New techniques in minimally invasive and open surgery of the aorta
Reducing operative trauma
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New techniques in minimally invasive and open surgery of the aorta
Reducing operative trauma

door

Vincent Jongkind
geboren te Amstelveen
promotor: prof. dr. W. Wisselink
# Table of contents

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>General introduction</td>
<td>7</td>
</tr>
<tr>
<td><strong>Part One</strong></td>
<td><strong>Aortic Aneurysm</strong></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Direct videoscopic approach to the descending thoracic aorta for aortic arch endograft delivery: evaluation in a porcine model <em>J Endovasc Ther</em> 2007;14:39-43.</td>
<td>27</td>
</tr>
<tr>
<td>4</td>
<td>Direct videoscopic approach to the thoracic aorta for aortic endograft delivery: evaluation in a human cadaver model <em>J Endovasc Ther</em> 2010;17:12-18.</td>
<td>37</td>
</tr>
<tr>
<td>5</td>
<td>Juxtarenal aortic aneurysm repair: a systematic review <em>J Vasc Surg</em> 2010;52:760-767.</td>
<td>49</td>
</tr>
<tr>
<td>6</td>
<td>Routine continuous cold perfusion of the kidneys during elective juxtarenal aortic aneurysm repair <em>Eur J Vasc Endovasc Surg</em> 2008;35:446-451.</td>
<td>71</td>
</tr>
<tr>
<td><strong>Part Two</strong></td>
<td><strong>Aortoiliac Occlusive Disease</strong></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>A systematic review of endovascular treatment of extensive aortoiliac occlusive disease <em>J Vasc Surg in press.</em></td>
<td>85</td>
</tr>
<tr>
<td>8</td>
<td>Middle-term results of robot-assisted surgery for aortoiliac occlusive disease <em>Vascular in press.</em></td>
<td>107</td>
</tr>
<tr>
<td></td>
<td>Summary and conclusions</td>
<td>123</td>
</tr>
<tr>
<td></td>
<td>Samenvatting en conclusies</td>
<td>129</td>
</tr>
<tr>
<td></td>
<td>Dankwoord en curriculum vitae</td>
<td>137</td>
</tr>
</tbody>
</table>
CHAPTER 1
General Introduction
The aorta is the main artery of the body, originating from the left ventricle and extending down to the abdomen, supplying blood to all parts of the body. Diseases of the aorta can have a significant effect on the patients' lives and are potentially life-threatening. The most common diseases affecting the aorta are aneurysmal (dilating) disease and occlusive (narrowing) disease.

**Aortic aneurysm**
Aneurysmal disease of the aorta is generally asymptomatic and the diagnosis is often made coincidentally. The thoracic as well as the abdominal aorta may be affected, although the majority of aortic aneurysms are located below the renal arteries (infrarenal abdominal aortic aneurysm, AAA). Rupture of an aortic aneurysm is a life-threatening emergency, requiring immediate treatment. In case of rupture, only half of the patients are able to reach the hospital alive. Even then, perioperative mortality of open repair of ruptured AAA is high (40% to 50%).

Aneurysm rupture can be prevented by surgical repair. Approximately 1,600 elective AAA repairs are performed in The Netherlands every year. Traditionally, open repair is performed: using a large skin incision the aorta is exposed, after which the aorta is cross-clamped and the aneurysm is replaced by a prosthetic graft. Elective open aneurysm repair is proven successful and has an excellent durability, but at the cost of peri-operative mortality and significant morbidity.

In 1991, the first endovascular repair of an abdominal aortic aneurysm (AAA) was reported. From a remote artery access site (e.g. the common femoral artery) a covered stent-graft is deployed across the aneurysm, excluding the aneurysm from the arterial circulation. In contrast to conventional open AAA surgery, requiring a long midline or flank incision, endovascular aortic aneurysm repair (EVAR) can be performed through two groin incisions and does not require aortic cross clamping. In elective AAA repair, EVAR has shown significant short-term advantages for the patient compared to open surgery. Randomized trials have demonstrated that EVAR is associated with fewer blood transfusions, lower perioperative morbidity and mortality, and shorter hospital stay. Also for thoracic aortic aneurysms (TAA) endovascular repair can be performed safely, with improved outcome compared to open surgery. Long-term outcome does not differ significantly, however, and periodic follow-up is required to monitor potential endoleak or migration. Nevertheless, increased patient demand for minimally invasive surgery and favourable clinical results have resulted in an increased application of EVAR. Outcome of ruptured AAA may be also be improved by endovascular treatment. An endovascular approach avoids the surgical stress of a midline laparotomy and minimizes third
space losses, hypothermia, blood loss, and coagulopathy. Hence, promising results of emergency EVAR have been reported in recent years.\textsuperscript{12} Although EVAR has become a desirable option for many patients, the feasibility of the procedure may be limited by patient anatomy and technical difficulties. For successful and durable endovascular aneurysm treatment adequate endovascular access is required as well as proximal and distal landing zones with appropriate length. In a significant number of patients, some of these conditions required for successful EVAR can not be fulfilled.\textsuperscript{13,14} These patients currently still require open aneurysm repair.

**Aortoiliac occlusive disease**

The most common occlusive disease process to affect the aorta is atherosclerosis. Atherosclerosis starts already during childhood, but clinical manifestations are often delayed until adult life when arterial narrowing has progressed and blood supply is affected. Atherosclerosis of the aorta is most prolific at the aortic bifurcation and iliac arteries. Aortoiliac occlusive disease (AIOD) may lead to disabling claudication, ischemic rest pain or non-healing ulcers. Open surgery, such as aortobifemoral bypass grafting or aortoiliac endarterectomy, has proven effective in relieving symptoms and has a low mortality rate. However, peri-operative morbidity is substantial and there is a long period of time before patients can return to their normal activities.\textsuperscript{15-17} Endovascular techniques have been developed as a minimally invasive alternative in the treatment of arterial occlusive disease with reduced morbidity and faster recovery as compared to surgical repair. Dotter was the first to successfully dilate narrowed arterial segments percutaneously.\textsuperscript{18} Since then there has been continuing development of endovascular techniques and percutaneous transluminal angioplasty (PTA) has become an important alternative to open surgery for aortoiliac occlusive disease. For localized AIOD endovascular therapy currently is the treatment of choice. Extensive AIOD, however, can still be best treated by open surgery according to current multidisciplinary guidelines.\textsuperscript{19} Next to endovascular treatment, laparoscopic surgery may be an alternative for open aortic surgery. In several fields of surgery, benefits of endoscopic surgery compared to open surgery have been reported. They include reduced postoperative pain, shorter hospital stay, earlier return to daily activities, fewer wound infections, a lower propensity to develop incisional hernias and better cosmetics.\textsuperscript{20-23} Since the first laparoscopic aortic procedure by Dion et al, laparoscopic techniques have been developed for both occlusive and aneurysmal disease of the aorta.\textsuperscript{24-27} However, laparoscopic aortic surgery is a challenging technique and has not (yet) been implemented by many vascular surgeons.
Aim
In recent years, minimally invasive techniques including endovascular and endoscopic surgery have been developed for both dilating and occlusive disease of the aorta. However, not all patients are able to profit from these minimally invasive techniques because of patient anatomy or technical limitations. These patients still require open aortic surgery with concomitant risks. The aim of this thesis is to investigate new techniques in minimally invasive and open surgery of the aorta that may reduce operative trauma and may improve postoperative recovery.

Outline of the thesis

Part one: aortic aneurysm
Despite advances in operative and peri-operative care, open repair of ruptured AAA is still associated with high mortality rates. Endovascular repair may improve outcome of ruptured AAA. The primary goal of emergency EVAR is rapid exclusion of the ruptured aneurysm from the circulation in order to minimize blood loss. Therefore, a tapered aortomonoiliac endograft combined with contralateral common iliac artery occlusion is often used. Blood flow to the contralateral limb is subsequently restored by performing a femorofemoral

Figure 1: Left: continued blood loss through the short limb of a bifurcated endograft during EVAR in case of a ruptured abdominal aortic aneurysm. Right: insertion of a hemostatic valve in the short limb of a bifurcated endograft potentially avoids excessive blood loss.
bypass. During elective EVAR a bifurcated endograft is preferred, avoiding the need for a femorofemoral bypass. However, bifurcated endografting requires insertion of a stent-graft extension before the aneurysm is excluded from the circulation. During emergency EVAR this would cost precious time, potentially leading to excessive blood loss. A hemostatic valve placed in the short limb of a bifurcated endograft could secure immediate aneurysm exclusion prior to insertion of the graft extension (Figure 1). This potentially avoids excessive blood loss. In **chapter two** we investigate the feasibility of a bifurcated endograft with a homemade valve placed in the short limb to facilitate endovascular treatment of ruptured AAA in an in vitro flow model.

For EVAR a remote arterial access site is required. The common femoral artery is most often used for this purpose. However, small size, tortuosity, calcification and atheromatous disease of the ilio-femoral systems may hinder or even preclude EVAR in a significant number of patients. This may be especially true for TAA. In endovascular thoracic aortic aneurysm repair the delivery sheaths involved are often larger and the distance to be traversed is longer than for abdominal aortic endografting. Alternatively, the descending thoracic aorta may be used for vascular access. By shortening the distance between the access point and the deployment site manoeuvrability may be enhanced, which could prove advantageous, particularly during branched endografting. We developed a videoscopic approach to the descending thoracic aorta to facilitate aortic endografting. In **chapter three** we examine the feasibility of this technique in a porcine model. To further investigate the feasibility of this technique for branched endografting of the aortic arch and pararenal aorta, a human cadaver study was conducted, which is presented in **chapter four**.

Approximately 15% of all AAA extend up to the orifices of the renal arteries (juxtarenal aortic aneurysms, JAA), thus lacking an adequate proximal landing zone for EVAR (Figure 2). Although there is great interest and much research in developing branched and fenestrated endografts for treatment of JAA, no such device is currently commercially available. Furthermore, procedures have proven to be complex, technically challenging, and time consuming. JAA will therefore still require standard open repair. For open JAA repair suprarenal cross clamping is required, causing temporary renal artery occlusion. This may lead to postoperative renal dysfunction, in some cases requiring (temporary) hemodialysis. To determine perioperative mortality and postoperative renal dysfunction after open repair for non-ruptured JAA a systematic review of the literature is performed, which is presented in **chapter five**.
Postoperative renal dysfunction is an important complication after suprarenal cross clamping during JAA repair, affecting a significant number of patients. Renal function may be preserved by cold renal perfusion, as is generally performed during thoracoabdominal aortic aneurysm repair. However, in juxtarenal aortic aneurysm repair renal cooling is not the current standard of care. Based on findings about renal cooling in kidney transplantation, we introduced a protocol of intention to treat with continuous 4°C saline perfusion through the renal arteries during suprarenal aortic clamping in open JAA repair. Results of a consecutive series of patients who underwent elective open JAA repair with cold renal perfusion are presented in chapter six.

Figure 2: Left: infrarenal aortic aneurysm. Right: juxtarenal aortic aneurysm; abdominal aortic aneurysm extending to the orifices of the renal arteries.

Part two: aortoiliac occlusive disease
According to current multidisciplinary guidelines endovascular therapy is the treatment of choice for localized AIOD, while extensive disease can be best treated by open surgery. However, increased experience of interventionists and further developments of endovascular devices and techniques have prompted the utilization of endovascular therapy for extensive AIOD. In chapter seven we systematically review the literature on contemporary results of endovascular therapy for extensive AIOD.

Although a growing number of patients will be amendable for endovascular treatment of AIOD, surgery will still be required for some patients, including those after failed endovascular therapy. For these patients laparoscopic aortic surgery may be an alternative to conventional open surgery.
Laparoscopic aortic surgery has been introduced to reduce operative trauma and enhance postoperative recovery. However, performing aortic surgery using laparoscopic techniques is very challenging, involving a long learning curve. Creation of an aortic anastomosis in particular requires a lot of skill, dedication and vast amounts of training. Robot technology may help to overcome some of the difficulties of traditional laparoscopy. Robotic systems translate the movements of the surgeon's hands in real time movements of surgical instruments inside the patient, enhancing the precision of the surgery. Currently, the da Vinci Surgical System by Intuitive Surgery is the only commercially available robotic system (Figure 3).

The surgical system consists of three parts: a cart placed next to the operating table on which the robotic arms are mounted, a console from which the arms are controlled and a separate tower for a second monitor. Robotic surgery offers several advantages over traditional laparoscopy: the da Vinci filters tremor from the surgeon's hands, produces motion scaling and provides additional degrees of freedom of motion by articulating robotic instruments. Further advantages include 3-D visualization, a natural working axis and elimination of the fulcrum effect.

Figure 3: The da Vinci surgical system. The surgeon sits at the console at the left and controls the instruments placed on a cart next to the operating table.© [2010] Intuitive Surgical, Inc.
Between 2002 and 2007, we performed robot-assisted laparoscopic surgery (RALS) to treat aortoiliac occlusive disease in 28 consecutive patients. In chapter eight our clinical experience and middle-term results of robot-assisted laparoscopic aortobifemoral bypass grafting and aortoiliac endarterectomy is reported.

Figure 4: Intra-operative view of robot-assisted performance of the aortic anastomosis of an aortobifemoral bypass.

References


General introduction
PART ONE: AORTIC ANEURYSM

CHAPTER 2

A Temporary Hemostatic Valve in the Short Limb of a Bifurcated Stent-Graft to Facilitate Endovascular Repair of Ruptured Aortic Aneurysm: Experimental Findings

V. Jongkind
J. Diks
M.A.M. Linsen
A.W.F. Vos
J.A. Rauwerda
W. Wisselink

Abstract

**Purpose:** To evaluate a homemade tricuspid valve placed in the short limb of a bifurcated aortic stent-graft to facilitate endovascular treatment of ruptured abdominal aortic aneurysms (AAA).

**Methods:** A valve consisting of 3 polytetrafluoroethylene cusps was constructed in the short limb of a bifurcated stent-graft. The endoprosthesis was placed into an in vitro circulation model with pulsatile flow. Angiography was performed before and after insertion of the second graft limb.

**Results:** Angiographically, there was complete occlusion of the short limb before and normal patency after deployment of the second graft limb. Cannulation of the short limb with a guidewire was performed without technical difficulty.

**Conclusions:** Addition of a temporary hemostatic valve in the short limb of a bifurcated stent-graft can potentially reduce blood loss during endovascular treatment of ruptured AAAs.

http://jevtonline.org/
Introduction

Recently, promising results of emergency endovascular aneurysm repair (EVAR) have been reported by several authors. In these studies, aortomonoiliac (AMI) endografting combined with contralateral common iliac artery occlusion and construction of a femorofemoral bypass has been used to rapidly exclude the ruptured aortic aneurysm. This is in contrast to elective abdominal aortic aneurysm (AAA) repair, in which a bifurcated stent-graft is preferred. During emergent EVAR, insertion of the stent-graft extension into the short limb of the bifurcated endoprosthesis could cost precious time before complete aneurysm exclusion is achieved, causing possible excessive blood loss. Avoiding additional iliac artery occlusion and femorofemoral bypass by using a bifurcated aortic stent-graft with a hemostatic valve in the short limb might improve outcome. In an in vitro circulation model, we investigated the feasibility of a bifurcated stent-graft with a homemade valve placed in the short limb.

Methods

A tricuspid hemostatic valve was constructed by sewing 3 leaflets of ultrathin polytetrafluoroethylene (PTFE) onto a rectangular piece of thin PTFE graft material (Fig. 1A), which was then sewn into the short limb (Fig. 1B) of a bifurcated Talent stent-graft (Medtronic Vascular, Santa Rosa, CA, USA). The long limb of the stent-graft was connected proximally and distally to circuit tubing with a pulsatile pump. The perfusate consisted of a solution of 0.5% NaCl and glycerin (40% by weight), achieving a viscosity similar to plasma. In the absence of a physiological clotting mechanism, leakage of the modular stent-graft was avoided by sealing the graft with a thin layer of latex, making it impervious to the perfusate. The downstream end of the short limb was not attached to the circuit (open air). A pressure gradient across the valve was created by increasing the circuit pressure from 10 to 120 mmHg during each experiment. “Angiography” was performed by injecting 20 mL of radiographic contrast solution into the perfusate just proximal to the stent-graft to examine occlusion by the hemostatic valve. The valve was then crossed from below with a 0.035-inch angled guidewire, allowing placement of a 16-mm-diameter tubular extension graft with its proximal end just above the valve. Following dilatation with a compliant balloon, patency was examined by angiography. The amount of perfusate leaking through the valve during the experiment was measured. The experiment was done in triplicate.
Figure 1(A) View of the hemostatic valve before insertion in the short limb of the bifurcated stent-graft: 3 leaflets of ultrathin PTFE sewn onto a rectangular piece of thin PTFE graft material. (B) Downstream view of the bifurcated stent-graft, showing the open long limb on the left side and the short limb that is obstructed by the deployed hemostatic valve on the right side.

Results

Angiographically, there was complete occlusion of the short limb by the hemostatic valve (Fig. 2A). The valve could easily be crossed from below with the angled guidewire (Fig. 2B) and subsequently be compressed against the graft wall by self-deployment of the second graft limb and dilatation with a compliant balloon. Angiography showed normal patency, with no signs of stenosis at the site of the compressed valve (Fig. 2C). The amount of perfusate leaking through the valve during the experiments was marginal (median 45 mL, range 30–70).

Discussion

In spite of therapeutic advances during the last decades, mortality rates associated with surgical repair of ruptured AAAs remain high (30% to 40%). Recently, promising results of emergency endovascular aneurysm repair have been reported by several groups. In most studies, emergent EVAR has been achieved by using a tapered aortomonoiliac endograft combined with contralateral common iliac artery occlusion and femorofemoral bypass, thus achieving rapid aneurysm exclusion. This technique, however, is known to be correlated with several disadvantages, including alteration of physiological blood flow and excessive surgical procedures. Furthermore, femorofemoral bypass grafting often requires general anesthesia, while bifurcated stentgrafting
can be performed under local anesthesia.\textsuperscript{4,6} Although the incidence of infection in femorofemoral bypass grafts is low (1.5% to 4%), mortality after graft infection is substantial (33% to 66%).\textsuperscript{7–10} Furthermore, intermittent claudication, although rare, could develop in patients who are asymptomatic due to altered flow through the tapered aortomoноiliac endograft and femorofemoral bypass graft.\textsuperscript{9}

During emergent EVAR, insertion of the stent-graft extension into the short limb of the bifurcated device could cost precious time before complete aneurysm exclusion is achieved, causing possible excessive blood loss. A bifurcated stent-graft with a hemostatic valve, which combines the advantages of both endovascular techniques, would be ideal. Our experimental investigations suggest that inflow exclusion of a ruptured aneurysm using a bifurcated stent-graft with a homemade tricuspid valve is feasible. After deployment of the stent-graft extension, normal patency is achieved.

In conclusion, addition of a temporary hemostatic valve in the short limb of a bifurcated stent-graft can potentially reduce blood loss during endovascular treatment of ruptured AAAs.
References


Hemostatic valve for endovascular repair of ruptured AAA