3

Robot-Assisted Epicardial Ultrasound for Coronary Artery Localization and Anastomosis Quality Assessment in Totally Endoscopic Coronary Bypass Surgery

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1. Introduction

Coronary artery bypass grafting (CABG) is a routine procedure, traditionally performed via median sternotomy access on the arrested heart with use of cardiopulmonary bypass (on-pump). It is the clinical gold standard for myocardial revascularization in patients with multivessel coronary heart disease but remains associated with significant morbidity and mortality (Borst & Gründeman, 1999).

Over the last 2 decades, minimally invasive approaches to CABG in the form of smaller incisions (Diegeler et al., 2002) and elimination of the heart lung machine (off-pump) (Borst et al., 1996) have been introduced to reduce surgical trauma and adverse effects of cardiopulmonary bypass, respectively. The introduction of robotic systems with 3D vision, tremor elimination and instruments with 7 degrees of freedom (mimicking the human wrist) has provided an important part of the technology that enables the ultimate form of minimally invasive CABG, namely off-pump totally endoscopic CABG (TECAB) (Loulmet et al., 1999; Falk et al., 2000a; Argenziano et al., 2006). TECAB (both on-pump and off-pump) remains a technically highly demanding procedure that is performed by only a selected number of surgeons worldwide. Major obstacles in TECAB include: creation of adequate working space, identification of the target vessel, exposure and stabilization of the coronary segment, anastomosis suturing and the evaluation of anatomosis quality.

High frequency (7.5 – 15 MHz) epicardial ultrasound (ECUS) is a non-invasive means to both locate and evaluate coronary arteries and assess the quality of the coronary anastomosis in open chest CABG (Suematsu et al., 2001; Haaverstad et al., 2002). In 2002, a 13 MHz epicardial ultrasound mini-transducer has become available that is small enough to pass a trocar and be handled by surgical robot systems (Budde et al., 2004a).

In this chapter we will summarize our previously published results of the endoscopic application of this ECUS mini-transducer to locate and assess target coronary arteries for bypass grafting as well as its use for quality assessment of the coronary anastomosis in a porcine model of robot-assisted closed-chest off-pump CABG (Budde et al., 2004a; Budde et al., 2004b; Gründeman et al., 2003).

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2. Da Vinci robot system

The robot system has been described in detail before (Loulmet et al., 1999). In brief, the surgeon sits at the surgeon console where a three-dimensional image from the endoscope is projected. By manipulating instrument controllers, the surgeon controls the actions of the surgical end-effectors in the patient that reproduce the motion of the surgeon's hands. The endoscope position is also controlled using the instrument controllers. The end-effectors of the endoscopic instruments have 7 degrees of freedom that mimick the human wrist, "endowrist". The endoscopic camera and instruments are attached to the patient console that is positioned at the operating table.

3. TECAB

The first TECAB procedure was described by Loulmet et al. in 1999 (Loulmet et al., 1999). Since then several groups have explored and refined this approach (Falk et al., 2000a; Kappert et al., 2001; Subramanian et al., 2005) and the results of a multicenter trial have been published (Argenziano et al., 2006). The current experience demonstrates that the procedure is feasible, remains mainly limited to single and double vessel disease, is associated with technical difficulties in up to 50% of cases (Bonatti et al., 2006) and requires long operative times (approximately 6 hours for a single vessel case) (Argenziano et al., 2006).

4. Ultrasound equipment

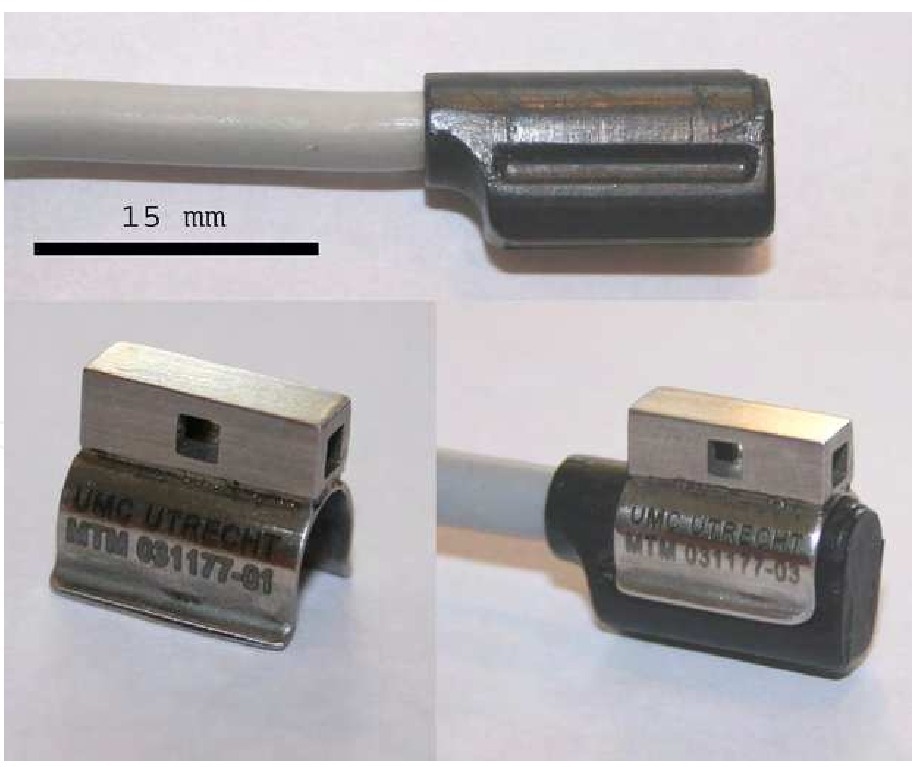

Figure 1. Thirteen MHz epicardial ultrasound mini-transducer (upper panel), custom made snap-on metal clip (left lower panel) and clip attached to mini-transducer (right lower panel). The clip is designed specifically for easy handling of the mini-transducer by the end-effectors of the robot instruments

A linear array ultrasound mini-transducer (Aloka, Tokyo, Japan) with an imaging frequency of up to 13 MHz has become available in 2002. It measures 15 mm in length, 6 mm in width and 9 mm in height, has an image scanwidth of 10 mm, an image depth of approximately 4 cm and offers both B-Mode and color-Doppler imaging (Figure 1). We used it in combination with an SSD 5000 Prosound ultrasound system (Aloka, Tokyo, Japan) for imaging. A custom made snap-on metal probe holder was developed by us to enable the end-effectors of the robot instruments to easily manipulate the mini-transducer inside the chest (Budde et al., 2004a).
The transducer is placed in a gel-filled protective cover which acts as a stand-off sleeve to facilitate scanning and improve image quality by limiting near-field artefacts. Furthermore, the sleeve acts as a sterile and current isolating barrier.
The ultrasound image is displayed picture-in-picture on the master console of the robot system. This provides the surgeon with the endoscopic and real-time ultrasound image simultaneously (Figure 2).

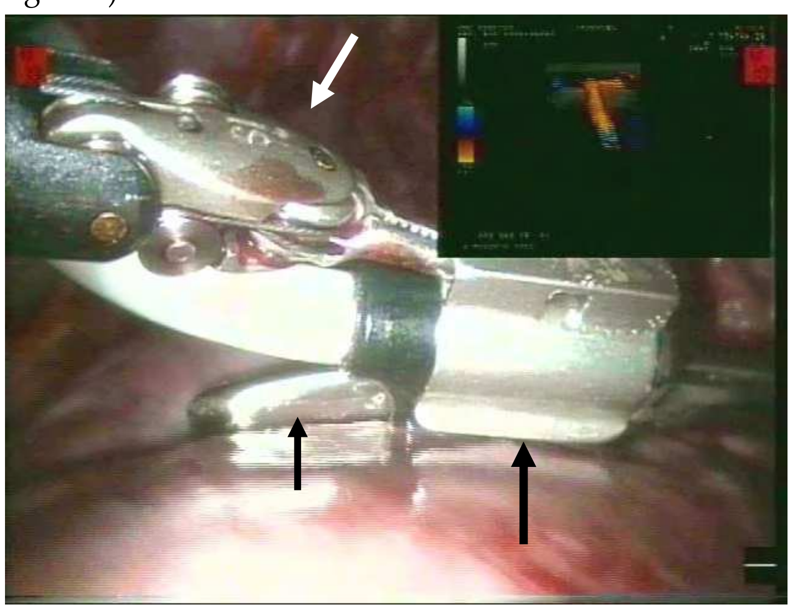

Figure 2. Surgeon's view on the master console of the robot system during scanning of the left anterior descending coronary artery in the porcine OPCAB model. The ultrasound mini-transducer (large black arrow) is positioned using the end effector of the robotic instrument (white arrow). The EndoOctopus suctionpod (small black arrow) is positioned on the epicardium behind the ultrasound transducer. The real-time ultrasound image is displayed as a picture-in-picture in the right upper hand corner which allows direct integration of the location of the probe and the visualized structures

5. Porcine off-pump TECAB model

We developed a porcine model of off-pump TECAB surgery (Gründeman et al., 2003). Pigs of 50-100 kg were anaesthetized and ports (5 or 6) for the instruments, camera and mini-transducer were placed on the left and right side of the thorax. Adaptations to the Octopus cardiac stabilizer (Borst et al. 1996; Gründeman et al. 2003) and Starfish cardiac positioner (Gründeman et al., 2003; Gründeman et al., 2004). were made for endoscopic use. To create additional working space inside the thorax, the sternum was lifted ventrally using a custom made sternum lift. In this model, by manipulation of the heart with the Endo-Starfish, access to all common target sites for CABG surgery can be obtained.

6. Coronary artery localization and assessment

In open chest CABG, the revascularization sites determined preoperatively on the angiogram are located intra-operatively by visual inspection and palpation. A thick layer of epicardial fibro-fatty tissue and/or an intramyocardial vessel course will render visual localization difficult.

In TECAB, in addition to the above mentioned difficulties, the limited overview, tangential angle of view and shift or lack of anatomical landmarks make the recognition of the anatomy by visual inspection even more difficult. Furthermore, the robot system lacks force feed back which prevents palpatory assessment of the target coronary artery. Failure to locate the left anterior descending artery (LAD) endoscopically resulted in intra-operative conversion to an open-chest procedure in up to 9% of patients undergoing TECAB (Kappert et al., 2001). In some cases, the diagonal branch of LAD or a coronary vein was mistakenly grafted instead of the LAD itself (Schachner et al., 2007).

7. Endoscopic vessel localization with ECUS

In the porcine TECAB model (n=8), we employed the ECUS mini-transducer to locate the common target arteries for bypass grafting (Budde et al., 2004a) The mini-transducer was introduced through a 15-mm port and was first manipulated over the anterior side of the heart in order to locate the LAD. Subsequently, the heart was lifted ventrally by the Endo-Starfish and the mini-transducer was manipulated over the posterior side of the heart to locate the third obtuse marginal (OM3) branch and the right posterior descending (RDP) coronary artery. The scanning procedure was performed both on the freely beating and partially stabilized heart. After localization of the vessel by ECUS, it was marked with a clip. Subsequently, the animal was terminated and the heart taken out to perform selective angiography of the left and right coronary arteries in order to determine the accuracy of ECUS localization.

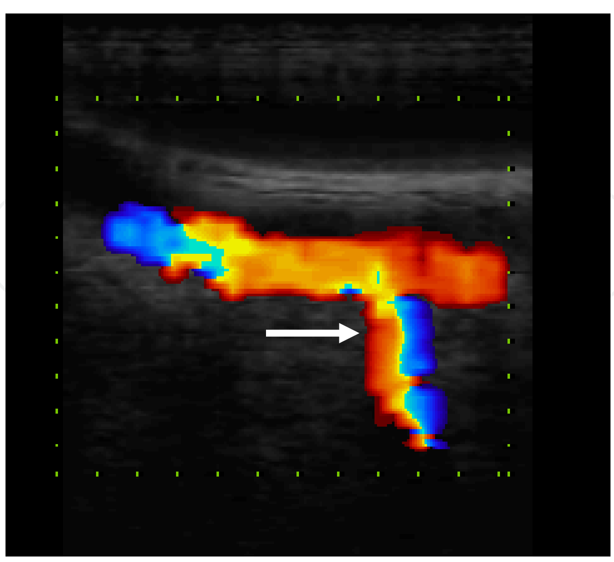

Figure 3. Longitudinal color-Doppler ultrasound image of the LAD with a septal perforator branch (arrow) scanned endoscopically

Localization required a median of 20 seconds (range: 12-25 seconds) for the LAD and 28 seconds (range 12-70 seconds) for the RDP on the freely beating heart. A subsequent scout scan in the up and downstream direction to evaluate the artery required 70 seconds (60-96 seconds) for the LAD and 51 seconds (18-104 seconds) for the RDP. After partial stabilization, the OM3 was located within 16 seconds (5-60 seconds) and assessed in 52 seconds (21-90 seconds). Side branches were easily seen (Figure 3). Overall, 23 out of 24 arteries were successfully located. One OM3 branch turned out to be a diagonal branch. The coronary anatomy, however, in this particular pig was somewhat unusual (diagonals extending prominently to the left lateral side of the heart).
Falk (Falk et al., 2000b) demonstrated feasibility of vessel assessment as well using a different ultrasound system in a canine TECAB model.

8. Anastomosis quality assessment

Even with a robot, endoscopic anastomotic suturing is difficult and technically challenging due to one or more of the following factors: motion of the target area, blood obscuring the arteriotomy edge, suboptimal angle of view, absence of force feedback on the telemanipulation systems and lack of an assistant to present the graft. The number of suture errors is reflected by the high number of intra-operative anastomotic failures in TECAB (11%, on the arrested heart) (Schachner et al., 2007). Intra-operative anastomosis quality assessment allows for direct graft revision in case of suboptimal results.
A number of techniques for anastomosis quality assessment have been described in open-chest CABG (Balacumaraswami & Taggert, 2007), but most can not be used in an endoscopic approach due to the large size of the imaging camera or potential risk for graft damage. Angiography is used but is invasive and the equipment is not available in most operating rooms. Furthermore, imaging time may be excessive (up to 110 minutes) (Schachner et al., 2007). and the intra-operative findings may be difficult to interpret (Hol et al., 2002).
ECUS is a promising technique for anastomotic quality assessment in open chest CABG and the advent of a mini-transducer has opened the possibility for its endoscopic use as well.

9. Endoscopic anastomosis quality assessment with ECUS

To evaluate the ability of the ECUS mini-transducer to assess anastomotic quality in TECAB, we constructed a total of 16 internal mammary artery (IMA) to LAD anastomoses in the porcine TECAB model. Eight of the anastomoses were constructed to be fully patent and the other 8 with an intended construction error (suture cross-over, in which the suture is interlocked in the middle of the anastomotic orifice). After endoscopic stabilization, the anastomosis was properly visualized endoscopically in both longitudinal and transverse directions by manipulating the mini-transducer over the anastomosis. Imaging required approximately 3 minutes per anastomosis.
The ultrasound images were stored and the still images of the anastomosis were scored perfectly off-line as correct (Figure 4) or incorrect (Figure 5) by 2 blinded observers in all 16 cases.

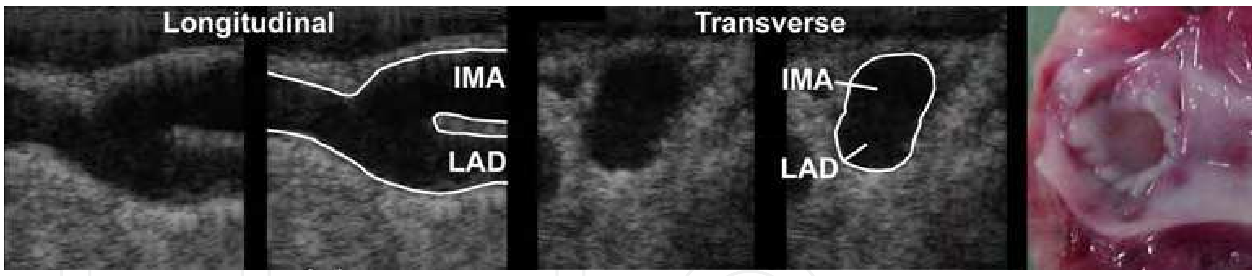

Figure 4. Longitudinal and transverse ultrasound images of a correct anastomosis with corresponding macroscopic view of the anastomotic orifice after incision of the posterior wall of the LAD. (Reprinted with permission from Budde R. et al, Robot-assisted 13 MHz epicardial ultrasound for endoscopic quality assessment of coronary anastomoses. Interactive Cardiovascular and Thoracic Surgery 2004;3:616-20)

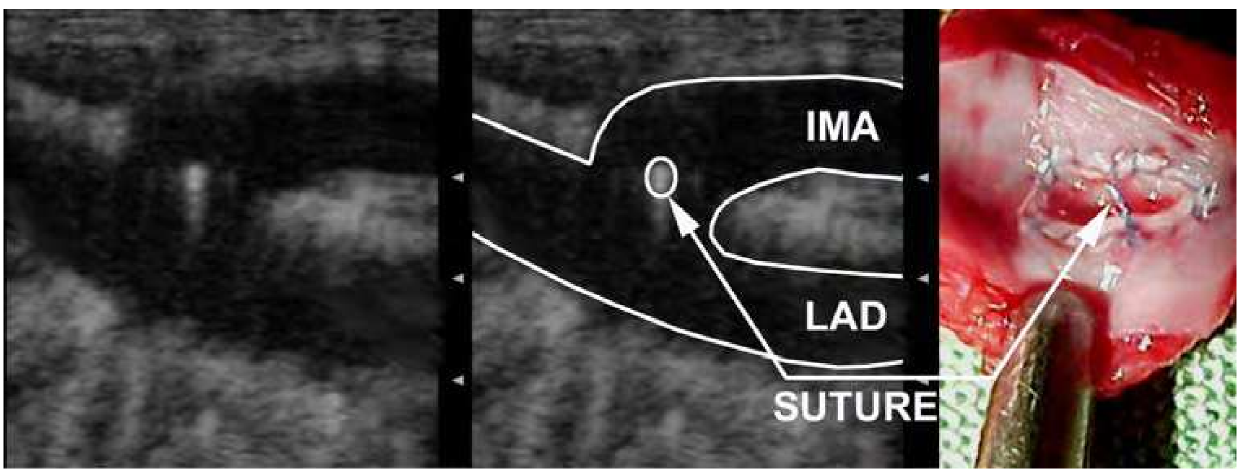

Figure 5. Longitudinal ultrasound image of an incorrect anastomosis with suture cross-over with corresponding macroscopic view of the anastomotic orifice after incision of the posterior wall of the LAD. Arrow indicates overcrossing suture. (Reprinted with permission from Budde R. et al, Robot-assisted 13 MHz epicardial ultrasound for endoscopic quality assessment of coronary anastomoses. Interactive Cardiovascular and Thoracic Surgery 2004;3:616-20)

9. Future of TECAB

The future of TECAB remains to be determined. Currently, routine multivessel TECAB seems still too challenging. Hybrid approaches, however, in which the left internal mammary artery is anastomosed to the LAD endoscopically and the other coronary arteries are treated by percutaneous transluminal coronary angioplasty with stent placement are being explored (Katz et al., 2006).
Coronary connectors may advance TECAB as well by providing a means to facilitate anastomosis construction and omit the tedious suturing process (Falk et al., 2003). ECUS can be used for size matching and quality assessment of some of the connectors (Budde et al., 2005).

10. Conclusions

Epicardial ultrasound can successfully locate and assess the coronary arteries and assess anastomotic quality in the porcine TECAB model within a few minutes. It therefore is a promising tool to help advance TECAB, but clinical confirmation of the experimental results remains to be established.

11. References

Argenziano, M.; Katz, M.; Bonatti, J.; et al. (2006). Results of the prospective multicenter trial of robotically assisted totally endoscopic coronary artery bypass grafting. *Ann Thorac Surg*,81,5,1666-1674.

Balacumaraswami, L. & Taggart, D. (2007). Intraoperative imaging techniques to assess coronary artery bypass graft patency. *Ann Thorac Surg,* 83,6,2251-2257.

Bonatti, J.; Schachner, T.; Bonaros, N.; et al. (2006). Technical challenges in totally endoscopic robotic coronary artery bypass grafting. *J Thorac Cardiovasc Surg,* 131,1,146-153.

Borst, C.; Jansen, E.; Tulleken, C.; et al. (1996). Coronary artery bypass grafting without cardiopulmonary bypass and without interruption of native coronary flow using a novel anastomosis site restraining device ("Octopus"). *J Am Coll Cardiol*,27,6,1356-1364.

Borst, C. & Gründeman, P. (1999). Minimally invasive coronary artery bypass grafting: an experimental perspective. *Circulation*,99,11,1400-1403.

Budde, R.; Meijer, R.; Bakker, P.; et al. (2004a). Endoscopic localization and assessment of coronary arteries by 13 MHz epicardial ultrasound. *Ann Thorac Surg,*77,5,1586-1592.

Budde, R.; Dessing, T.; Meijer, R.; et al. (2004b). Robot-assisted 13 MHz epicardial ultrasound for endoscopic quality assessment of coronary anastomoses. *Interact CardioVasc Thorac Surg*,3,616-620.

Budde, R.; Suyker, W.; Suyker, P.; et al. (2005). Quality assessment of distal S(2)AS connector anastomosis by 13 MHz epicardial ultrasound. *Eur J Cardiothorac Surg,*28,6,833-837.

Diegeler, A.; Thiele, H.; Falk, V.; et al. (2002). Comparison of stenting with minimally invasive bypass surgery for stenosis of the left anterior descending coronary artery. *N Engl J Med*,347,8,561-566.

Falk V.; Diegler, A.; Walther T. et al . (2000a). Total endoscopic off-pump coronary artery bypass grafting. *Heart Surg Forum*,3,1,29-31.

Falk, V.; Fann, J.; Grunenfelder, J.; Burdon, T. (2000b). Endoscopic Doppler for detecting vessels in closed chest bypass grafting. *Heart Surg Forum,*3,4,331-333.

Falk, V.; Walther, T.; Stein, H.; et al. (2003). Facilitated endoscopic beating heart coronary artery bypass grafting using a magnetic coupling device. *J Thorac Cardiovasc Surg,* 126,5,1575-1579.

Gründeman, P.; Budde, R.; Mansvelt Beck, H.; et al. (2003). Endoscopic exposure and stabilization of posterior and inferior branches using the endo-starfish cardiac positioner and the endo-octopus stabilizer for closed-chest beating heart multivessel CABG: hemodynamic changes in the pig. *Circulation*,108, Suppl II,II34-II38.

Gründeman, P.; Verlaan, C.; van Boven, W.; Borst, C. (2004). Ninety-degree anterior cardiac displacement in off-pump coronary artery bypass grafting: the Starfish cardiac positioner preserves stroke volume and arterial pressure. *Ann Thorac Surg,*78,2,679-684.

Haaverstad, R.; Vitale, N.; Williams, R.; Fraser, A. (2002). Epicardial colour-Doppler scanning of coronary artery stenoses and graft anastomoses. *Scand Cardiovasc J,*36,2,95-99.

Hol, P.; Fosse, E.; Lundblad, R.; et al. (2002). The importance of intraoperative angiographic findings for predicting long-term patency in coronary artery bypass operations. *Ann Thorac Surg,*73,3,813-818.

Kappert, U.; Schneider, J.; Cichon, R.; et al. (2001). Development of robotic enhanced endoscopic surgery for the treatment of coronary artery disease. *Circulation,*104,12,I102-I107.

Katz, M.; van Praet, F.; de Canniere, D.; et al. (2006). Integrated coronary revascularization: percutaneous coronary intervention plus robotic totally endoscopic coronary artery bypass. *Circulation,*114,I473-I476.

Loulmet, D.; Carpentier, A.; D'Attellis, N.; et al. (1999). Endoscopic coronary artery bypass grafting with the aid of robotic assisted instruments. *J Thorac Cardiovasc Surg,*118,1,:4-10.

Schachner, T.; Feuchtner, G.; Bonatti, J.; et al. (2007). Evaluation of robotic coronary surgery with intraoperative graft angiography and postoperative multislice computed tomography. *Ann Thorac Surg,*83,4,1361-1367.

Subramanian, V.; Patel, N.; Patel, N.; Loulmet, D. (2005). Robotic assisted multivessel minimally invasive direct coronary artery bypass with port-access stabilization and cardiac positioning: paving the way for outpatient coronary surgery? *Ann Thorac Surg,*79,5,1590-1596.

Suematsu, Y.; Takamoto, S.; Ohtsuka, T. (2001). Intraoperative echocardiographic imaging of coronary arteries and graft anastomoses during coronary artery bypass grafting without cardiopulmonary bypass. *J Thorac Cardiovasc Surg,*122,6,1147-1154.

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The first generation of surgical robots are already being installed in a number of operating rooms around the world. Robotics is being introduced to medicine because it allows for unprecedented control and precision of surgical instruments in minimally invasive procedures. So far, robots have been used to position an endoscope, perform gallbladder surgery and correct gastroesophogeal reflux and heartburn. The ultimate goal of the robotic surgery field is to design a robot that can be used to perform closed-chest, beating-heart surgery. The use of robotics in surgery will expand over the next decades without any doubt. Minimally Invasive Surgery (MIS) is a revolutionary approach in surgery. In MIS, the operation is performed with instruments and viewing equipment inserted into the body through small incisions created by the surgeon, in contrast to open surgery with large incisions. This minimizes surgical trauma and damage to healthy tissue, resulting in shorter patient recovery time. The aim of this book is to provide an overview of the state-of-art, to present new ideas, original results and practical experiences in this expanding area. Nevertheless, many chapters in the book concern advanced research on this growing area. The book provides critical analysis of clinical trials, assessment of the benefits and risks of the application of these technologies. This book is certainly a small sample of the research activity on Medical Robotics going on around the globe as you read it, but it surely covers a good deal of what has been done in the field recently, and as such it works as a valuable source for researchers interested in the involved subjects, whether they are currently “medical roboticists” or not.

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