrasound (EUS) sequences using an EchoClip (1) (Staalsen et al. 2011). The EchoClip contain a cavity (2) for the ultrasound gel to maintain acoustic contact of the anastomosis without deforming the graft (3). (b) A longitudinal plane of an end-to-side anastomosis obtained using the EchoClip (G = bypass graft, CA = coronary artery). The *yellow lines* represent the heel (H) and toe (T) sites of the anastomosis. These sites mark the endpoints of the middle section of the anastomosis. Distal to heel and toe sites are the heel and toe sections of the anastomosis. These sections can be used to obtain a reference vessel area of the native coronary artery to determine the stenotic rates of heel and toe sites. (c) Cross-sectional image of the heel site corresponding to the *yellow line* on the left in (b). (d) Cross-sectional image of the toe site corresponding to the *yellow line* on the right in (b).

can be time consuming, which may limit the use of EUS in clinical practice (Budde et al. 2005).

Automatic extraction of the vessel lumen area of anastomotic structures from cross-sectional EUS sequences may help the surgeon objectively assess anastomotic quality (Fig. 1). To our knowledge, no other research groups have proposed automatic algorithms for segmentation of cross-sectional anastomotic structures through *in vivo* EUS sequences. This is a challenging task as the vessel area changes during the cardiac cycle, and movement artifacts occur when obtaining *in vivo* EUS sequences on the beating heart. Furthermore, the appearance of vessel structures in EUS images is affected by sound reflection properties creating speckle, artifacts and low-contrast anisotropic tissue structures. Tissue information can also be missing because of septal perforators emanating from the coronary artery.

Other studies have proposed semiautomatic algorithms for segmentation of vessel structures in ultrasound images (Guerrero et al. 2007; Ukwatta et al. 2012; Zahalka and Fenster 2001). Guerrero et al. (2007) proposed using a modified Star–Kalman filter to segment and track vessel structures through ultrasound sequences. The Kalman filter predicted ellipse parameters in subsequent frames to segment vessel structures. However, ellipse parameters do not describe all the possible shape variations of anastomotic structures caused by surgical manipulation of the vessels (Budde et al. 2005). Zahalka and Fenster (2001) and Ukwatta et al. (2012) have proposed using active contour models based on gradient and/or regional information for segmentation of the vessel lumen. However, using gradient information is not very robust for segmentation of low-contrast and anisotropic vessel structures (Jørgensen et al. 2012). Additionally, the intensity within the vessel lumen can also be anisotropic, making it difficult to obtain a suitable regional intensity term for the segmentation.

Model-based approaches such as active shape models (ASM) (Cootes et al. 1995) have been proposed for segmentation of structures with characteristic appearances and shapes. The ASM describes variations in the shape and appearance of objects using principal component analysis (PCA) based on training data from manual segmentations. The trained model is then used for