Eur J Vasc Endovasc Surg (2010) 40, 729—735

The Incidence of Spinal Cord Ischaemia Following Thoracic and Thoracoabdominal Aortic Endovascular Intervention

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Submitted 4 May 2010; accepted 14 August 2010
Available online 29 September 2010

KEYWORDS
Thoracic aortic aneurysm;
Thoracoabdominal aortic aneurysm;
Acute aortic syndrome;
Endovascular repair;
Stent graft;
Paraplegia

Abstract *Objectives:* To determine the incidence and risk factors for spinal cord ischaemia (SCI) following thoracic and thoracoabdominal aortic intervention.
Methods: A prospective database of all thoracic and thoracoabdominal aortic interventions between 2001 and 2009 was used to investigate the incidence of SCI. All elective and emergency cases for all indications were included. Logistic regression was used to investigate which factors were associated with SCI.
Results: 235 patients underwent thoracic aortic stent grafting; 111(47%) thoracic aortic stent-grafts alone, with an additional 14(6%) branched or fenestrated thoracic grafts, 30(13%) arch hybrid procedures and 80(34%) visceral hybrid surgical and endovascular procedures. The global incidence of SCI for all procedures was 23/235 (9.8%) and this included emergency indications (ruptured TAAA and acute complex dissections) but the incidence varied considerably between types of procedures. Of the 23 cases, death occurred in 4 patients but recovery of function was seen in 6. Thus, permanent paraplegia occurred in 13/235 (5.5%) patients. Of the nine pre-specified factors investigated for association with SCI, only percentage of aortic coverage was significantly associated with the incidence of SCI; adjusted odds ratio per 10% increase in aorta covered = 1.78[95% CI 1.18—2.71], $p = 0.007$. The procedures in patients who developed SCI took longer (463.5 versus 307.2 minutes) and utilised more stents (4 versus 2).
Conclusion: SCI following thoracic and thoracoabdominal aortic endovascular intervention is associated with the proportion of aorta covered. The degree of risk varies between different

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doi:10.1016/j.ejvs.2010.08.013

types of procedure and this should be carefully considered in both selection and consenting of patients.

Introduction

Surgical repair of the thoracic and thoracoabdominal aortic segments for a range of pathologies broadly encompassed by degenerative atherosclerotic aneurysmal disease, Type B dissections and the acute aortic syndrome carries a significant risk of spinal cord ischaemia (SCI), ranging from 5 to 20%.[1,2] The great hope was that the advent of endovascular intervention, with concomitant avoidance of proximal aortic cross clamp, thoracotomy or thoracolaparotomy, would lead to a reduction in complications including paraplegia. After a decade of experience the reported SCI rate is between 0 and 10% for thoracic aortic endovascular repair[3–21] and 0–30% for thoracoabdominal aortic endovascular repair (see Table 1). The evolution of endovascular and hybrid endovascular techniques for thoracic and particularly thoracoabdominal aneurysms is ongoing, and the considerable variance in reported paraplegia rates mandates continued effort to determine the underlying causes of SCI and those most at risk. Potential mechanisms of ischaemic damage to the cord include coverage of critical extrinsic vertebral, intercostal, lumbar and internal iliac supply to the anterior spinal artery,[22] peri-operative hypotension and possibly embolisation during device introduction and deployment. A number of risk factors have been identified, including disease pathology, extent and length of the aorta covered, hypotension and coverage of the left subclavian artery without revascularisation.[16] In this study we conducted a retrospective review of patients undergoing thoracic (TEVAR) and thoracoabdominal aortic intervention in order to determine the incidence and identify risk factors for this grave complication.

Methods

The patients

Details of all aortic stent graft procedures covering part or all of the thoracic aorta performed at St Mary's Hospital Imperial College Healthcare NHS Trust, between 2001 and 2009 were recorded in a prospectively collected database. During the time period in question all thoracic pathologies were treated with stent-grafts. All Crawford extent I, II and III and arch TAAAs were treated by a hybrid endovascular approach or a total endovascular approach. Type IV TAAAs were treated by open surgery and excluded. Juxtarenal and difficult necked infrarenal aneurysms treated by fenestrated or branched endovascular grafts were excluded. All cases of patients with neurological complications were identified, and the case notes examined to determine those who had evidence of spinal cord ischaemia. This was distinguished from cerebrovascular accident by the clinical signs (bilateral lower limb versus unilateral weakness) and confirmation from brain CT or MRI scans and spinal MRI. Any patient with unilateral leg weakness underwent a CT brain scan to exclude stroke as well as a spinal MRI to confirm cord infarction. A Consultant neurologist reviewed all patients suspected of SCI post-operatively The spinal cord ischaemia was further categorised into whether this was transient with complete recovery during the hospital admission, whether there was a partial defect (paraparesis), or whether there was complete paraplegia. SCI was categorised into immediate (immediate or upon wakening) or delayed (occurring after a period of normal neurological function). For all cases, information including patient demographics, Crawford classification, type of procedure, indication for treatment, urgency of procedure, use of a spinal drain, procedure duration, number of stents deployed, and left subclavian artery (LSA) coverage with or without revascularisation, were gathered from the database and theatre records. The presenting pathology is demonstrated in Table 2. The majority of cases were degenerative atherosclerotic aneurysms treated electively, but the series included chronic Type B dissections complicated by aneurysmal degeneration and acute aortic syndrome. The last category included acute Type B dissections complicated by expansion, rupture or visceral or limb malperfusion, symptomatic penetrating atherosclerotic ulcers and pseudoaneurysms and aortic transections. These constituted the

Table 1 Risk of 30-day mortality or SCI after endovascular intervention for thoracoabdominal aortic aneurysms.

	N	Mortality (%)	SCI (%)
Anderson 2005* [26]	4 (TAA)	25	0
Saleh 2006[27]	15 (Arch)	0	0
Zhuo 2006	31 (16 Arch, 15 TAA)	3.2	0
Resch 2006[28]	13 (TAA)	23	30
Black 2006[23]	29 (TAA)	13	0
Greenberg 2008* [24]	9 (TAA)	0	22
Roselli 2007* [29]	73 (TAA)	5.5	2.7
Gilling Smith 2008* [30]	6 (TAA)	0	0
Chuter 2008* [31]	22 (TAA)	9.1	4.5
Greenberg 2008* [24]	352 (TA + TAA)	5.7	4.3
Murphy 2009 [32]	18 (8 Arch, 11 TAA)	6	0
Bicknell 2009* [33]	8 (TAA)	0	12

*denotes wholly endovascular approach.

Table 2 Presenting pathology.

Pathology	Urgency	Patients with SCI	% with SCI
Aneurysmal disease	Emergency	2/13	15.4
	Urgent	1/15	6.7
	Elective/NA	11/104	10.6
Chronic dissection	Emergency	0/2	0
	Urgent	0/7	0
	Elective/NA	4/36	11.1
Acute Aortic Syndrome	Emergency	4/22	18.2
	Urgent	1/16	6.3

highest risk group for development of SCI. Of the five patients who developed SCI two had penetrating aortic ulcers with rupture, one suffered a ruptured anastamotic aneurysm following open TAAA repair 30 years previously, one had an aortic transaction and one an acute dissection. All were treated with thoracic endografts except the ruptured anastamotic aneurysm who underwent an emergency visceral hybrid repair. The post-operative CT scans were then obtained, where available, and loaded onto a CT workstation (Philips). The length of aorta stented and the total aortic length from the origin of the brachiocephalic artery to the iliac bifurcation were measured, in order to calculate the percentage of aorta covered (see Fig. 1). The aortic segments were measured using a reformatted oblique coronal view. The image thickness was changed to 30 mm on the workstation to account for tortuosity of the aorta. All measurements were made along a central luminal line. The brachiocephalic origin was used as the first point of measurement to ensure that all segments of the aorta contributing arterial branches to the spinal cord were included. Measurements were taken just distal to the braciocephalic and the origin was not included. We categorised procedure into four groups: TEVAR (stent deployment in the thoracic aorta alone), arch hybrid (stent deployment in the arch/thoracic aorta with coverage of one or more arch branches necessitating revascularisation), visceral hybrid (stent deployment in the thoracic and abdominal aorta necessitating visceral debranching and revascularisation) and a wholly endovascular branch/fenestrated group. Latterly in the series we have adopted a total endovascular approach to thoracoabdominal aneurysms (TAAAs) in suitable cases utilising branch grafts or coeliac fenestrations for thoracic aneurysms with a very short distal landing zone. This group does not include branched or fenestrated endografts for juxtarenal or infrarenal aneurysms with a hostile neck.

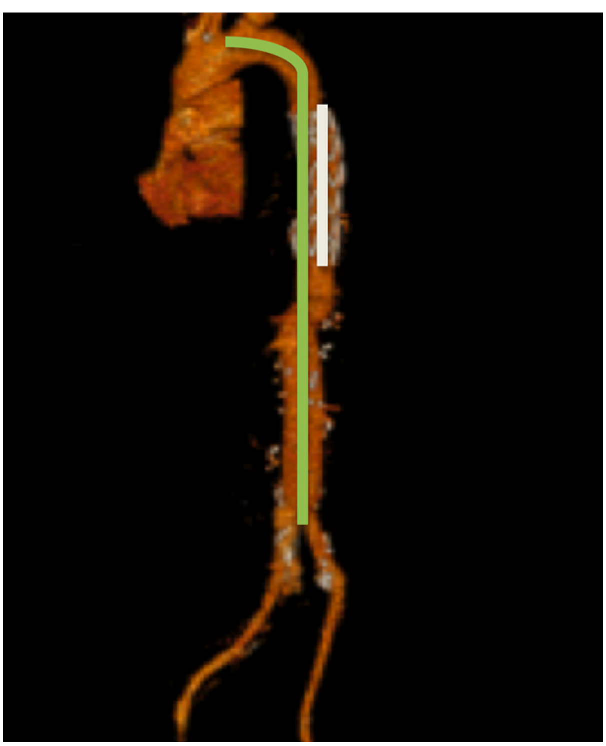

Figure 1 Image of aorta showing measurements taken of length of aorta from brachiocephalic origin to iliac bifurcation and stent length.

Statistical Analysis

Statistical analysis was performed using Stata version 10 (Stata Corporation, Texas, USA). Logistic regression modelling was used to assess whether any of nine pre-specified factors were associated with the incidence of spinal cord ischaemia. Histograms and Normal plots were used to check the distributions of continuous variables. Age and percentage aortic coverage were approximately normally distributed. Length of procedure was positively skewed but log transformation improved the distribution markedly. Therefore, median and interquartile ranges are used to present the non-transformed length of procedure data but log transformed values were included in the logistic regression model. Crude odds ratios were calculated as well as ones adjusted for all other factors being assessed. This reduced the size of the adjusted model to 17 SCI cases in 131 patients. Imputation of missing data was considered but as the data were not missing at random and appeared to be related to the SCI outcome (post-operative CT scans missing from paraplegic patients who died on ITU meant missing data concerning accurate length of aorta stented), conventional methods for inclusion of patients with missing data were not undertaken. As 9 variables were being assessed on the same sample, the *p*-value threshold for statistical significance was reduced to 0.006 to account for multiple testing.

Results

A total of 235 patients were identified from the database. 23 patients developed spinal cord ischaemia, of whom four died within 30 days of the procedure. Two patients suffered a temporary paralysis from which they made a full recovery. Four patients experienced a partial recovery, and thirteen patients suffered full and permanent paraplegia, (see Table 3). One patient undergoing an endovascular four vessel branch graft for a TAAA developed a delayed paraplegia on day 6 and subsequently died. Unsurprisingly the rate of spinal cord ischaemia was very low in patients with a stent graft confined to the thoracic aorta, but was higher for those patients with arch hybrids (involving stenting around the aortic arch requiring bypass to at least one of the neck vessels) and fenestrated/branched graft total endovascular approach to thoracoabdominal aneurysms (TAAAs), and highest for patients who had a visceral hybrid repair (involving aortic debranching of the visceral segment and retrograde bypass from the distal aorta or iliac arteries) (Table 3). Overall 30-day mortality was 29/235 (12.3%). 4/23 (17.4%) SCI patients died within 30 days v 25/212 (11.8%) patients who did not develop SCI. 4 patients who died on table were not included in these figures as their SCI status was unknown.

The patients who developed SCI had longer procedure times than those without SCI (median times of 460 versus 240 min respectively) and required more extensive use of endovascular stents (median 4 versus 2). No patients developed SCI with less than 54% of aortic coverage (Fig. 2).

Table 4 shows the results of logistic regression modelling. The percentage of aorta stented was significantly higher in patients who developed SCI even when correcting for all other factors; adjusted odds ratio per 10% increase in aortic coverage 1.78 [95% CI 1.18–2.71], $p = 0.007$. Another observation of note is that the visceral hybrid procedure appeared to carry the highest crude risk of SCI (odds ratio 13.7, $p = 0.001$) but it did not appear to be an independent risk factor for SCI when corrected for all other variables; odds ratio 0.97, $p = 0.976$. Patients presenting with acute aortic syndrome appeared to be at considerably increased risk of SCI even after adjustment for all other factors; odds ratio (relative to thoracic aneurysm procedures alone) 16.6[95% CI 1.3–205], $p = 0.029$. However, this result is difficult to interpret as the confidence interval is very wide and the level of confounding between groups is high.

SCI developed in 5 of the 89 cases where the LSA had been covered compared with 17 of the 130 cases left uncovered. Therefore, in this series, coverage of the LSA appeared to reduce the risk of spinal cord ischaemia, even after adjustment for the other factors, but this was not statistically significant.

Table 3 Risk of spinal cord ischaemia and permanent paraplegia by type of procedure.

Procedure	Spinal Cord Ischaemia	Paraplegia
TEVAR	2/111 (1.8%)	1/111 (0.9%)
Fenestrated/Branched Graft	2/14 (14.3%)	1/14 (7.1%)
Arch Hybrid	3/30 (10%)	2/30 (6.7%)
Visceral Hybrid	16/80 (20%)	9/80 (11.3%)
Global SCI risk	23/235 (9.8%)	13/235 (5.5%)

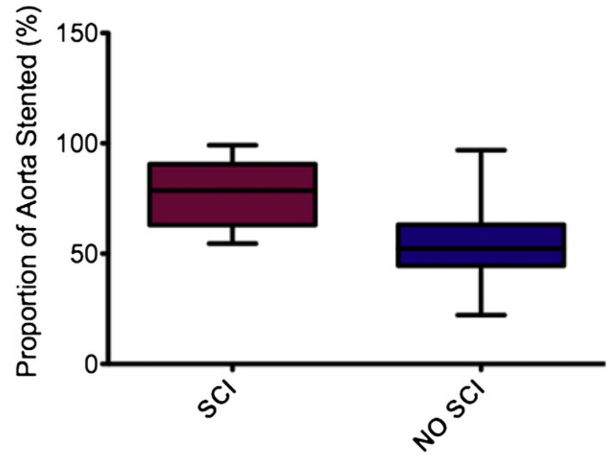

Figure 2 Box and whiskers plot to compare the percentage of aorta stented in patients who developed spinal cord ischaemia. The minimum percent aortic coverage that developed spinal cord ischaemia was 55%.

Discussion

These data demonstrate clearly that the greater the length of the aorta covered, the greater the risk of developing paraplegia. Other series have found that length of aorta covered is an important factor for developing spinal cord ischaemia with 20.5 cm being reported as a critical length.[18] In our series the shortest length of aorta covered by stent that developed SCI was 27.4 cm. This equated with percentage coverage of 55%. Martin *et al*. quoted an odds ratio of 2 for every 10% aorta covered[20] and this very similar to the odds ratio of 1.78 presented for this series. It has long been recognized that the anterior spinal artery receives important contributions from branches of the vertebrals, intercostals, lumbars and internal iliacs[22] and moreover this extrinsic blood supply varies amongst individuals. Increasing coverage of the collateral blood supply to the spinal cord is the principle mechanism of SCI based upon these observations and others, and underlines the importance of careful pre-procedural planning to minimize aortic coverage as well as avoidance of peri-operative hypotension in this vulnerable group.

This study encompassed patients with both a heterogenous group of conditions (atherosclerotic degenerative aneurysms, chronic Type B dissections and acute aortic syndromes) and different endovascular and hybrid solutions. Underlying pathology did not appear to predict risk of developing SCI although patients presenting with acute aortic syndrome may fare particularly poorly when account is taken for other confounders. One of the problems in reporting outcomes and events for thoracic aortic endovascular intervention is the disparity in the magnitude of procedures performed. These range from single thoracic stents to cover a penetrating atherosclerotic ulcer or dissection tear entry point through to hybrid procedures involving aortic visceral debranching, extra-anatomic revascularisation and multiple stents deployed in the thoracic and abdominal aorta. Manifestly risk of SCI increases significantly depending on the magnitude of procedure necessary, and we have attempted to categorise

Table 4 Results from logistic regression analysis of factors associated with spinal cord ischaemia (SCI) in 231 patients undergoing thoracic or thoracoabdominal endovascular intervention.

Variable[a]	SCI group $N = 23$	No SCI group $N = 208$	Crude odds ratio [95% CI] *p*-value	Adjusted [b]odds ratio [95% CI] *p*-value
Pre-operative data				
Age (years)	69.7 (7.7)	66.7 (13.1)	1.24 [0.84–1.84]	0.84 [0.42–1.67]
Odds ratio per 10 year increase	[0]	[0]	0.276	0.614
Sex				
Male	12 (52)	139 (67)	Ref	Ref
Female	11(48)	69 (33)	1.85 [0.77–4.40] 0.166	1.81 [0.49–6.74] 0.374
Indication				
Aneurysm (TAA)	16 (70)	115 (55)	Ref	Ref
Chronic dissection	3 (13)	41 (20)	0.53 [0.15–1.90] 0.326	0.45 [0.08–2.57] 0.369
Acute aortic syndrome	4 (17)	52 (25)	0.55 [0.18–1.73] 0.310	16.58 [1.34–205.2] 0.029
Urgency				
Elective	16 (70)	106 (51)	Ref	Ref
Emergency/urgent	6 (26)	66 (32)	0.60 [0.22–1.62] 0.314	0.41 [0.08–2.18] 0.284
Missing	1 (4)	36 (17)	–	–
Peri-operative data				
Type of procedure				
TEVAR	2 (9)	108 (52)	Ref	Ref
Fenestrated/branched	2 (9)	12 (6)	9.00 [1.16–69.82] 0.036	54.7 [0.86–3461] 0.059
Arch hybrid	3 (13)	25 (12)	6.48 [1.03–40.86] 0.047	2.17 [0.20–23.37] 0.522
Visceral hybrid	16 (69)	63 (30)	13.71 [3.05–61.61] 0.001	0.97 [0.11–8.63] 0.976
Procedure duration (mins)[a]	460 {345–550}	240 {135–505}	4.04 [1.80–9.05]	7.76 [1.19–50.71]
Increase per log(hour)	[0]	[23]	0.001	0.032
Percentage of aorta covered	76 (15)	54 (17)	1.92 [1.42–2.58]	1.78 [1.18–2.71]
Odds ratio per 10% increase	[5]	[40]	<0.001	0.007
Spinal drain used				
No	4 (17)	49 (23)	Ref	Ref
Yes	18 (78)	120 (58)	1.84 [0.59–5.71] 0.293	2.27 [0.28–18.08] 0.440
Missing	1 (4)	39 (19)	–	–
Subclavian artery covered				
No	17 (74)	113 (55)	Ref	Ref
Yes	5 (22)	84 (40)	0.40 [0.14–1.12] 0.080	0.40 [0.10–1.62] 0.200
Missing	1 (4)	11 (5)	–	–

[a] All continuous variables presented as mean (SD) apart from procedure duration which was positively skewed and is presented as median {interquartile range} and log transformed for inclusion in the logistic regression model. Numbers in square brackets indicate number with missing covariates. All categorical variables presented as number (%).

[b] Adjusted for all other variables in the table. Note that adjusted model reduced to 17 SCI cases in 131 patients due to missing covariates.

procedures into appropriate groups so that accurate reporting of risk can be undertaken.

Our SCI rate for TEVAR was low at 1.9%, and this figure compares well with other single centre series and registry data that quotes a range of between 0 and 10%. The SCI rate became progressively higher for the arch hybrid group, branch/fenestrated group and visceral hybrid group(See Table 3). Our crude logistic regression results suggest that the risk increases with the complexity and extent of procedure performed, but after adjustment for confounders it is possible that fenestrated and branched procedures carry the greatest risk of SCI.

Table 1 shows data from published series for endovascular treatment of the arch and thoracoabdominal segments of the aorta. Across this series there is heterogeneity of procedure performed, with 7 papers reporting a total endovascular approach, and 5 papers reporting a combined surgical and endovascular hybrid approach. Our own initial experience of 29 hybrid procedures was very encouraging with no episodes of SCI reported,[23] but we now report an SCI rate of 20%. Nine patients had complete paraplegia, whilst four experienced varying degrees of recovery giving a permanent paraplegia rate at 30 days of 11.3%. One would expect that a learning curve effect would have meant the global SCI rate fell over time; in fact we observed the opposite effect, with 4 episodes of SCI complicating the first 60 cases, and 8 complicating cases 181–235. A possible explanation for this finding is that progressively more complex cases have been taken on over time presenting with more extensive aneurysmal disease. 12/80 visceral hybrid cases had stents extending into the common iliac arteries, necessitating use of the external iliac artery as the site for anastomosis of the retrograde visceral bypass grafts. Four of these patients developed SCI and one of them subsequently died. We recorded the incidence of internal iliac coverage on post-operative CT scans. This was observed in 5 of the 187 CT scans examined and one patient of those five went on to develop SCI (20%). 2/80 also involved a concomitant arch hybrid procedure. The high in-hospital mortality associated with paraplegia was reinforced in this study, with 4 patients dying during the in-hospital episode. This observation has been made by other centres, with Greenberg demonstrating that the two of nine patients treated for TAAAs that developed SCI both suffered late mortality as a direct result of the original complication.[24]

Coverage of the left subclavian artery (LSA) without revascularisation is known to carry a potential risk of arm ischaemia, myocardial infarction (with a patent left internal mammary graft), hindbrain stroke (with a dominant left vertebral artery) and SCI. The EUROSTAR registry involving 606 patients undergoing TEVAR showed that coverage of the LSA was one of four factors associated with increased risk of SCI on multivariate analysis (odds ratio 3.9).[16] However this experience is not ubiquitous and several studies have failed to demonstrate this.[18,20] Our study also failed to demonstrate a significant association, an observation that we ascribe to the fact that in our series most cases where the subclavian artery was covered involved stents confined to the thoracic aorta alone.

Our usual practice is to employ the use of spinal CSF drainage in all patients considered high risk, but use did not appear to be associated with reduced risk of SCI. On the contrary, there was some evidence to suggest it was associated with an increased risk of SCI, even after adjustment for confounding variables such as urgency, indication and procedure type. The result is non-significant but the odds ratio of approximately 2 remains unchanged between the crude and adjusted models, so does not appear to be strongly affected by confounding. CSF drainage has been reported to reduce the incidence of SCI in open TAAA repair[25] and several groups have advocated its use in endovascular repair. However spinal drainage is not without complications including intra-spinal haematoma formation, infection and subdural haematoma. A policy of selective drainage for high risk patients (long coverage lengths, previous aortic surgery, and left SCA coverage without revascularisation) may offer the advantage of CSF drainage for those requiring it without subjecting low risk patients to possible complications.[19] Our data also showed that one third of patients showed improvement in function following paraplegia. SCI can develop up to three weeks after stenting, and immediate CSF drainage and blood pressure augmentation can rescue the situation entirely or result in a better functional outcome.

Limitations of the study

We acknowledge that there are limitations to this study. The extent of missing data is problematic and limits the generalisability of our results to other cohorts of patients. Strategies for including patients with missing data in the adjusted models would be complex and possibly misleading as many of the important missing covariates appear to relate to the SCI outcome making conventional imputation methods inappropriate. Although four patients who had developed SCI died before 30 days on ITU, we included them in the multivariate analysis as we felt the factors that may have played a role in the development of SCI were still valid.

In summary, of the factors we have investigated here, length of aortic coverage was the most significant risk factor for the development of SCI in patients undergoing endovascular repair of the thoracic and thoracoabdominal aorta. This has important implications for selection of patients for treatment and the risk-benefit ratios on an individual basis. For those presenting with extensive aneurysmal disease mandating significant aortic coverage careful consideration about the threshold diameter for intervention needs to be made and this should be factored into the consent process for each individual patient. It is to be hoped that further improvements in non-invasive imaging of the spinal cord blood supply may further help guide intervention on a personalised basis in the future.[34] We would advocate routine use of adjuncts (maintenance of mean arterial pressure of over 80mmHg and spinal drain) in all patients undergoing stenting procedures where coverage exceeds half their native aorta, and vigilance in the post-operative period once the spinal drain has been removed for any developing neurological defect.

Conflict of Interest

There are no known conflicts of interest.

Acknowledgements

The surgeons involved in operating on and contributing to this series are C Bicknell, NJW Cheshire, RGJ Gibbs, MP Jenkins, M Mireskandari and JHN Wolfe. The interventional radiologists were M Clarke, M Hamady and M Pelling.

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