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Symptomatic spinal cord malperfusion after stent-graft coverage of the entire descending aorta[☆]

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Abstract

Objective: The study aims to identify risk constellations for symptomatic spinal cord malperfusion in patients undergoing extensive stent-graft coverage of the thoracic aorta. **Methods:** From 1997 through 2009, 26 patients (mean age 70 years) underwent extensive stent-graft coverage of the thoracic aorta. Indications for stent-graft placement were atherosclerotic aneurysms ($n = 18$) and penetrating atherosclerotic ulcers (PAUs) ($n = 8$). In 16 patients, a re-routing procedure was required to gain sufficient proximal landing zone length. Cerebrospinal fluid (CSF) drainage was not routinely applied owing to the necessity of maintaining continuing anti-platelet therapy due to severe cardiovascular co-morbidities. **Results:** Technical success was 100%. Five patients developed symptomatic spinal cord malperfusion. All symptomatic patients had impaired spinal cord blood supply by acute or chronic occlusion of at least two major blood-supplying vascular territories of the spinal cord. Secondary CSF drainage improved neurologic symptoms in all patients without causing any anti-platelet therapy-related collateral injury. **Conclusions:** Extensive stent-graft coverage of the entire thoracic aorta can be performed with a high rate of success. If collateral blood supply to the spinal cord is maintained, occlusion of the intercostal arteries does not cause symptomatic malperfusion. However, if acute or chronic occlusion of the subclavian, lumbar or hypogastric arteries is present, likelihood of symptomatic malperfusion dramatically increases.

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Keywords: Descending aorta; Stent graft; Spinal cord malperfusion; Collateral blood supply

1. Introduction

Stent-graft placement in aortic pathology requiring coverage of the entire thoracic aorta is performed in an increasing number of patients. Recent work has shown that coverage of longer segments is directly related to a higher incidence of neurologic complications [1]. However, to date, the literature focusses merely on intercostal arteries but not on the complex entity of the collateral network of the major spinal cord supplying vessels [2].

The aim of this study was to identify risk constellations for symptomatic spinal cord malperfusion in patients undergoing extensive stent-graft coverage of the thoracic

aorta, taking into account the entire collateral network supply.

2. Patients and methods

Between 1996 and 2009 at our department, 277 patients underwent endovascular stent-graft placement due to thoracic aortic diseases. Twenty-six patients with a disease extent requiring stent-graft coverage of the entire thoracic aorta from the aortic arch to the coeliac trunk were included into this study. The institutional review board approved the study and waived the need for patient consent.

All patients had substantial co-morbidities. Patient demographics are shown in Table 1. All patients underwent risk stratification according to the European system for cardiac operative risk evaluation (EuroSCORE) guidelines [3]. EuroSCORE is known as an extensive preoperative risk stratification system comprising demographic, cardiac-related as well as surgery-related variables. Both additive and logistic values were collected as logistic EuroSCORE has been reported to be a better risk predictor in high-risk patients [4].

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Table 1

Demographics	
Mean age	70 (57–82) years
Male/female	18/8
Underlying pathology	
Thoracic aortic aneurysm	18
Penetrating atherosclerotic ulcer	8
Co-morbidities	
CAD	13 (50%)
COPD	16 (61%)
Hypertension	24 (92%)
PAD	5 (19%)
Renal insufficiency	4 (15%)
Diabetes	6 (23%)
Previous MCI	5 (19%)
Previous aortic procedures	
Abdominal aorta	6 (23%)
Ascending aorta	3 (11%)
EuroSCORE	
Numeric EuroSCORE	10.9 (7–15)
Logistic EuroSCORE	31.5 (10.6–64.0)

CAD – coronary artery disease – defined as morphological correlate in coronary angiography.

COPD – chronic obstructive pulmonary disease – defined as long-term use of bronchodilators or steroids for lung disease.

Hypertension – defined as requirement of chronic medical therapy to maintain normotonic blood pressure profiles.

PAD – peripheral artery disease – defined as clinical or morphological proven impairment of peripheral blood supply.

Renal insufficiency – defined as serum creatinine ≥ 2 mg/dl in repeated measurements.

Diabetes – defined as requirement of therapy to maintain normal blood sugar levels.

Previous myocardial infarction – defined as enzyme infarction with morphological or functional correlate in coronary angiography or echocardiography.

2.1. Preoperative evaluation, landing zones and surgical approach

Preoperative evaluation was done by multislice computed tomography (CT) scans to evaluate the aorto-iliac axis for later arterial access for stent-graft insertion. These CT scans were also carefully reviewed for critical stenoses or occlusions of the vessels that form the collateral network as an alternate blood supply of the spinal cord [5,6].

Furthermore, these CT scans were used as a tool to predict the required length of the intended proximal landing zone. As a prerequisite for successful stent-graft placement, a proximal landing zone of at least 2.0 cm was claimed. If preoperative evaluation revealed disease extent into the aortic arch, re-routing procedures were applied to gain sufficient landing zone. After re-routing, an additional CT scan was performed to reconfirm the effective length of the intended landing zone extension.

2.2. Re-routing procedures

In three patients, a subclavian-to-carotid transposition was required to gain a sufficient landing zone; in 10 patients, a double transposition was required while three patients required total arch re-routing. The original methods have been described in detail previously [7–10]. Re-routing procedures were performed metachronously. Median interval

between supra-aortic transposition and stent-graft placement was 7 days. In one patient who presented with contained aortic rupture, the subclavian artery was overstented owing to paucity of time to perform a preceding subclavian-to-carotid transposition.

2.3. Stent-graft systems used

Four different commercially available stent-graft systems were used. The Talent and, after having been modified, the Valiant endovascular stent grafts (Medtronic Inc., Santa Rosa, CA, USA) were used in seven patients. The Relay stent graft (Bolton Medical, Sunrise, FL, USA) was used in eight patients. The Gore Excluder or TAG stent graft (W.L. Gore & Associates, Flagstaff, AZ, USA) was used in 11 patients. For all systems, the diameter of the stent graft was calculated from the largest diameter of the proximal or distal neck, and an oversizing factor of 10–20% was added.

2.4. Stent-graft placement

Stent-graft placement was performed under general anaesthesia. In 16 patients, a transfemoral approach was chosen. If the diameter of the external iliac artery was not sufficient, the common iliac artery was used for arterial access ($n = 8$). Stent-graft deployment was routinely performed under hypotonic conditions (80 mmHg systolic pressure).

2.5. Definition of endoleaks

Endoleaks were defined according to the reporting standards [11]. Type I endoleaks were defined as attachment site leaks, type Ia at the proximal attachment site and type Ib at the distal attachment site. Type II endoleaks were defined as branch leaks without attachment site connection. Type III endoleaks were defined as junctional leaks between stent grafts if more than one graft was used. Persistent endoleak rate was defined as the rate of endoleaks persisting after watchful waiting, balloon dilatation or additional stent-graft placement.

2.6. Postoperative management

For early detection of spinal cord malperfusion, patients were extubated immediately after stent-graft placement or, if extubation was not possible due to poor pulmonary function, sedation was superficialised to allow neurologic evaluation. In addition, mean arterial pressure was kept above 80 mmHg for the first 96 h to prevent spinal cord hypoperfusion.

2.7. Cerebrospinal fluid drainage

Cerebrospinal fluid (CSF) drainage was not routinely applied because of the necessity of maintaining continuous anti-platelet therapy due to severe cardiovascular comorbidities. If neurologic symptoms occurred, CSF drainage was installed immediately.

Table 2
Patent vessels for collateral spinal cord blood supply – preoperative.

	Subclavian artery	Intercostal arteries	Lumbar arteries	Left hypogastric artery	Right hypogastric artery
Patient 1	+	+	–	–	–
Patient 2	+	–	–	+	+
Patient 3	+	+	–	+	+
Patient 4	–	+	–	+	+
Patient 5	+	+	–	+	+

(+) Open vessels, (–) occluded vessels.

Table 3
Patent vessels for collateral spinal cord blood supply – postoperative.

	Subclavian artery	Intercostal arteries	Lumbar arteries	Left hypogastric artery	Right hypogastric artery
Patient 1	+	–	–	–	–
Patient 2	+	–	–	+	+
Patient 3	+	–	–	+	+
Patient 4	–	–	–	+	+
Patient 5	+	–	–	--	+

(+) Open vessels, (–) occluded vessels.

2.8. Follow-up protocol

Patients were followed up according to a strict protocol that required a contrast spiral CT scan and clinical as well as laboratory evaluation at 3, 6 and 12 months after surgery, and then annually thereafter. Magnetic resonance angiography was used alternatively when chronic renal insufficiency or allergy to iodinated contrast were detected. Additional investigations were obtained whenever indicated.

3. Results

3.1. Surgical results

All supra-aortic transpositions were performed successfully. One patient required concomitant aortic valve replacement due to severe aortic valve stenosis. One patient underwent elective splenectomy due to an isolated offspring of the lienal artery within the intended landing zone to prevent potential lienal malperfusion and necrosis.

3.2. Stent-graft placement and concomitant procedures

Stent-graft placement was successfully performed in all patients. A mean of 2.8 prostheses was used. In four patients additional vascular procedures were concomitantly performed (infrarenal bifurcation stent-graft placement, $n = 1$, iliacofemoral bypass, $n = 2$, femoral patch plasty, $n = 1$).

3.3. In-hospital morbidity and mortality

Two patients required prolonged intubation due to respiratory failure. In one patient, bleeding at the access site had to be treated. One patient (4%) died 2 days after stent-graft placement due to myocardial infarction. One patient developed a lymphatic fistula in the groin.

3.4. Adverse neurologic events and collateral spinal cord supply

Preoperative evaluation of collateral blood supply showed occlusion of one or more vascular beds responsible for collateral blood supply in eight patients. In one patient the left subclavian artery was occluded, the intercostal arteries in one, the lumbar arteries in six patients, the left hypogastric artery in one and both hypogastric arteries in two patients. In five patients, paraparesis was observed within an interval of 3–48 h after stent-graft placement. As a consequence CSF drainage was installed, leading to resolution of symptoms in four patients. The remaining patient showed improvement of symptoms with enduring weakness of the left lower extremity. All five patients had impaired collateral spinal cord blood supply by acute or chronic occlusion of at least two major supplying vascular territories. Table 2 shows spinal cord blood supply before stent-graft placement and Table 3 after stent-graft placement. Three of these patients had undergone prior infrarenal replacement due to atherosclerotic aneurysms. One patient underwent concomitant infrarenal bifurcation stent-graft placement for bilateral iliac aneurysms. Despite continuing anti-platelet therapy, insertion of CSF drainage did not result in any kind of bleeding complications.

3.5. Endoleaks, need for re-interventions and survival

The rate of assisted primary types I and III endoleak was 8%. Two late type Ia endoleaks were observed. One patient was treated successfully. The mean follow-up period was 25 months, ranging from 3 to 81 months. During follow-up, nine patients died whereas just one aortic-related death was observed.

4. Discussion

Extensive stent-graft coverage of the entire thoracic aorta can be performed with a high rate of success. If

collateral blood supply to the spinal cord is maintained, occlusion of the intercostal arteries does not cause symptomatic malperfusion. However, if acute or chronic occlusion of the subclavian, lumbar or hypogastric arteries is present, likelihood of symptomatic malperfusion dramatically increases.

Supra-aortic transpositions are now an established procedure for extending the proximal landing zone to enable stent-graft placement [7–9]. In our setting, this method is used extensively as short- and mid-term results have shown excellent patency as well as no increase in procedural risk as compared with isolated descending stent-graft placement [10]. Furthermore, supra-aortic transpositions can be safely combined with routine open-cardiac procedures such as aortic valve replacement in our setting.

Mean number of stent grafts was high, reflecting the long covered segments to effectively exclude the underlying aortic pathology. The risk of type III endoleak formation due to decreased lateral stability of stent grafts is directly correlated with the number of prostheses [12]. However, this fact could not be observed in this series, as extensive overlapping between prostheses was applied. In patients with an underlying dilatative arteriopathy, access vessels normally are large enough to advance the delivery system by femoral access. In patients with an underlying obliterative arteriopathy such as penetrating atherosclerotic ulcer (PAU), a side graft to the common iliac artery must be chosen in a large number of patients due to narrowing of the external iliac artery. As in our setting, this graft may be extended to the groin as an iliaco-femoral bypass in order to concomitantly treat symptomatic peripheral artery disease.

Recent investigations newly defined the functional anatomy of spinal cord blood supply. Against the long-standing doctrine that the major spinal cord blood-supplying vessel is located at the thoraco-abdominal transition, experimental and clinical work have shown that the spinal cord blood supply is supported by a complex network of several contributing major vascular territories [13–15].

The main contributors, besides intercostal arteries, are the subclavian, lumbar and hypogastric arteries [5,6]. Interestingly, spinal cord injury after thoracic stent-graft placement is lower than after conventional aortic surgery. [16] Potential explanations are based in the maintenance of normotonic blood pressure during stent-graft placement as well as the lack of steal phenomena [17,18]. Furthermore, due to the limited surgical exposition, homeostasis in these physiologically frail patients is better preserved. However, as other vascular territories may be affected by the underlying disease, the collateral network may be impaired by acute or chronic occlusion of major supplying vessels. When applying this hypothesis to our neurologically symptomatic patient cohort we could clearly demonstrate that this concept is of clinical relevance. All patients suffering from symptomatic spinal cord malperfusion had occlusion of two or more major supplying vessels, including the intended occlusion of intercostal arteries by stent-graft placement (Tables 2 and 3).

CSF drainage is a useful means of lowering pressure in the spinal canal thereby improving spinal cord perfusion in both open and endovascular thoracic aortic repair. Absence of any ongoing anticoagulation therapy is a prerequisite for elective

CSF drainage insertion [19]. As many patients depend on continuing anti-platelet therapy due to severe concomitant disease, such as those after drug-eluting stent implantation, the risk–benefit ratio of withdrawing the anti-platelet therapy may be excessively high. Therefore, CSF drainage is not routinely applied in these patients in our setting. As shown, secondary insertion can be performed without subjecting this group of patients to additional risk.

In summary, extensive stent-graft coverage of the entire thoracic aorta can be performed with a high rate of success. If collateral blood supply to the spinal cord is maintained, occlusion of the intercostal arteries does not cause symptomatic malperfusion. However, if acute or chronic occlusion of either the subclavian, lumbar or hypogastric arteries is present, the likelihood of symptomatic malperfusion dramatically increases.

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Appendix A. Conference discussion

Dr A. Pavie (Paris, France): You undertook perioperatively a visual re-routing aortic arch procedure on 16 patients of your series. I assume that no patient had cerebral vascular accident after that?

Dr Gottardi: No, we didn't see any.

Dr Pavie: Okay. In this subgroup of patients who had the re-routing procedure before the operation, how many of them had paraplegia after that? Because you don't say in your paper in which group the paraplegia accident occurs.

Dr Gottardi: Actually, right now, I'm not sure about the numbers. But as I remember, there were also patients with paraparesis that underwent prior re-routing procedures.

Dr Pavie: You said that you don't drain systematically the CSF leakage due to risk of haemorrhage and after that during the implantation of the device. At the opposite, you said when you have spinal cord injury you drain systematically. You define in a slide (not in your manuscript) a subgroup of high risk of spinal cord accident. Why don't you use systematically in this subgroup cerebrospinal drainage for this type of patient?

Dr Gottardi: I completely agree with you, and you're completely right that CSF drainage carries a certain amount of risk. And our conclusion from this study, this is what we learned when we were reviewing our data and looked at it, and that's how this study also will change our policies. So what we did in the beginning, we had in the beginning lots of patients who required this stent-graft placement of the entire aorta and there we had many patients who were on continuing antiaggregatory therapy. That's why we didn't want to routinely apply CSF drainage. As you can see, we have 21 patients where we don't need it. So I think it's justified.

And we found out when we were reviewing the data that if you have two or more vascular beds occluded, these are now high-risk patients where we will do preoperative CSF drainage. If it's only the intercostal arteries that will be occluded, we don't see any necessity in doing it.

Dr Pavie: But in the subgroup it seems logical.

Dr Gottardi: In the subgroup, yes, it's justified.

Dr F. Bilgen (Istanbul, Turkey): In your study you have seen paraparesis in 5 cases.

Dr Gottardi: Yes.

Dr Bilgen: And your previous abdominal aneurysm operation ratio is 23%. Is that right?

Dr Gottardi: Yes.

Dr Bilgen: Is there any relation between these two?

Dr Gottardi: Yes. It's related, all our symptomatic patients had previously undergone infrarenal aortic replacement and had occluded lumbar arteries.

Dr L. von Segesser (Lausanne, Switzerland): In our experience we sum it up as the more Dacron, the higher the risk.

Dr E. Weigang (Mainz, Germany): I come to the same conclusion, but my protocol is more aggressive. We use CSF drainage routinely for every thoracic and thoraco-abdominal stent-graft procedure, and we have used it in more than a hundred cases now. You need someone, either an anaesthesiologist or a neurologist, to insert the CSF drainage. We have observed no complications with CSF drainage so far, and so I would recommend using it more frequently. I would also recommend increasing the blood pressure after your stent-graft deployment to more than 80. I personally increase the MAP up to 100 mmHg.

Dr Gottardi: I totally agree with you that we perhaps could raise blood pressure a little bit higher, but 80 mmHg is our cutoff pressure. Sometimes it's also higher, up to 90, but 80 is our lowest acceptable mean arterial pressure of the stent-graft placement.

Dr von Segesser: What about the patients with Plavix and aspirin in your group?

Dr Weigang: We do not use CSF drainage if the patients are taking clopidogrel.

Dr Czerny: But these are the patients we are talking about.

Dr Gottardi: And the rate of complications is given in the literature. Major complications with haemorrhage and infection is given up to 5% and also mortality associated with CSF drainage up to 0.6%. So I agree with you, if it's necessary you should use it; but we don't think that it's good to use it on a routine basis if you don't have to use it.

Dr Weigang: If we are talking about acute cases on therapy with clopidogrel, I totally agree. But for the routine cases not on anti-platelet therapy, I would be a bit more aggressive with the CSF drainage indication.

Dr C. Padmanabhan (Coimbatore, India): Do you have any experience on neuromonitoring during these procedures, like an MEP or something? And if so, whether it would help identify the subgroup of patients whom you say is high risk so that the drainage can be instituted at an early point in time?

Dr Gottardi: No, we don't use any neuromonitoring during the procedures, especially as most of the problems don't occur immediately but will come after 24 hours or so. So it's not an immediate onset of symptoms, they will occur a little bit later. So it would not make sense, to our understanding, to use routine neuromonitoring during stent-graft placement. And if you extubate them immediately, or at least superficialise anaesthesia, that you can see if they can move the legs, I think that that's sufficient.

Dr Padmanabhan: So you think it's not required as a routine thing?

Dr Gottardi: In our setting, we don't have it. And I think we have good results without it, so I wouldn't recommend it.

Dr R. Cartier (Montreal, Quebec, Canada): Did you have any delayed paraplegia in the 5 symptomatic patients? And how long did it take to get the reversal of the paraplegia in those that responded to the CSF drainage?

Dr Gottardi: Paraplegia or paraparesis occurred between 12 and 48 hours after stent-graft placement and resolved within 12 hours, or 6 to 12 hours, after initiation of CSF drainage.

Dr Cartier: And it was initiated right at the beginning of the symptoms.

Dr Gottardi: Yes, at the beginning of the symptoms.

Dr Cartier: So those patients all woke up with no symptoms?

Dr Gottardi: Yes. All were extubated immediately at the operating table and could move a little bit the legs and symptoms occurred later.

Dr J. Bachet (Abu Dhabi, United Arab Emirates): The more and more we see papers and presentations of this kind, the more and more we hear about paraparesis cases as compared to paraplegia cases. And I'm wondering whether this is not a way to reduce our guilt in front of this terrible complication.

So I would like to know, what is your definition of paraparesis? If a patient awakes and tries to stand up and can't stand up, he's paraplegic. How do you make the difference between those two kinds of complications?

Dr Gottardi: As a matter of fact, I can't give you an exact definition as it would stand in a medical textbook. For us, the difference is with paraplegia he can't move anything, and with paraparesis there is still some motor function left. And the one patient who has persistent neurologic deficit from paraparesis, he has a weakness in the left leg. So on the right leg he's able to stand and walk, on the left leg it's a little bit weaker.

Dr Bachet: Sorry. In the patient this is irrelevant. If a patient has a weakness in one leg only, this is monoplegia. This has nothing to do with the spinal cord. This is neurology.

Dr von Segesser: We are in the wrong session.