In totally endoscopic coronary artery bypass surgery, intra-operative assessment of anastomotic quality is needed. We evaluated the endoscopic application of epicardial ultrasound to visualize the coronary anastomosis and detect a construction error. In 8 pigs (71–78 kg), 16 internal mammary artery to left anterior descending coronary artery anastomoses were constructed conventionally, either correctly (n=8) or incorrectly with a suture cross-over construction error (n=8). A 13 MHz mini-transducer (15×9×6 mm) was introduced through a port and manipulated by the ‘da Vinci’ system. The chest was re-opened and scanning repeated manually. Postoperatively, macroscopic inspection served as reference and the intra-operative ultrasound images were scored as ‘correct’ or ‘construction error’ by two blinded observers. All anastomoses were scored accurately by both observers. One anastomosis constructed to be correct was scored as construction error, due to narrowing of the outflow corner and anastomotic orifice. Ultrasound images corresponded with macroscopic inspection. Closed-chest scan time was about 1.5 times longer than open-chest scan time, 176 s (88–464) (median, range) versus 125 s (75–314) (P<0.01), respectively. Closed-chest epicardial 13 MHz ultrasound scanning required a median of 3 min and enabled discrimination between correctly and incorrectly constructed coronary anastomoses.

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Keywords: Echocardiography; Ultrasound; Robotics; Anastomosis

1. Introduction

In totally endoscopic coronary artery bypass surgery (TECAB), anastomosis suturing is technically more demanding compared to open-chest surgery [1,2]. Limited working space, lack of an assistant to present the graft, more difficult to control bleeding from the arteriotomy and lack of tactile feedback on the telemanipulation systems hamper anastomosis construction. As a result, the risk of a technical construction error like, for example, accidental interlocking of the suture on opposite sides of the anastomosis (suture cross-over) is likely to be increased. Therefore, a method to intra-operatively assess anastomotic quality is needed in TECAB [3].

Recently, we described a 13 MHz epicardial ultrasound mini-transducer (15×9×6 mm) for visualization of different construction errors [4] and endoscopic localization of coronary arteries [5]. We investigated in the pig the endoscopic application of this mini-transducer to visualize coronary anastomoses and detect a construction error.

2. Materials and methods

2.1. Animals

Eight female Dutch landrace pigs (71–78 kg) were used. The animals received humane care in compliance with the ‘Guide for the Care and Use of Laboratory Animals’. The study was approved by the Animal Experimentation Committee of the Utrecht University.
2.2. Surgery

After anesthetizing the animals as described before [5], a partial median sternotomy was performed and the left and right internal mammary arteries (LIMA, RIMA) were harvested. Heparin was administered intravenously to obtain and maintain an activated clotting time (Hemotec, Inc., Englewood, CO, USA) of at least 200 s during anastomosis construction. The pericardium was opened and its edges suspended.

Using the Octopus-2 tissue stabilizer (Medtronic, Inc, Minneapolis, MN) [6], the distal anastomotic site on the left anterior descending coronary artery (LAD) was immobilized and dissected free. The pressurized LAD outer diameter and unpressurized IMA half circumference (diameter calculated with circle formula) was measured with a calliper. As described below, the distal RIMA-LAD anastomosis was constructed first followed by the proximal anastomosis (LIMA-LAD) at least one transducer length (15 mm) upstream. The pericardial suspension sutures were removed.

Trocars were placed as follows: one trocar (Ø 12 mm) in the left 6th intercostal space (stereoscope); one trocar (Ø 11 mm) subxiphoidally and one trocar (Ø 11 mm) in the left 5th intercostal space (‘da Vinci’ instruments) [2]; two trocars (Ø 15 mm) in the left second and the right fifth intercostal space for the EndoOctopus endoscopic cardiac stabilizer [7] and the ultrasound mini-transducer.

The chest was closed and the sternum hoisted ventrally (5 cm) by a table rail mounted sternum lifting device [7]. The ‘da Vinci’ computer enhanced telemanipulation system (Intuitive Surgical, Sunnyvale, CA) [2], was used for endoscopic manipulation of the mini-transducer. After the endoscopic scanning procedure, the chest was re-opened for open-chest manual scanning.

After sacrificing the animal, the anastomoses were excised and the posterior wall of the LAD was incised longitudinally to allow detailed macroscopic inspection of all areas of the anastomosis at 4.5× magnification and photography of the anastomosis.

2.3. Anastomotic procedure

A single investigator (RPJB) constructed all anastomoses in a running suture fashion using a 7–0 prolene suture (Ethicon, Inc, Sommerville, NJ).

Anastomoses were constructed to be correct (n = 8) or incorrect with a suture cross-over construction error (n = 8) in which two suture bites on opposite sides of the arteriotomy were deliberately interlocked midway between heel and toe. In each animal, one correct and one incorrect anastomosis was constructed. Anastomosis types were distributed equally over the proximal and distal anastomotic sites.

The LAD was clipped (medium Atraumaclip; Piling, Inc, Fort Washington, PA) midway between the anastomoses and upstream of the proximal anastomosis.

2.4. Ultrasound equipment

As before [4,5], a commercially available, high-frequency (up to 13 MHz in B-mode) linear array mini-transducer (15×9×6 mm) (Aloka, Tokyo, Japan) placed in a gel filled protective cover (Ultracover, International Medical Products, Inc, Zutphen, the Netherlands) was used.

For endoscopic handling of the mini-transducer by the ‘da Vinci’ instruments, a custom made snap-on metal probe holder was used [5]. The ultrasound image was displayed picture-in-picture on the ‘da Vinci system’ master console, providing the operator with the real-time scan image [5].

Open-chest manual handling was done using a commercially available handling tool (Aloka, Tokyo, Japan) [4]. Imaging was performed with an SSD 5000 Prosound ultrasound system (Aloka, Tokyo, Japan). Selected images were stored for retrospective analysis.

2.5. Ultrasound scanning protocol

After immobilization by the EndoOctopus [7] or Octopus-2 stabilizer [6], all anastomoses were scanned by the same investigator (RPJB). First, the anastomosis was visualized in a longitudinal scan plane using power Doppler imaging. Second, in the same longitudinal scan plane, the anastomosis was visualized in B-mode. Third, by translating the transducer from the toe towards the heel of the anastomosis, a sweep of the anastomosis in the transverse scan plane was performed using power Doppler imaging. Fourth, a transverse power Doppler image was obtained at the level of the visually determined maximal anastomotic orifice. Fifth and sixth, the transverse sweep and image, respectively, were obtained in B-mode. The time required to finish each scanning step was recorded.

2.6. Off-line assessment by independent observers

Two independent observers with prior experience in interpreting epicardial ultrasound images but without prior knowledge about number and type of anastomoses scanned, were separately presented sets of scan images in random order. Each set contained 4 images of one anastomosis (longitudinal and transverse image at level of visually determined maximum anastomotic orifice in both power Doppler and B-mode). The observers scored the anastomosis as correctly or incorrectly constructed.

2.7. Statistical analysis

Scanning times are presented as median with range and were compared using Wilcoxon signed ranks test. A P-value of P < 0.05 was considered statistically significant.
3. Results

3.1. Surgery

Diameter of the IMA and LAD were 2.3±0.4 and 3.2±0.6 mm, respectively. Correct and incorrect anastomoses could not be discriminated by external examination.

3.2. Ultrasound scanning

The picture-in-picture displayed ultrasound image provided sufficient detail for the operator to accurately position the transducer. Power Doppler imaging facilitated first time visualization and subsequent transducer manipulation to obtain images in the longitudinal axis. The transducer was easily manipulated endoscopically. By freezing the instruments and thus the transducer position, the operator was able to leave the master console of the ‘da Vinci’ system and inspect the real-time image in detail on the monitor of the ultrasound machine.

Images of a correct anastomosis are shown in Fig. 1. In the incorrect anastomosis, the overcrossing suture was easily spotted in longitudinal and transverse images as a strong echo reflection in the anastomotic orifice (Fig. 2). One anastomosis intended to be fully patent revealed a lateral ridge at the level of the anastomotic orifice and narrowing of the outflow corner (Fig. 3). Endoscopically obtained image quality was comparable to manual scanning.

Scan times are presented in Table 1. Endoscopic scanning was significantly more time consuming than manual scanning, 176 s (88–464) (median with range) versus 125 s (75–314), respectively (P=0.01).

3.3. Inspection

The lateral ridge detected in one correct anastomosis during scanning, proved to be a small flap of the distal IMA end that was inverted between two suture bites (Fig. 3). This anastomosis also showed outflow corner narrowing. In all incorrect anastomoses, a suture was seen transversing the middle of the anastomotic orifice (Fig. 2). One incorrect anastomosis revealed an unintended second suture cross-over at the level of the heel.

3.4. Off-line anastomosis assessment by independent observers

A total of 30/32 image sets were scored. Two sets were unavailable due to failed data storage (manual scanning of 1 correct and 1 incorrect anastomosis). Of the remaining 15 correct anastomoses sets, 13 were scored as correct and 2 (endoscopic and manual image sets of the same anastomosis) as incorrect. The latter was the anastomosis that revealed irregularities at macroscopic inspection. Of the incorrect anastomosis sets, 15 out of 15 were scored as incorrect. Thus, all anastomosis image sets were scored accurately by both observers. Overall, scoring required less than 1 min per anastomosis.

4. Discussion

The principal results of this study are: (1) Epicardial ultrasound enabled closed-chest visualization and assessment of the coronary artery anastomosis in a median of
3 min; (2) correct and incorrect anastomoses were identified properly during off-line assessment.

4.1. Anastomotic quality control

In conventional coronary artery bypass grafting (CABG), several techniques have been described to intra-operatively assess anastomotic quality including: graft flow measurement [8], epicardial ultrasound imaging [4,9,10], and fluorescence imaging [11]. All these techniques have one or more features that limit or prohibit their use in TECAB. Angiography [12] is used in TECAB, and still considered the gold standard, but is invasive, time consuming and unavailable in most operating rooms. Flowmetry is fast and easy to use but may require removal of periadventitial tissue from the graft to ensure proper contact. This may damage the graft. Furthermore, only severe stenoses are detected (>75%) [8]. Fluorescence imaging uses a large camera to obtain images, preventing its use endoscopically [11]. In addition, the penetration depth of a fluorescence camera is limited, making visualization of vessels and anastomoses embedded in the epicardial fat and/or myocardium difficult. Epicardial ultrasound has shown promising results in open-chest CABG [4,9,10]. It is non-invasive, relatively inexpensive, fast, provides anatomical information and can also be used to select the optimal anastomotic site on the target artery [13]. The relatively large size of the transducer has limited its use mostly to the anterior side of the heart. With the recent development of smaller and higher frequency transducers they are under renewed interest [4,9,10,13].

In addition to the IMA-LAD anastomoses, we endoscopically scanned two IMA to obtuse marginal anastomoses in the pig model, indicating that the mini-transducer is small enough for visualization of anastomoses on the posterior side of the heart [unpublished observation].

4.2. Suture cross-over anastomosis

We feel that the suture cross-over is a technical construction error that might occur during endoscopic anastomosis construction. It is conceivable that such an error would go unnoticed intra-operatively, possibly leading to anastomotic failure during longer follow up periods. Furthermore, it is difficult to detect by any other quality control method.

4.3. Validation by macroscopic inspection

Macroscopic inspection at 4.5× magnification provides a true anatomical inspection and supplies more detailed information than the clinical gold standard angiography. We have made angiograms of suture cross-over anastomoses on ex-vivo hearts and found the suture cross-over error is very hard to detect angiographically (unpublished observation).

4.4. Epicardial ultrasound scanning

Overall, endoscopic scanning time consumption was acceptable (maximum 464 s). Moreover, not all scanning steps as explored in this study need to be performed, as longitudinal still, transverse still and sweep B-Mode images provided most information. These were obtained by endoscopic scanning in 64 s (39–217) for correct and 133 s (58–242) for incorrect anastomosis.

4.5. Off-line assessment

Even though epicardial ultrasound images are most easily interpreted on-line, all image sets were scored accurately off-line by both observers, including the unintended errors in one correct anastomosis (scored as incorrect). This illustrates the potential of epicardial ultrasound for anastomotic quality assessment. However, the anastomosis type was known to the person scanning the anastomosis. Potentially, this might have introduced a bias.

5. Conclusion

In the pig, epicardial 13 MHz ultrasound was able to visualize correctly and incorrectly constructed coronary anastomoses.
anastomoses in closed-chest beating heart CABG. During off-line assessment all anastomoses were accurately identified as correct or incorrect by two blinded observers. It therefore is a promising technology for intra-operative anastomotic quality control in totally endoscopic coronary artery bypass surgery.

Acknowledgements

The authors acknowledge the technical contributions of J. Dries, E. van Zwol, C. Verlaan and M. Schurink.

References