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Robot Assisted Laparoscopic Surgery for Aortoiliac Disease; a systematic review

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1. Abstract

Robotic systems have been used to overcome the technical difficulties in laparoscopic aortoiliac surgery. In this chapter the outcomes of clinical and experimental studies using a robotic surgical system for treatment of aortoiliac disease are reviewed.

1.1 Methods
A computerized search was conducted in the medical databases Medline (from January 2000 to July 2007), Embase (from January 2000 to July 2007) and the Cochrane Database of Systematic Reviews. Operative times, ICU-stay, clamping time, blood loss, anastomosis time, time to resume to solids, hospital stay, mortality and conversion rates were described. Experimental studies reporting on the creation of an aortic anastomosis with the robotic system were included.

1.2 Results
Experimental studies on vascular anastomoses showed equal results when compared to laparoscopy using the Zeus system, whereas the da Vinci robot showed better anastomosis-times and more precise anastomoses when compared to laparoscopic surgery.
Five clinical studies were identified, with in total 70 patients. Operative time varied from 188 to 480 minutes, anastomosis time was 27 to 40.8 minutes. Total hospital stay differed between 4 and 7.3 days. An overall conversion rate of 7 (10%) was reported.

1.3 Conclusion
Little data on robotic assisted laparoscopic surgery exist and the available data are of low quality. The application of robotic systems is feasible and safe, but no robust conclusions can be drawn with respect to comparison with conventional laparoscopic techniques or its cost effectiveness. Robotic assistance might facilitate an endoscopic vascular anastomosis and enhance laparoscopic surgery for aortoiliac disease, but comparative studies are necessary to support this hypothesis.

2. Introduction

Conventional aortoiliac surgery for either occlusive disease or aneurysm repair is accompanied by significant surgical trauma. Minimal invasive surgery reduces the tissue trauma and might result in reduced morbidity and mortality of aortoiliac surgery. Dion et al. pioneered towards the first total laparoscopic approach of the aortoiliac tract in 1993, by performing a laparoscopy assisted aortobifemoral bypass (Dion et al., 1993). Several open minded surgeons followed into his footsteps and several techniques for a total laparoscopic approach of aortoiliac disease were developed (Ahn et al., 1997; Alimi et al., 2000; Kolvenbach et al., 2001; Coggia et al., 2002). One-and-a-half decade later minimally invasive surgery of the aortoiliac vessels is performed only in a few centers around the globe. The slow implementation of laparoscopic assisted aortoiliac surgery can be explained by the technical difficulties encountered embarking on this kind of surgery. The most demanding parts of the total laparoscopic approach for aortoiliac disease are the creation of sufficient and stable exposure, and suturing of the aortic anastomosis. Various techniques are described to approach the abdominal aorta, such as a retro-peritoneal approach, use of the "apron" technique (a peritoneal 'flap' which is used to suspend the bowel), or a total transabdominal approach with extreme lateral rotation of the patient (Ahn et al., 1997; Alimi et al., 2000; Wisselink et al., 2000; Kolvenbach et al., 2001; Coggia et al., 2002; Dion et al., 2003).

Creation of the anastomosis requires a lot of skill, exercise and dexterity. Various authors reported to have been practicing for several months before gaining sufficient proficiency to implement vascular laparoscopy into everyday practice (Coggia et al., 2004; Olinde et al., 2005).

Robotic surgical systems have been developed to facilitate advanced laparoscopic procedures particularly suturing anastomosis as in aortoiliac laparoscopic surgery (Wisselink et al., 2002; Killewich et al., 2004; Desgranges et al., 2004; Kolvenbach et al., 2004; Ruurda et al., 2004; Nio et al., 2004; Nio et al., 2005a; Nio et al., 2005b; Stadler et al., 2006; Ishikawa et al., 2006; Mehrabi et al., 2006; Diks et al., 2007; Diks et al., submitted).

This chapter reviews the use of robotic assistance in laparoscopic surgery of the aortoiliac vessels and its potentially additional value.

3. Methods

A computerized search was conducted in the medical databases Medline (from January 2000 to July 2007), Embase (from January 2000 to July 2007) and the Cochrane Database of Systematic Reviews, using the keywords "robot AND vascular surgery". The results were extended using a combination of the following Medical Subject Heading (MeSH) terms: robotics, aortoiliac disease, arterial occlusive disease, abdominal aneurysm, laparoscopy, robotic assistance, abdominal, experimental.

After identifying relevant titles, the abstracts of these studies were read to decide if the study was eligible. The full article was retrieved when the information in the title and/or abstract appeared to meet the objective of this review. A manual cross-reference search of the bibliographies of relevant articles was conducted to identify studies not found through the computerized search. The "related articles" feature of Pubmed was simultaneously used. Only articles in English language were included.

All experimental studies in which a robotic surgical system was utilized to perform an anastomosis of the aorta are included, evaluated and results described.

All clinical studies describing the use of a robotic surgical system for operating on the abdominal aorta were evaluated. Only papers describing the original patient group were selected. When duplicate material was reported in consecutive articles, the last publication – describing the largest patient group – was included. Data on operation time, ICU stay, clamping time, blood loss, anastomosis time, time to resume oral diet, total hospital stay, mortality and complication rate were identified and evaluated.

4. Results

Experimental studies:

Five experimental studies were included in which a laboratory setup model was used to perform a vascular anastomosis. These studies included two training box models (Nio et al., 2004; Nio et al., 2005b), one human cadaver study (Ishikawa at al., 2006), two porcine models (Ruurda et al., 2004; Mehrabi et al., 2006) and one rat model (Mehrabi et al., 2006). Either the Zeus (Nio et al., 2004; Nio et al., 2005b) – or the daVinci surgical system (Ruurda et al., 2004; Mehrabi et al., 2006; Ishikawa et al., 2006) was used.

In the training box models, the Zeus robotic system (n=40) was compared with a conventional laparoscopic approach (n=40) to conduct a vascular anastomosis. Results showed no significant benefit of the use of the Zeus robotic system in operative time, surgical efficacy and learning curve.

The human cadaver case study described replacement of the thoracic aorta with assistance of the daVinci surgical system (n=1). It reported the feasibility of a thoracic aortal tube replacement with both the proximal and distal anastomoses being conducted in less than 20 minutes each.

In the porcine model, the da Vinci surgical system was used to compare robotic assisted with totally laparoscopic abdominal aortic tube replacement (n=20 vs n=20). The authors concluded that robotic assistance is superior to conventional laparoscopic techniques, because of shorter anastomotic- and clamping times and less blood loss (respectively 22 vs 40 min, $p<0.01$; 63 vs 106 min, $p<0.01$ and 55 vs 280 ml, $p<0.01$). At autopsy the robotic anastomoses showed to be more precise, with less space between consecutive stitches (> 3 mm space between stitches was found in 0/20 vs 12/20 anastomoses).

In a porcine/rat model, the learning curve of an aortic anastomosis using the daVinci surgical system was described. The authors used a training module (n=4) in which an aortic tube replacement was performed in a pig, subsequently in four rats and finally in another pig. The first aortic tube replacement was compared to the last one and a learning curve in the rat model was described. They demonstrated that after training the time to perform an aortic anastomosis was significantly reduced (25:19 vs 12:29 min:sec, $p<0,05$). The authors concluded from this study that robotic assistance has a steep learning curve for conducting an aortic anastomosis.

Patient series:

Five clinical studies were identified (total number of patients: n=70). These studies included one case-report (Killewich et al., 2004), one small case-series (n=5) (Desgranges et al., 2004) and three larger series from Kolvenbach (n=10), Stadler (n=30) and Wisselink (n=24) (Kolvenbach et al., 2004; Stadler et al., 2006; Diks et al., submitted). Of one series earlier results were reported in separate papers (Nio et al., 2005a; Diks et al., 2007). In these studies,

either the Zeus (Computer Motion, Santa Barbara, CA, USA) (n=15) or the daVinci surgical system (Intuitive Surgical, Sunnyvale, CA, USA) (n=55) was used to construct aortic anastomoses in surgery for aortoiliac occlusive – or aneurysmal disease (Table 1).

	Number of patients	Indication for surgery	Robotic system	Conversion (n)	Operative time (minutes)	Anastomosis time (minutes)	Clamping time (minutes)	Blood loss (ml)	ICU stay (days)	Resume diet (days)	Hospital stay (days)
Killewich	1	AOD	dV	0/1	480	X	65	500	X	2	4 (po)
Desgranges	5	AOD	dV	1/5	188	X	75 (± 28)	540	X	X	8 (po) (± 2.4)
Kolvenbach	10	AAA	Z	2/10	242.5 (± 40.5)	40.8 (± 4.1)	95.9 (± 21.6)	X	2.1 (± 1.0)	1.3 (± 0.6)	7.3 (± 2.4)
Stadler	30	AOD/AAA	dV	0/30	236 (180-360)	27 (20-60)	54 (40-120)	320 (100-1500)	1.8 (1-5)	2.5 (2-4)	5.3 (4-10)
Diks	24	AOD	Z / dV	4/24	355 (225-589)	40 (21-110)	77.5 (25-205)	1000 (100-5800)	1 (1-16)	3 (1-4)	5 (3-57)

dV: da Vinci, Z: Zeus, AOD: Aortoiliac Occlusive Disease, AAA: Abdominal Aortic Aneurysm, X: not reported, po: post operative

Table 1. Operation requirement

Operative times varied from 188 to 480 minutes. ICU-stay, reported only in some of the cases, varied from 1 to 2.1 days. Clamping time was reported from 54 to 95.9 minutes. Blood loss varied between 320 and 1000 milliliters. Anastomosis time is reported inconsistently, but when reported it varied from 27 to 40.8 minutes. The time to resume a normal diet varied between 1.3 and 3 days. Total hospital stay varied from 4 to 7.3 days. One of the 70 reported patients died postoperatively. Seven of the 70 patients were converted to open surgery (10%). Reasons for conversion were either technical difficulties with the robotic system (n=4) or an unstable operative field (n=3). The technical difficulties with the robotic system consisted of failure of the robotic system and interference of the robotic arms outside the patient (Desgranges et al., 2004; Kolvenbach et al., 2004; Diks et al., submitted).

Some of the studies described patient selection criteria for robot assisted laparoscopic surgery. Patients with replacement of infected prostheses, with prior abdominal surgery, with redo-surgery of occluded prostheses and with class 4 ASA (American Society of Anesthesiologists) were generally excluded (Diks et al., 2007).

5. Discussion

Two contradictory conclusions emerge from the experimental studies. When the Zeus robotic system was used, no additional value in creating a vascular anastomosis was observed. However, the Zeus system, which was used in these experiments, was not equipped with microwrist instruments yet. In studies where the da Vinci robotic system was used, all authors concluded robotic assistance to be helpful. They noted operation times to be significantly shorter and the anastomoses to be significantly more precise when

compared to conventional laparoscopy. A conclusion that the da Vinci robot would be superior to the Zeus could be speculated. This is consistent with results found in other experimental studies which compared the Zeus with the da Vinci robotic system (Sung & Gill, 2001; Dakin & Gagner, 2003). This observation is irrelevant, since the Zeus robot is no longer commercially available.

Only a few patient series were identified. The number of reported patients was small and the study quality of most series was low. Inclusion criteria, study population and individual patient data were poorly described. Since a variety of surgical procedures was performed, patient data could not be pooled to one large series. For this reason no robust conclusions can be made with respect to patient outcomes of robotic assisted aortoiliac surgery compared to conventional laparoscopic surgery.

This review shows that robot assisted laparoscopic surgery (RALS) is an under-explored technique when it comes to minimally invasive treatment for aortoiliac disease. Where RALS has been used in various fields of surgery, such as cardiac-, general-, gynecologic-, thoracic-, and urologic surgery, vascular surgery remains an area in which robotic surgery has yet to establish its current role.

Reported series show that RALS is a feasible and safe procedure, with operative- and clamping times which are comparable to larger series of totally laparoscopic aortoiliac surgery (Coggia et al., 2004; Dion et al., 2004; Olinde et al, 2005). Conversion rate was less when compared to some smaller series in laparoscopic vascular surgery (Barbera et al., 1998; Rouers et al., 2005; Dooner et al., 2006). Outcome parameters e.g. post operative pain and incidence of incisional hernias were not studied, so no conclusions can be made.

An alternative minimally invasive approach, viz. endovascular therapy, is gaining rapidly in popularity in vascular surgery. The implementation of endovascular therapy has been broadened over the last decade and it has shown good results in patient outcome. Nevertheless, long-term results of endovascular treatment still do not surpass those of surgical bypass (Rzucidla et al., 2003). For aneurysm repair, the promising early results favouring endovasculair compared to open repair are not sustained in time. The applicability of endovascular therapy is also limited by the extension of occlusive lesion in aortic occlusive disease and the anatomic suitability in aneurismal disease. Since (robot assisted-) laparoscopic surgery is less bound by vascular anatomy and the same reconstruction is obtained as in open surgery, the solid and durable results of open repair are likely extrapolated to the laparoscopic approach.

The advantages of robotic systems consist of a 3D view and articulating instruments, providing increased degrees of freedom of movement over conventional laparoscopic instruments. These aspects seem helpful when performing complex endoscopic procedures such as suturing a vascular anastomosis. Furthermore, RALS has shown to overcome a long learning curve which is associated with laparoscopic vascular surgery (Coggia et al., 2004). Even with few numbers of patients, clamping - and anastomosis time reduced significantly after only eight patients (Diks et al., 2007). These results show that robotic assistance can help conventional vascular surgeons to start up laparoscopic surgery, even without prior extensive laparoscopic experience.

The use of a robotic system does not obviate training and exercise in advanced laparoscopic techniques. (Laparoscopic) surgical proficiency is established by education and training. A robotic system must be considered as a tool to improve the performance of the surgeon, not be a means to obviate education and training. Several laparoscopic vascular surgeons have

shown to suture vascular anastomoses with great proficiency (Coggia et al., 2004; Kolvenbach et al., 2004).

So far, no totally robotic vascular procedures have been described. Robotic systems were only used to create the aortic anastomosis, while conventional laparoscopic techniques were used to approach the aortoiliac vessels. The larger part of the operation however, consists of conventional laparoscopic aortic dissection. Criticasters might argue that since the robotic system is merely used to create the vascular anastomosis, the time advantage compared to conventional laparoscopic suturing is limited. It has to be established whether the purchase of robotic systems and the use of extremely expensive disposables is cost effective compared to laparoscopic suturing of the anastomosis. A benefit of using robotic systems for the total operation has not been evaluated.

Otherwise it has to be considered that if the case volume is insufficient for maintaining these specific endoscopic skills, a robotic system, when available, might be useful to ensure a high quality vascular anastomosis.

It has been shown that RALS for aortoiliac disease is still in a very early stage. Operative times, although comparable to conventional laparoscopic series (Nio et al., 2007), still surpass those of open surgery by far. Furthermore, no research has been done to investigate the cost-effectiveness of a robotic surgical system. It is the task of dedicated centers to answer this research question, ideally in the setting of a randomized clinical trial, in order to provide scientific evidence for the additional value of robotic assistance in laparoscopic vascular surgery.

Meanwhile, with new developments at the horizon – such as an intravascular stapler (Shifrin et al., 2007) – it is yet to see whether this bridging technology has a future in the field of minimally invasive treatment for aortoiliac disease.

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Medical Robotics

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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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