Chapter 9

Robot-assisted versus standard videoscopic aortic replacement: a comparative study in pigs
Abstract

Background: Reconstruction of the infrarenal aorta for aneurysms is routinely performed through laparotomy. A less invasive videoscopic approach has not gained wide acceptance, due to technical difficulties. Robotic systems could potentially improve imaging of the operative field and surgeon’s dexterity during videoscopic surgery and therefore might facilitate the performance of this procedure. The aim of this animal study was to compare the safety and efficacy of a robot-assisted videoscopic aortic replacement to the standard videoscopic approach.

Methods: In 10 female pigs, the infrarenal aorta was partially replaced by a 10-mm polytetrafluoroethylene (PTFE) interposition graft through a videoscopic retroperitoneal approach, using the da Vinci robot system (robot group). Ten other pigs were operated in a similar fashion, using standard videoscopic instruments (control group). Relevant procedure times, blood loss and complications were registered. Efficacy of the anastomoses was evaluated by measuring patency and blood loss after removing the clamps. Furthermore, circumference and number of stitches were evaluated at autopsy.

Results: The procedure-, suturing and clamping times were significantly shorter in the robot group and blood loss was less. In the control group, the inferior vena cava was injured in one pig. In two cases in the control group, haemostasis could not be established after clamp removal.

At autopsy, all anastomoses in the robot group were adequate. In the control group, a stitch crossing the aortic lumen was found in two distal anastomoses and a large distance (>3 mm) between two stitches was encountered at least once in 12/20 suture lines. All 20 grafts were patent. No anastomotic narrowing was encountered. The number of stitches used for proximal and distal anastomosis was higher in the robot group.

Conclusion: This study demonstrates the superiority of robot-assisted videoscopic aortic replacement over standard videoscopic techniques in an animal model.

Introduction

The gold standard for abdominal aortic aneurysm repair is exclusion of the aneurysm, and interposition with a tube- or bifurcated prosthesis. This is usually performed through a midline laparotomy. In 1993, the first laparoscopy-assisted intervention for infrarenal aortic occlusive disease was performed by Dion and Gracia. In the following years, completely laparoscopic techniques for abdominal aortic repair for both occlusive and aneurysmatic disease were developed.

A videoscopic approach limits the operative trauma and might therefore diminish postoperative pain complications and hospitalisation and offers patients cosmetic advantages. However, the technical challenges of this procedure are emphasised in most published papers. First of all, proper exposition of the aorta must be accomplished for dissection, cross-clamping and aortic replacement. Second, suturing an anastomosis on the aorta is technically challenging with standard videoscopic instruments and therefore time-consuming, if feasible at all.

The technical challenges derive from an impairment of dexterity and the loss of 3D-visualisation in standard videoscopic surgery. Robotic telemanipulation systems were introduced with the objective to alleviate these challenges. Feasibility of robot-assisted videoscopic surgery for aortoiliac occlusive disease was recently demonstrated. The advantages offered by robotic systems might support surgeons in dealing with the technical challenges of standard videoscopic aneurysm repair without extensive time-loss and learning curves.

The purpose of this study is to compare the efficacy of robot-assisted videoscopic aortic replacement for aneurysmatic disease to a standard videoscopic approach in a porcine model.
Materials and Methods

Between November 2002 and February 2003, the infrarenal aorta of 20 female pigs (80-110 kg) was partly replaced by an interposition graft, either with use of the da Vinci (robotic telemanipulation system (Intuitive Surgical, Sunny Vale, Ca, robot group, n=10), or in a standard videoscopic fashion (control group, n=10). All procedures were performed by one of three surgeons: a vascular surgeon (WW) and a videoscopic surgeon (MC) both with limited experience with robot-assisted surgery, and another videoscopic surgeon with extensive experience in robot-assisted surgery (IB). At the start of the experiment, all surgeons were trained to get familiar with the equipment by performing five ex-vivo anastomoses using both techniques.

Operative technique

The pigs were positioned in supine position and a pneumoperitoneum was established using a Veress-needle. A 12 mm trocar was introduced at the umbilicus and the peritoneal cavity was inspected. The pigs were then repositioned to a right semilateral position and a two cm incision was made in the left midaxillary line at a level just below the lower pole of the left kidney. Through this incision, blunt retroperitoneal dissection was performed using digital manipulation and an inflatable balloon (BBraun Aesculap, Tuttlingen, Germany). This was performed under direct visual control through the umbilical trocar. In this way, a retroperitoneal cavity from the upper pole of the kidney to the level of the aortic trifurcation was created. A 12 mm blunt-tip balloon-trocar (Tyco Healthcare, Basingstoke, UK) was introduced through the flank incision and the retroperitoneal cavity was insufflated to a pressure of 15 mm Hg. Three more trocars were introduced: two working ports (8 mm in the robot group and 5 mm in the control group) and an assisting port (12 mm) (Figure 1).

Following the surface of the psoas muscle, the aorta was identified and circumferentially dissected from the surrounding fat tissue in order to enable controlled clamp placement. Two to three lumbal arteries (at the level of the renal artery, inferior mesenteric artery and in between) were identified and clipped prior to clamping. The aorta was clamped just infrarenally and above the trifurcation with the use of detachable vascular clamps with a length of 45 mm and a clamping pressure of 4,41 N (BBraun/ Aesculap, Tuttlingen, Germany). The aorta was transected and a short segment of aorta removed. A 10 mm polytetrafluoroethylene (PTFE) graft (stretch, standard wall, W.L. Gore and associates, Flagstaff, Arizona) was cut at the appropriate length (range 3 to 5 cm). At both sides a double armed CV 5.0 PTFE suture, with a PH 13 needle (W.L. Gore and associates, Flagstaff, Arizona) was sutured to the graft and cut at a length of 7 cm at each end. Before introducing the prosthesis into the retroperitoneal cavity, the first knot was tied. End-to-end aorta-graft anastomoses were sutured proximally and distally.

Total operating (skin-to-skin) time was recorded and divided into separate phases: trocar introduction time, time required for dissection and exposition, total clamping time, proximal anastomosis time, and distal anastomosis time. Additionally, total
blood-loss, blood-loss after clamp removal, complications, suture breaks and technical problems were registered. The primary end-point of the procedure was defined as complete haemostasis after clamp removal with adequate circulation in both lower limbs.

Efficacy of the anastomosis was evaluated by intraoperative inspection of leakage and by palpable pulsations in the pig’s groin. Next, the pig was sacrificed by an intravenous overdose of barbiturates. Autopsy was performed immediately hereafter in order to evaluate the mechanical integrity and patency of the anastomosis by inspection. A distance of > 3mm in between stitches was considered an error. The number of stitches was recorded, as well as the distance between individual stitches and the circumference of the anastomosis. All data were analysed using SPSS and are expressed as median and range. Statistical significance was assessed using the Mann-Whitney-U test, with significance at p<0.05. The study protocol was approved by the Institutional Review Board for animal experimentation of the University Medical Centre Utrecht and conforms to the Guidelines for the Care and Use of Laboratory Animals, published by the US National Institutes of Health (NIH Publication No. 85-23, revised 1996).

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Figure 1
Trocar placement for robot-assisted retroperitoneal videoscopic aortic replacement in pigs.
The pig is positioned in right semi-lateral position. U: umbilical camera trocar, C: camera trocar, R: robot trocars, A: assisting trocar.
Results

Total operating time, clamping time and time needed to perform the anastomoses were shorter in the robot group (Table 1). No intraoperative complications occurred in the robot group. In the control group, the vena cava was injured in one case and subsequently compressed with gauzes and blunt instruments before continuing the procedure. Total blood-loss and blood-loss after clamp removal were also less in the robot group (Table 1). In two control cases, haemostasis could not be established after clamp removal, resulting in termination of the experiment. In all cases, palpable pulsations in both groins were identified.

At autopsy, all robot anastomoses were adequate (Figures 2&3). In the control group, a stitch crossing the aortic lumen was found in two distal anastomoses and a large distance (>3 mm) between two stitches was encountered 15 times in 12 suture lines.

All 20 grafts were without anastomotic narrowing. The number of stitches for proximal anastomoses and distal anastomoses was higher in the robot group (Table 1). In the robot group, a rupture of the suture during suturing occurred in 4 cases compared to 3 suture ruptures in the control group. In these cases, the anastomosis was either finished with the other end of the double-armed suture or a new suture was introduced and tied to the first one. Also, in two cases in the control group, the knot was not securely tied, resulting in anastomotic dehiscence during manipulation at autopsy.

No significant differences in performance between the three surgeons could be demonstrated.

Table 1

<table>
<thead>
<tr>
<th></th>
<th>Robot group</th>
<th>Control group</th>
<th>p</th>
</tr>
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<tbody>
<tr>
<td>Total OR-time</td>
<td>164 (116-225)</td>
<td>205 (162-244)</td>
<td>0.008</td>
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<tr>
<td>Aorta exposition time</td>
<td>30 (20-55)</td>
<td>38 (20-50)</td>
<td>NS</td>
</tr>
<tr>
<td>Dissection time</td>
<td>38 (31-78)</td>
<td>32 (20-78)</td>
<td>NS</td>
</tr>
<tr>
<td>Clamping time</td>
<td>63 (37-95)</td>
<td>106 (79-151)</td>
<td>0.0003</td>
</tr>
<tr>
<td>Proximal anastomosis</td>
<td>22 (15-37)</td>
<td>40 (31-75)</td>
<td>0.0003</td>
</tr>
<tr>
<td>Distal anastomosis</td>
<td>22 (14-40)</td>
<td>41 (28-46)</td>
<td>0.001</td>
</tr>
<tr>
<td>Blood-loss total</td>
<td>55 (0-300)</td>
<td>280 (105-1700)</td>
<td>0.004</td>
</tr>
<tr>
<td>Blood-loss after clamp removal</td>
<td>28 (0-200)</td>
<td>200 (50-1500)</td>
<td>0.01</td>
</tr>
<tr>
<td>Stitches proximal</td>
<td>15 (11-17)</td>
<td>13 (11-14)</td>
<td>NS</td>
</tr>
<tr>
<td>Stitches distal</td>
<td>14.5 (11-18)</td>
<td>9 (9-12)</td>
<td>0.001</td>
</tr>
<tr>
<td>Time per stitch proximal (sec)</td>
<td>93 (53-149)</td>
<td>180 (143-409)</td>
<td>0.001</td>
</tr>
<tr>
<td>Time per stitch distal (sec)</td>
<td>83 (56-185)</td>
<td>246 (180-294)</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>
Figure 2
The aortic replacement graft. The renal arteries (R) and aortic trifurcation (T) with the anastomosis placed in-between. The proximal and distal anastomoses are marked PA and DA.

Figure 3
Close-up of the anastomotic line in the robot group. A regular suture distance without distances > 3mm is visible.
Discussion

The gold standard for abdominal aortic aneurysm repair is exclusion of the aneurysm, and interposition with a tube- or bifurcated prosthesis. This is usually performed through a midline laparotomy. Traditional surgical AAA repair holds significant morbidity and mortality, partly caused by the extensive surgical trauma. Therefore, an endovascular approach was introduced in the early nineties of the past century. Enthusiasm for this minimally invasive technique has increased over the last decade due to the good initial outcomes in terms of reduced blood-loss, less peri-operative complications, faster recovery and high patient satisfaction.

However, a distinct number of patients remain unfit for endovascular surgery, with only half of the patients with an infrarenal aneurysm estimated to have a suitable anatomy for endograft repair. Next to this, long-term durability and performance of endografts have not yet been established. Serious problems like graft migration and endoleakage have been reported in 20% to 30% of cases, requiring treatment in over 10%. Therefore, surgical intervention remains indicated in over 50% of patients.

In a thrive to limit surgical trauma pioneers started applying videoscopic techniques in vascular surgery. Dion and Gracia described the first videoscopy assisted aortobifemoral bypass in 1993. The dissection of the aorta was performed video-scopically, but the anastomosis was made through a mini-laparotomy. The first completely videoscopic procedures for aortoiliac occlusive disease were described by Berens and Dion in 1995. The next challenge was videoscopic aneurysm repair. In 2001, the first case of complete laparoscopic aneurysm repair was published.

Although proven feasible, most authors emphasise the technical challenges of the procedure. The first troublesome issue is the exposition of the aorta. This is either performed by a transperitoneal or a (left) retroperitoneal approach or by a combination of both techniques. The main advantage of the laparoscopic, transperitoneal route is the accessibility of the dissection plane at the right side of the aorta, but a disadvantage is the difficulty to keep intestines out of the operative field. This can partly be compensated for by positioning the patient in Trendelenburg position and tilting to the right.

This problem does not exist in the retroperitoneal approach. However, it is technically challenging to develop the retroperitoneal cavity, without creating defects in the peritoneum. Even a small rent in the peritoneum will impair visualisation, since carbon dioxide will leak to the peritoneal cavity and make the retroperitoneal space collapse. Another drawback is the visualisation of the right side of the aorta and the right common iliac artery. Additionally, the retroperitoneal cavity only comprises a small volume. If suction is applied, the cavity might easily collapse, resulting in impaired visualisation. A solution for this problem might be the use of mechanical tissue retractors. The combination of both approaches, the APRON-approach, in which a peritoneal flap is attached to the anterior abdominal wall, offers an adequate working space, without the drawbacks of the trans- and retroperitoneal approaches, but requires a significant amount of time.
In our retroperitoneal exposition, no peritoneal leaks occurred, most probably due to the laparoscopic control while carefully creating the cavity. We used a 30-degree angled scope to compensate as much as possible for the impaired visualisation of the right side of the aorta. After acquisition of a proper exposition, the dissection of the aorta could be performed in a smooth way in both groups.

The second challenge is videoscopic clamping of the aorta. Most authors described the use of specially designed- or standard vascular clamps positioned through a keyhole entrance. This necessitates one or two small additional incisions. Detachable vascular clamps were used in this experimental study. These clamps could be applied through the 12-mm assisting trocar. They deliver sufficient force to clamp the pig’s healthy aorta with a relatively small diameter, but will need to be modified in order to clamp a sclerotic human aorta.

The third and most important challenge appears to be suturing the aorto-prosthetic anastomoses. Handling the delicate tissue of the fragile aortic wall and placing sutures tangential to the aortic wall is technically challenging mainly due to the limitations in visualisation and manipulation in standard videoscopic surgery. Most surgeons prefer therefore a hand-assisted approach in which the anastomosis is performed through a mini-laparotomy.

Robotic surgical systems offer a solution to the technical difficulties of videoscopic surgery. The system used in this experiment enhances visualisation by a true three-dimensional view based on a double optical system. In addition, the natural working axis is restored and the surgeons viewing axis is always in line with the image acquisition axis. The surgeon can optimise the field of view due to personal control of the optical system. Additional degrees of freedom of motion, filtering of tremor and friction and the ability to downscale the movements of the robotic instruments can contribute further to the feasibility of advanced videoscopic suturing. The aim of this study was to compare this new robot-assisted videoscopic approach to the current standard videoscopic approach.

Our results clearly demonstrate that the procedure can be performed safer and more efficient with the use of the da Vinci robot system. The time-loss during the standard videoscopic procedures occurred while suturing the anastomosis, leading to a significantly longer clamping time. After as little as three cases, every surgeon was capable of suturing an anastomosis with robotic assistance in approximately 20 minutes or less. However, the number of cases per surgeon in this study is low and we expect to find a continuing learning curve leading to shorter anastomoses times in both approaches and for all surgeons involved.

Also, the success rate and the significantly decreased blood-loss in the robot group indicate the increased safety of this procedure. A superior quality of the anastomoses was not only reflected by the decreased blood-loss but also by an increased number of stitches, the absence of distances > 3mm in between stitches and absence of knot failures in the robot cases. However, the two surgeons with limited experience with the da Vinci system both broke two sutures while tying a knot. This problem was
reported earlier and is attributed to the lack of force feedback in the robotic instruments 8,26.

Whether our results are deductible to the human situation will have to be proven. The pig model has definite advantages compared to clinical practice. First of all, retroperitoneal fat is almost absent in the pig which facilitates aortic dissection. Second and even more important, the quality of the healthy pig’s aortic wall is incomparable to the fragile, calcified aortic wall in diseased patients. Furthermore, the presence of an aneurysm sac in patients might impose a further challenge to this procedure.

In conclusion, this study demonstrates the efficacy and safety of robot-assisted videoscopic aortic replacement in a porcine model. The procedure could be performed faster, with fewer complications and lower blood-loss with robotic assistance than through a standard videoscopic approach, with technically superior anastomoses.
References


