

Detection of Coronary Arteries and Evaluation of Anastomoses with a Commercially Available 15-MHz, Broadband, Linear Array Transducer

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ABSTRACT

Background. In coronary artery bypass surgery the detection of the target vessels can be difficult due to their intramural location, coverage by adipose tissue, calcification, or fibrous tissue formation. Their identification is especially critical during off-pump coronary artery bypass (OPCAB) and minimally invasive direct coronary artery bypass (MIDCAB) surgeries. Our objectives were to identify whether (1) the epimyocardial use of the broadband linear array transducer CL15-7 allows a clear and rapid identification of the target artery during on-pump coronary bypass (CPB), OPCAB and MIDCAB surgeries; and (2) if this transducer is helpful in investigating the anastomotic morphology with 2D and color flow Doppler.

Methods. Thirty-two patients without a visually identifiable left anterior descending artery (LAD) were included in the study and epimyocardial ultrasonography was performed. Stabilization of the beating heart was used in 19 patients; in 13 patients, the surgery was carried out with CPB on the arrested heart. Two-dimensional ultrasound alone, or in combination with color Doppler, was used to identify the affected vessel as well as a suitable anastomosis site. Pulsed wave Doppler had to be used occasionally to differentiate between artery and vein. Patency of the anastomoses was established with color Doppler immediately after reinitiating blood flow. An evaluation of the distal graft diameter, its length, and the quality of the anastomosis was made with 2D and color Doppler. Transit-time Doppler flow was used to confirm patency.

Results. The LAD could be identified ultrasonographically in all 32 patients at a depth of 3 to 15 mm. The right coronary artery (RCA) was located at a depth of 3 to 10 mm in the 5 patients where this vessel was to be bypassed. The coronary arteries located on the lateral or posterior aspect of

the heart could not be reached due to the shape and rigidity of the transducer handle. The intended anastomosis sites of the LAD and RCA were identified with ultrasound according to their topography and morphology. In all cases the vessel could be dissected and bypassed without undue damage or bleeding. In one OPCAB patient, the LAD was identified in close proximity to the overlying vein along the whole of the anterior wall. This resulted in conversion to CPB, thus facilitating secure exposure of the LAD. The ultrasonographic visibility of the left internal mammary artery to LAD and saphenous vein graft to RCA anastomoses was excellent, and patency correlated well with the transit time flow measurements.

Conclusion. The CL15-7 transducer gives excellent near field visibility of the LAD and RCA. This is extremely valuable for the safe dissection of these vessels, especially during off-pump coronary surgery. The anatomical morphology of the anastomoses can be identified but, due to the shape of the transducer handle, only the coronary arteries on the anterior surface of the heart can be evaluated. A flexible, rather than a rigid, hockey stick-shaped handle would eliminate this problem. Training is essential to obtain reliable results.

INTRODUCTION

Off-pump coronary artery bypass (OPCAB) and minimally invasive, direct coronary artery bypass (MIDCAB) surgery have been employed to minimize the problems associated with on-pump coronary bypass (CPB) surgery, particularly postperfusion syndrome. However, a higher rate of anastomosis-related stenoses have been reported with these methods [Haaverstad 2002]. The operator is confronted with 3 major problems that are particularly important during minimally invasive surgeries: the localization and presentation of the target artery, the identification of a suitable anastomosis site distal to the stenotic plaque, and the qualitative evaluation of the anastomosis [Suematsu 2002]. The identification of the targeted coronary arteries by sight or palpation may be impossible if the vessel runs intramurally [Miwa 2004], is fibrosed due to previous surgery, or is covered by a large layer of fibrous-fatty tissue [Budde 2004]. In addition, bleeding from surrounding tissue during extensive dissection may make it difficult to see the optimal anastomosis site

Received February 26, 2007; received in revised form May 22, 2007; accepted May 24, 2007.

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Figure 1. CL 15-7 linear array transducer (Philips Medical Systems, Eindhoven, Netherlands).

consistently [Budde 2004]. Intraoperative ultrasonography with custom-built transducers has been used to minimize the time to detection and any tissue injuries [Haverstaad 2001; Eikelaar 2002; Budde 2004; Miwa 2004]. As it is more difficult to achieve the same quality of anastomosis during minimally invasive compared to conventional CPB surgery [Suematsu 2003; Budde 2004], a means of identifying not only the flow, generally assessed with transit-time flowmetry (TTF), but also the morphology of the site is beneficial. The coronary artery and variable anastomotic vessel resistances result in the absence of a clear cut-off point for adequate flow and make the interpretation of the TTF values difficult [Haaverstad 2000; Suematsu 2002]. Intraoperative ultrasonography with 2D [Eikelaar 2002], color [Tjomsland 2003; Budde 2004] and power Doppler [Suematsu 2001] has been used to overcome this limitation.

Our article investigates the use of a 15-MHz ultrasound transducer (CL 15-7, Philips Medical Systems, Eindhoven, Netherlands) for the detection of visually nonidentifiable coronary arteries and for the appreciation of the morphology of their diseased segments. The use of this transducer for the evaluation of graft patency, especially between the left internal mammary artery (LIMA) and the left anterior descending coronary artery (LAD), is also evaluated.

MATERIAL AND METHODS

Thirteen of our 32 patients were scheduled for CPB, 15 for OPCAB, and a further 4 patients for MIDCAB surgery (Table). The LAD could not be identified in any of the patients during surgery either visually or on palpation. To enable identification, a broadband, compact, linear array, high-resolution, rigid transducer (Figure 1) with a 2D frequency range of 7-15 MHz, a footprint of 3.5×1 cm, and a maximal imaging depth of 4 cm was used. The transducer was placed into a sterile sleeve. Sterile coupling gel inside the sleeve provided good contact between heart and transducer, and improved visibility. The probe was connected to a HDI 5000 ultrasound system (ATL; Philips Medical Systems) via a long, flexible cable.

In all patients an attempt was made to identify all target vessels with 2D ultrasound in long as well as short axis: LAD in 32, right coronary artery (RCA) in 5, either obtuse marginal branches (OMBs) or posterior descending artery (PDA) in 19, and the diagonal branch of the LAD (DIAG) in 17 patients. On the arrested heart, the ultrasound investigation was performed under continuous, antegrade administration of warm blood cardioplegic solution. On the beating heart, it was performed with the aid of tissue stabilizers (Medtronic Octopus System, Medtronic, Minneapolis, MN, USA; Immobilizer, Genzyme Surgical Products, Cambridge, MA, USA; or MIDCAB retractor, Baxter Healthcare, Chicago, IL, USA).

Once the affected artery had been identified in 2D, then pulse wave and color Doppler allowed the differentiation between artery and vein on the beating hearts. On the arrested heart, artery and vein could be differentiated with 2D echo due to the morphology of the vessel wall and with Doppler due to the direction of blood flow. This differentiation is especially important in cases where the vein is located close to and anterior to the artery. Long axis, 2D imaging established the location of the atherosclerotic plaque, thus avoiding dissecting into any calcification. The optimal point for the anastomosis was marked with the tip of a nontraumatic microforceps. Dissection was performed at that point after removal of the transducer.

All 32 patients received a pedicled LIMA to LAD bypass. In the 4 MIDCAB patients, this was the only bypass surgery performed. Five patients received an additional saphenous vein graft (SVG) to the RCA. A further 19 patients received

Patient Data

Age, y	67 ± 8 (42-87)
Male:female	18:14
No. of bypasses	
MIDCAB, n = 4	1 ± 0
OPCAB, n = 15	2.2 ± 0.9 (1-4)
CPB, n = 13	2.8 ± 0.9 (1-4)

*Data presented as mean ± standard deviation (range). MIDCAB indicates minimally invasive direct coronary artery bypass; OPCAB, off-pump coronary artery bypass; CPB, on-pump coronary bypass.

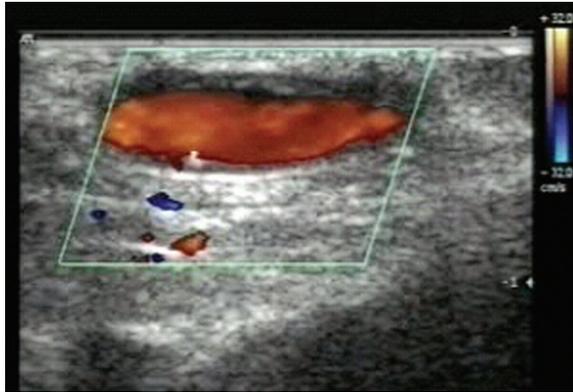


Figure 2. Two-dimensional and color flow Doppler of the right coronary artery.

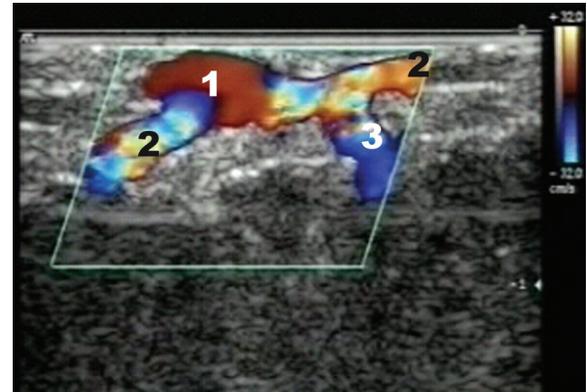


Figure 4. Color flow in a left internal mammary artery (LIMA) to left anterior descending artery (LAD) anastomosis. 1 indicates anastomosis between LIMA and LAD; 2, LAD; 3, septal branch of LAD.

SVG bypasses to OMB and/or PDA and another 17 patients an SVG to DIAG. Once the SVG was attached to the aorta, an attempt was made to establish patency with 2D and color Doppler. After the anastomoses were complete a 2D and color Doppler ultrasound investigation was carried out to assess patency and to check for hematoma, intimal flaps, or purse-string of the distal anastomosis sites. TTF measurement was used before chest wall closure as the standard method for confirming patency of all anastomoses.

RESULTS

Vessel Identification

In both stabilized and arrested hearts, the intramural course of the LAD was identified in all 32 patients at a depth between 3 and 15 mm. In the sternotomy patients (28/32), the vessel was fully visible down to the distal segment. In one patient the intended anastomosis site of the LAD proved surgically inaccessible due to the deep intramural course of the artery and associated vein. The intended OPCAB, therefore, had to be converted to a conventional CPB to facilitate secure

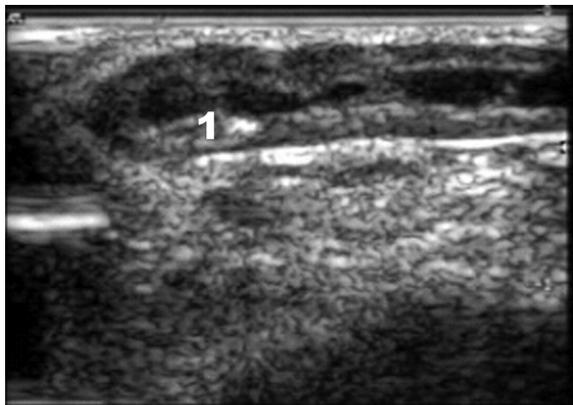


Figure 3. Altered morphology of the left anterior descending artery in two-dimensional imaging. 1 indicates atheromatous plaque

exposure of the LAD. The DIAG branches of the LAD were also easily found. The RCA (Figure 2) in the sternotomy patients could be followed as far as the crux cordis and was located at a depth of 3 to 10 mm. Due to the shape of the transducer, it was not possible to localize the OMBs or PDA in any of the patients. Altered morphology, such as thickening of the wall and atheroma formation within the original lumen of the LAD and RCA, was easily recognised with 2D imaging (Figure 3).

Assessment of Anastomoses

The investigation of the anastomosis sites with TTF showed patency and an acceptable pulsatility index (PI) < 5 in all but one anastomosis. All LIMA-to-LAD anastomoses performed through a median sternotomy (28/32) could be evaluated with the CL 15-7 transducer on the arrested as well as on the stabilized heart.

The distal aspect of the anastomosis, which describes the tip of the LIMA, did not show luminal narrowing. The length of the anastomosis was as long as the LAD incision. The diameter of the anastomoses was at least equal to the diameter of the attached LIMA. These parameters were visually assessed with 2D echo and color Doppler (Figure 4). In one anastomosis, the ultrasound investigation suggested a good anastomotic quality but the TTF showed sub-optimal flow of 8 mL/min (PI = 8). On closer inspection of the LIMA, a mural hematoma, located at the origin of a side branch, was identified as the cause. After release of the hematoma the blood flow rose to 32 mL/min with a PI of 2.2. The antero-lateral approach used for the 4 MIDCAB interventions did not allow appropriate ultrasonographic assessment of the LIMA-to-LAD anastomosis in two cases. This was due to the rigid handle of the CL 15-7 transducer. The evaluation of a venous anastomosis is much more difficult as veins are easily compressed by the weight of the transducer, but in all 5 patients with an additional SVG to RCA anastomosis, patency could be established with 2D and color flow imaging. The assessment of the 17 anastomoses between the SVG and the DIAG, however, was not always optimal. Patency of the

10 SVG-to-OMB and nine SVG-to-PDA anastomoses could only be established with TTF.

DISCUSSION

Vessel Identification

The transducer under investigation gives excellent visibility of the LAD and proximal RCA. This is in accordance with the results of other authors [Haaverstad 2002; Budde 2004, 2005, 2006; Miwa 2004]. In our study, the identification of the LAD, its branches, and the RCA was possible on the arrested, as well as on the beating but stabilized, heart. This is in accordance with the findings of Haaverstad [2001, 2002] and Tjomsland [2003], who describe the use of a Vingmed 10-MHz transducer and of Eikelaar [2002] as well as Budde [2006], who used an Aloka 13-MHz transducer.

Nevertheless, the use of this technique requires patience on part of the surgeon and is initially time consuming, especially when performed on the beating heart. A suction device, connecting the transducer to the myocardium, would ensure that the apposing surfaces of heart and transducer remain at the same level during the cardiac cycle. In on-pump surgery, an ultrasound scan over the region of interest prior to initiation of CPB would be helpful to differentiate between coronary artery and vein while there is still pulsatile, arterial flow.

Assessment of Anastomoses

The assessment of the quality of the anastomosis between the LIMA and LAD as well as between the SVG and RCA using the CL15-7 is equal to results achieved with the Philips 15 MHz transducer used by Miwa [2004], the Aloka [Eikelaar 2002; Suematsu 2002; Budde 2004, 2006], and the Vingmed [Haaverstad 2001, 2002; Tjomslands 2003] transducers. In all studies, the diameter, length, and lumen of the anastomoses were clearly visible. Although no anastomotic errors were detected in our study, it can be assumed that they would have been obvious because of the excellent image quality the CL15-7 transducer provides.

TTF may detect a decreased flow in cases of flawless anastomoses. This can be due to a graft kinking, spasm, intramural hematoma, or an anastomotic problem. On the other hand, a normal flow may be detected in the presence of adventitial flaps [Budde 2006]. The combined use of TTF and ultrasound in our study ensured that the inadequate TTF value in one case was identified as being due to a hematoma and not due to an inaccurate anastomosis.

Transducers

Due to the rigid, hockey stick-like shape of the transducer handle it was not possible to localize the coronary arteries on the lateral or posterior aspect of the heart.

OPCAB performed on pigs allowed Budde [2004] to detect the PDA, left circumflex artery, and OMBs with the Aloka transducer as well as assessing their anastomosis sites. Haaverstad [2002] describes that the coronary arteries on the lateral and posterior aspect of the heart could be inspected with the Vingmed transducer but only on the arrested heart, where displacement of the organ is possible. The

investigation of the OMBs and PDA on the beating heart as well as on CPB proved to be impossible in our study.

The high resolution and frame rate of the CL15-7 give excellent images of small structures. Its use for the investigation of the small and rapidly beating murine heart has been described by the study group of one of the authors [Ghanem 2006].

Conclusion

Epimyocardial ultrasonography is a quick and effective method for locating coronary arteries with an intramural course. The CL 15-7 transducer gives an excellent near-field visibility of the LAD, DIAG, and RCA. Atherosclerotic plaques or stenoses are easily identifiable. Anastomoses on the anterior aspect of the heart are clearly seen.

The use of this technique requires patience and is time consuming due to the cardiac movement. A suitable suction device would help to keep the orientation of the ultrasound beam during the cardiac cycle.

A major disadvantage of the CL15-7 transducer is its shape and inflexibility. However, with the transducer head connected to a flexible handle, the rectangular footprint and shape of the CL 15-7 transducer head would allow the investigation of the coronary arteries around the entire heart.

In our institution, the use of the CL15-7 transducer includes epi-aortic scanning and scanning of the proximal RCA, in certain cases of aortic surgery and in congenital heart surgery. It is also used in the experimental set-up where its high resolution and frame rate allows studies on the murine heart.

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