Original article

Visceral ischaemia and organ dysfunction after hybrid repair of complex thoraco-abdominal aneurysms

Lukla Biasi[1,2], Tiziano Tecchio[2], Tahir Ali[1], Rob Morgan[1], Ian Loftus[1], Matt Thompson[1]
[1] St. George's Vascular Institute, London; [2] University Hospital of Parma, Italy

Abstract.*Background:* The visceral hybrid repair of thoracoabdominal aneurysms (TAAAs) is a feasible and relatively safe alternative to traditional open repair in a cohort of patients at high surgical risk, averting the need for thoracotomy and supra-coeliac aortic cross clamping. The visceral ischaemia-reperfusion syndrome and organ dysfunction following visceral debranching is still unkown. This study investigates the relationship between visceral ischemia and multi system organ dysfunction. *Patients and Methods:* 18 consecutive patients undergoing elective, urgent and emergent hybrid repair of TAAAs between February 2005 and October 2007 were prospectively analyzed. Preoperative organ dysfunction and intraoperative risk factors (operating time, extent of the aneurysm, number of visceral vessels by passed) were assessed and compared with postoperative organ dysfunction (pulmonary, hepatic, renal, pancreatic and haematological disorders). Blood sampling for neutrophil CD 11b quantification was performed at baseline, on postoperative days 1, 3, 7 and before discharge. *Results:* Perioperative Multi System Organ Dysfunction (MSOD) was diagnosed in 22.2% of patients (n=4/18). Three of these patients died within 30 days (16.7%, n=3/18). No relationship between preoperative organ dysfunction, blood loss, or operative time and postoperative organ dysfunction was observed. A significant correlation between the visceral retrograde revascularization and postoperative neutrophil expression in MSOD patients regardless of preoperative neutrophil baseline, TAAA extent and number of vessels by passed was present. *Conclusions:* Upregolation of neutrophils may be responsible for the higher incidence of MSOD and it may be an important marker predicting a severe multiple organ failure following visceral debranching in hybrid procedures. (www.actabiomedica.it)

Key words: hybrid repair, thoraco-abdominal aneurysms, Multi System Organ Dysfunction

Introduction

The expectant non-surgical management of thoracoabdominal aneurysms is associated with an unacceptable risk of death from aneurysm rupture within five years of diagnosis, in one of three patients with aneurysms greater than six centimetres (1-3).

Aneurysms 8 cm or larger have an 80% risk of rupture within 1 year of diagnosis.

Patients who are 70 years old or older with large aortic aneurysms have a 50% risk of death resulting from rupture within 1.5 years if the aneurysm is not excluded. The relative risk of rupture may increase by a factor of 2.6 for every decade of age with a Number Needed to Treat (NNT) of 2 to prevent one death at 5 years (4).

Aneurysm resection and prosthetic graft replacement of the involved segment of diseased thoracic and abdominal aorta has formed the mainstay of treatment over the last fifty years since the first successful report of the surgical resection of a thoraco-abdominal aneurysm and homograft aortic replacement com-

bined with re-implantation of the celiac and superior mesenteric vessels, as described by Samuel N. Etheredge in 1954 (5).

M.E. Debakey, after his first four-cases original experience presented at the American Surgical Association (White Sulphur Springs, West Virginia, April 1956), subsequently popularised the use of a novel warp-knitted polyester fibre tube forming a woven Dacron® graft as an aortic replacement for the thoracic aorta in conjunction with a four vessel, visceral and renal artery, revascularization (6).

In the following fifty years, patient morbidity and mortality had been shown to be intrinsically related to the period of aortic cross clamping and operative blood loss therefore requiring rapid and exact fashioning of numerous haemostatic anastomosis(7,8). Other additional identifiable prognostic factors have included emergent presentations, previous aortic replacement, age greater than 80 years, extent of aortic replacement (especially for TAAA of Crawford type II extent), established coronary heart disease, chronic obstructive lung disease, renal failure and the need for perioperative renal replacement therapy (9,10).

This era of "clamp and go" aortic replacement has been eschewed (by most surgeons) in favour of adjunctive strategies such as distal aortic perfusion (11) or full cardiopulmonary bypass with or without selective cryoperfusion of the visceral and renal vessels (12). Other Authors have advocated the routine drainage of cerebrospinal fluid, the use of somatosensory or motor evoked potentials (13), routine implantation of large or patent intercostals arteries (14), induction of moderate or deep hypothermia and the avoidance of diaphragmatic transaction (15), in order to further minimise spinal paraplegia rates and adverse patient outcomes.

In spite of the above measures the complication rates following conventional repair of TAAA is still significant with higher volume surgeons and hospitals in institutes of excellence reporting mortality rates of 5-16% with paraplegia rates of 4-11% (Table 1; Ref. 16-19). These figures may be more difficult to reproduce in smaller units with low volume case mix, with U.S. national reported morbidity rates approaching 62.2% and peri-operative mortality rates of up to 30% (20, 21).

The application of evolving combined surgical and endovascular stratagems in the management of complex thoracoabdominal aneurysms has been anticipated to reduce further adverse patient outcomes, by obviating the need for thoracotomy and aortic cross clamping and thereby reducing surgical trauma and concomitant blood loss. The exclusion of the thoraco-abdominal aortic aneurysm by means of an endoluminal stent graft delivered via a remote arteriotomy or conduit requires sufficient length of proximal and distal landing zones in non-diseased or replaced aorta and in addition needs to safeguard perfusion of the vital organs.

A hybrid repair is defined as a combined synchronous or staged surgical and endovascular approach in which open transperitoneal retrograde visceral revascularization is often allied with extra-anatomic supra-aortic vessel transposition in order to create an adequate distal and proximal landing zone for thoracoabdominal aneurysm endograft exclusion and thereby maintaining perfusion to the visceral and renal arteries.

We report our preliminary experience with a cohort of 18 consecutive patients and we investigate the ischaemia-reperfusion syndrome and organ dysfunction after visceral hybrid repair.

Patients and methods

From February 2005 to October 2007, the hospital records of 18 consecutive patients who had under-

Table 1. Comparable outcome data following open TAAA repair from selected high volume centres of excellence

Authors	Case series	Mortality	Spinal cord deficit
Coselli (16)	2286 TAAAs	5%	3.8%
Safi (17)	1100 TAAs + TAAAs	7.1% (841 procedures)	3.4%
Cambria (18)	337 TAAAs	8.3%	11.4%
Estrera (19)	654 TAAs + TAAAs	16%	2.4-5%

gone combined visceral revascularization and endovascular stenting of complex thoracoabdominal aortic aneurysms at St George's Regional Vascular Institute, London, were prospectively analysed.

Primary pre-operative diagnostic imaging was obtained in all patients by means of 64-slices CT scan of the thorax, abdomen and pelvis with multi-planar and three dimensional reconstructions.

In five patients, radio-nucleotide excretion renogram (MAG-3) was necessary to evaluate dynamic renal function and dominance before proceeding towards renal revascularization.

Thoracoabdominal aortic aneurysms were classified according to the revised Crawford-Safi TAAA extent classification into type II (n=8), type III (n=7), type I (n=2) and type V (n=1).

The study group comprised of ten men (55.6%) and eight women (44.4%) with an average age of 73 years (range 50-79 years).

All patients were deemed at high risk for conventional open surgical repair because of their severe comorbidities and history of previous aortic surgery.

Previous abdominal aortic aneurysm open repair had been undertaken in (n=4) 22.2% of this cohort (2 patients for ruptured infrarenal aneurysm) with a further three patients having had a history of earlier TAA open repair.

The median maximum aneurysm diameter was 65mm. (range 45-96 mm.) with the majority of aneurysms being atherosclerotic in aetiology (n=13, 72.2%). The remaining five patients had previous chronic aortic dissections with aneurysmal degeneration of which two had occurred in patients with underlying Marfan's Syndrome.

All elective and urgent patients had been pre-operatively classified ASA 3-4 on the basis of the American Society of Anaesthesiologist (ASA) Physical Status Classification System; emergent patients were classified ASA 5.

Elective repairs were undertaken in 14 (77.8%) patients. Two patients (11.1%) required urgent procedures for symptomatic TAAAs and a further two patients (11.1%) were emergently treated for radiologically proven aneurysm ruptures in the presence of haemodynamic instability (one thoracic and one abdominal rupture).

All patients were routinely post operatively admitted to the Intensive Care Unit (ICU).

Hybrid procedure

Five patients in this series (27.8%) were treated within a single hospital admission with sequential surgical and endovascular procedures with endograft deployment proceeding immediately after visceral vessel debranching in the operating suite (*simultaneous procedure*) using a portable digital C-arm angiographic system with image intensifier and road map capabilities.

The remaining patients (n=13) underwent staged exclusion of the aortic aneurysm with endovascular procedure performed in the angio-suite.

The median duration between initial visceral revascularization and final endovascular exclusion of thoraco-abdominal aneurysm was 112 days (range 49-240 days). The timing was contingent on the patient's general condition and rehabilitation from the first stage.

No patient died from aneurysm related rupture in this interim but one patient died in the early post-operative period precluding subsequent endovascular repair as a result of left colonic infarction and subsequent multi-organ failure on the third postoperative day.

Visceral debranching was performed under general anaesthesia and epidural anaesthesia with the patient lying supine. A midline transperitoneal incision was preferentially used to gain access to the coeliac trunk, superior mesenteric artery, renal arteries and inflow vessels.

Preferentially an inverted 16 x 8mm silver impregnated, rifampicin bonded Dacron® graft was fashioned end to side to the inflow vessel, by passing with a lazy 'C' configuration to the coeliac (retro-pancreatic approach) and superior mesenteric artery.

Each individual renal artery where accessible, was revascularised with a separate 6mm Dacron® graft distal end to end anastomosis, with an end to side proximal anastomosis to each limb of the inflow graft (Fig. 1).

Common femoral artery access for the endovascular procedure was achieved by oblique skin crease incision, contra lateral to the site of retrograde inflow.

Figure 1. Two vessel debranching: an inverted bifurcated 16 x 8 mm. silver bonded Dacron® graft, fashioned end to side to the left common iliac artery (CIA), by passing to the coeliac trunk and SMA.

Routine peri-operative spinal drainage of cerebrospinal fluid was not performed in this series of patients.

Results (Table 2)

A total of 54 visceral vessels were by passed in 18 patients.

Four patients (22.2%) underwent a complete retrograde four-vessel debranching revascularization.

Four renal arteries in three patients were inaccessible requiring ensuing revascularization by means of a custom made fenestrated or branched stent graft at the subsequent admission for endovascular exclusion of the aneurysm.

Technical success, defined by aneurysmal exclusion without intra-procedural evidence (at completion angiography and at intra-operative DynaCT [Fig. 2]) of type 1 or type 3 endoleaks, was achieved in all seventeen patients who underwent the endovascular stage.

Mortality

The overall 30-day mortality in this patient cohort was 16.7% (n=3/18), regardless of elective, urgent or emergent presentation.

One of these deaths occurred following visceral debranching (*post mortem examination excluded graft thrombosis*).

Another patient died as a result of aspiration pneumonia on day six following simultaneous aneurysm exclusion of a post dissection type II TAAA, whilst a further patient died following a middle cerebral artery stroke after an uneventful, staged visceral and supra-aortic trunk debranching followed by endovascular exclusion of a post dissection type II TAAA.

One late post operative death at 46 days following synchronous exclusion of a type III TAAA, attributed to embolic intestinal infarction and subsequent MOF occurred. Re-laparotomy excluded graft thrombosis and despite small bowel resection, this patient died.

Morbidity

Only one patient in this series developed delayed lower limb paraplegia following repair of a revised Safi-Crawford type II TAAA .Signs of motor and sensory loss at the level of T-10 occurred four days after completion of a staged hybrid repair and this did not completely improve in spite of cerebrospinal fluid drainage.

Table 2. Tabulated details of visceral debranching and endovascular aneurysmal exclusion

Visceral debranching (n=18)			Endovascular procedure (n=17)		
Inflow vessels*	left CIA	(n=5)	**Proximal**	**1**	(n=1)
	right CIA	(n=11)	**Landing Zone**	**2**	(n=3)
	infrarenal aorta (n=1)			**3**	(n=11)
	infrarenal graft (n=2)			**4**	(n=2)
Outflow vessels	coeliac trunk	(n=16)	**Distal**	**0**	(n=11)
	SMA	(n=18)	**Landing Zone**	**2**	(n=6)
	left renal	(n=9)			
	right renal	(n=11)			
Operative time	360 min		**Manufacturer of**	**Talent**	(n=3)
	(range 210-600 min)		**endografts****	**Valiant**	(n=15)
				Zenith	(n=4)
				Cook fenestrated	(n=2)
				Cook branched	(n=1)
Blood loss	3200 ml		**intraoperative leak 1,3**	(n=0)	
	(range 1000-1800 ml)				
ICU stay	3 days		**renal arteries sacrificed**	2 arteries in two pts.	
	(range 1-14 days)				
Hospital stay	18 days		**hospital stay**	7 days	
	(range 5-42 days)			(range 3-13)	

CIA: common iliac artery; SMA: superior mesenteric artery; ICU: intensive care unit.
* in one patient both right and left CIAs were used as inflow vessels;
** multiple endografts were delivered in the same patients.
PLZ according to Ishimaru's mapping of thoracic aorta; DLZ according to Chiesa's mapping of abdominal aorta

Figure 2. Intraoperative DynaCT (3D rendering) of a completed hybrid procedure: four vessel visceral debranching with simultaneous TAAA endovascular exclusion.

Follow up

All surviving patients were discharged from hospital with a clinic review at six weeks. Subsequent follow up and surveillance imaging as per protocol with both CT and Duplex scan surveillance (Philips HDI, curvilinear probe C5-2 Mega Hertz; IU 22 probe C1-4 Mega Hertz) were scheduled at 1, 6, and 12 months

Table 3. Assessment of pre-operative organ function and peri-operative organ dysfunction patterns

Organ dysfunction	Pulmonary	Cardiac	Hepatic	Renal	Pancreatic	Haematological
Pre-operative	COPD FEV1<65%	AMI<6 months NYHA III-IV Angina II-IV EF<45%	Chirrosis Δ function	Creat<1.5mg/dl	Amilase>300 U/L	Major bleeding Δ coagulation
Peri-operative	MVS<7days ARSD	Δ ECG + Trop>0.05 ng/ml	Transam>200U/L; Transam>50U/L obl Phosph>140U/L obl + Bilirubin>3 mg/dL GammaGT>50U/L	Creat>2.0 mg/dl ovb	Amilase>300U/L	Platelet<5000/mm^3 WBC<4500 mm^3

MVS: Mechanical Ventilatory Support; ARSD: Acute Respiratory Syndrome (PaO2/FiO2 ratio <200 according to the American-European Consensus Conference); Transam: transaminase; Phosph: phosphatase; ovb: over base line

and annually thereafter. At death or a median follow up of 23 months (range 8-42 months) all visceral grafts but one (53/54) had remained patent (98.1% patency rate). One coeliac artery graft anastomosed to the common hepatic artery, occluded in the time interval between stage 1 and stage 2 but was not associated with symptoms of acute or chronic ischaemia.

The incidence of type I endoleaks in surviving patients was 11.8 % (n=2).

Only one (type 1A) required an adjuvant, successful, carotid-carotid by pass and proximal stenting. The other patient is yet to be readmitted for a proximal extension cuff, following a supra-aortic trunk transposition to maintain a LIMA coronary graft.

No type III endoleaks were observed. Five type II endoleaks which did not necessitate further endovascular intervention were identified.

Ischaemia-Reperfusion Syndrome

A clinical analysis was performed to establish the relationship between visceral ischaemia and organ dysfunction in patients who showed visceral vessels revascularization.

Clinical and laboratory data were analyzed from all patients to assess pre-operative organ function and peri-operative (at day 1, at ICU discharge and before hospital discharge) organ dysfunction patterns.

Pulmonary, cardiac, hepatic, renal, pancreatic and haematological functions were investigated.

Objective parameters were set to standardize the definitions of organ dysfunction (Table 3). Laboratoristic thresholds were consistent with previous studies on clinical outcomes after traditional thoracoabdominal aneurysm repairs (22).

Preoperative pulmonary dysfunction was defined through a previous clinical and radiological diagnosis of COPD or spirometric evidences of reduced FEV1 less than 65% predicted.

Cardiac status was defined by recent history of myocardial infarction (<6 months) or congestive heart failure (NYHA III-IV) or stable-unstable angina (class II-IV), ejection fraction less than 45% predicted.

Preoperative hepatic disorders were defined by abnormal liver function or history of cirrhosis.

Preoperative renal and pancreatic dysfunction threshold was set at plasma creatinine level of >1.5mg/dL and amylase >300 U/L respectively.

Preoperative haematological disorders were defined by known coagulative factors deficiency or history of major bleeding.

Perioperative respiratory dysfunction was termed as hypoxia requiring prolonged (>7 days) mechanical ventilatory support or onset of Acute Respiratory Distress Syndrome (ARSD) with PaO2/FiO2 ratio <200.

Perioperative Acute Coronary Syndrome was defined by specific electrocardiogram alterations and throponin rise (> 0.05 ng/mL).

Perioperative hepatic dysfunction was defined by plasma transaminase >200 U/L; transaminase >50 U/L or phosphatase >140 U/L over base line associat-

ed to either total bilirubin >3mg/dL or gammaGT >50 U/L.

Perioperative renal and pancreatic dysfunction was defined by an increase of plasma creatinine >2mg/dL over base line and plasma amylase >300 U/L respectively.

Perioperative haematological dysfunction was defined by a platelet count <50000/mm^3 or a drop in white blood count < 4500/mm^3.

Patients with two or more organ systems meeting these criteria were diagnosed having a Multi System Organ Dysfunction.

No patients required positive pressure ventilatory assistance or intubation longer than 7 days but 4 patients were diagnosed with acute respiratory distress syndrome in the acute post operative phase.

Hepatic dysfunctions occurred in 2 patients and renal impairment and pancreatic dysfunction occurred in 1 patient respectively.

Haematological disorders occurred in 3 patients: 2 with a drop in WBC and 1 with a drop in the platelet count.

The frequency rate of perioperative MSOD was 22.2% (n=4/18). Three of these patients died.

MSODs consisted of hepatic and haematological dysfunctions in one patient who later developed a MOF and died at day 3; pulmonary, hepatic, renal, pancreatic and haematological dysfunctions developed in a further patient who died on day 6 for aspirational pneumonia; one more patient presented pulmonary and hepatic dysfunctions and died post-operatively (on day 46) for a late small bowel massive infarction leading to MOF; the fourth MSOD consisted of pulmonary, cardiac and hepatic dysfunctions in a patient admitted with thoracic ruptured TAAA and discharged without further complications on day 20 after the hybrid procedure.

Statistical comparison of categorical data was carried out using homoscedastic, two tailed Student's T Test.

No significant relationship was found between pre-operative and peri-operative organ injuries.

MSOD seems to be statiscally unrelated ($p > 0.05$) to the extent of the aneurysm, the number of visceral vessels revascularized, the operative time and the estimated blood loss.

Venous blood samples were collected and processed with flow cytometric analysis for neutrophil (CD11b) determination at fixed time intervals (preoperatively, on post operative days 1, 3, 7 and before hospital discharge).

From statistical analysis (Student's T-Test) we observed a progressively significant increase of median neutrophil concentration in the cohort of 18 patients, on day 1 ($p= 0.006$), on day 3 ($p= 0.001$) and on day 7 ($p< 0.001$) and an almost complete regression at discharge.

But from a sub-analysis emerged a significant difference in perioperative neutrophil expression between patients who developed MSOD and those who did not presented multi organ dysfunction.

In MSOD patients the neutrophil profile rose close to statistical significance on day 3 ($p= 0.06$) and reached a significant peak on day 7 ($p= 0.002$), while no significant increase among patients who didn't developed multi organ failures was observed.

Pre-operative levels of neutrophils were not significantly higher in patients who later developed a MSOD ($p> 0.05$);

No evident correlations between the number of vessels debranched and the magnitude of CD11b response emerged.

Discussion

Open surgery for TAAA, remains a challenging procedure with high rates of neurological, cardiopulmonary and renal complications in spite of current surgical adjuncts in a high risk surgical population with poor cardiac and respiratory reserves. Outcomes are more unfavourable in those patients with extensive Crawford type II and III aneurysms.

Even at major academical medical centres, multivariate stratification of competing risks pointed out a 30 day mortality rate of 50% in octogenarians at high risk (emergent presentation, congestive heart failure or diabetes) (23).

Negative outcomes (renal failure, paraplegia/paraparesis, stroke or death) are reported in 43.4% of type II TAAA open repairs (24); paraplegia alone, still occurs in up to 25% of extensive type II patients (25).

The evolving approach of sequential retrograde visceral revascularization followed by endoluminal exclusion of TAAAs (hybrid procedure) shows clear theoretical advantages of the hybrid technique which are the avoidance of thoracotomy and supra-coeliac aortic clamping with resultant greater intra operative haemodynamic stability, the avoidance of prolonged visceral ischemia, and a potential to reduce cardiopulmonary injury and spinal cord ischaemia.

Since Quinones-Baldric et al. first case report (San Francisco, 1999) of a successful type IV TAAA combined repair preliminary encouraging results have been published (26).

A recent systematic review by Donas et al., had identified a total of 58 patients treated with a hybrid approach until October 2006 with a reported peri operative and mid-term mortality rate of 10.7% and 15.5% (median follow up of 14.2 months) respectively, with reported graft patency of 97.8% (229/234 grafts) and no spinal cord injuries[30] , suggesting the feasibility and safety of this technique (27).

This study, however was disadvantaged in that only one of the thirteen case series included in the review-analysis showed greater than 8 patients and moreover, extensive thoraco-abdominal aneurysms (Crawford type II) were under represented in these case series, comprising of little over a third of the population studied.

In a contemporary review of all hybrid case series with cohort numbers greater than ten patients, overall mortality rates vary between 6.7 to 24% (28-33). Surprisingly, despite extensive endoluminal exclusion of the thoraco-abdominal aorta, spinal deficit is reported but rates remain low in all series. Technical and clinical outcomes of our institutional study are consistent with previously reported largest case series.

Despite an encouraging technical success in terms of graft patency and endoleak detection (hybrid's main concerns) mortality and morbidity are still impressive and comparable to traditional open repair (although most of the patients wouldn't be deemed candidates for a pure surgical approach). The reason could be found understanding the physiopathology of the visceral ischemia-reperfusion syndrome.

Acute visceral ischemia and reperfusion during TAAA traditional open repair have been previously shown to produce a relevant systemic pro-inflammatory response leading to distant organ dysfunction. Supra-celiac clamping time > 40 minutes is associated with greater incidence of pulmonary, hepatic, renal and haematopoietic dysfunction.

The near global ischemia induced by supra-celiac clamping is associated with an increased plasma concentration of TNF-α and IL-6 whose magnitude is correlated to the time of aortic clamping (34). In comparable animal models, blocking TNF-α or IL-1 reduced organ failures.

A recent clinical study on major aortic surgery showed early and persistent upregulation of the genes for IL-6 and for the components of the local renin-angiotensin system in the ischemic muscle, leading to a systemic inflammatory reaction followed by impaired pulmonary function (35).

Such dysfunctional systemic cytokine release is triggered by intraoperative polymorphonuclear neutrophils activation.

In TAAA open repair there is a significant correlation between visceral ischemia time and intraoperative neutrophil CD11b expression and cytokine response when compared with infrarenal aneurysm surgery and major non-aortic abdominal surgery (36).

No previously reported study has investigated the magnitude of neutrophil activation and organ dysfunction patterns in TAAA hybrid procedures.

In our clinical analysis we pointed out that visceral debranching is associated with a dysfunctional peri-operative systemic inflammation sustained by polymorphonuclear neutrophils.

This severe pro-inflammatory response is significantly associated to the development of delayed perioperative organ injuries.

The visceral ischemia-reperfusion syndrome in visceral debranching seems to be pathogenically comparable with traditional procedures with supra-celiac clamping.

Similarly to traditional open TAAA repairs, postoperative organ dysfunctions are not associated with pre-operative risk factors, aneurysm extent and intraoperative procedures: number of revascularized vessels, mean operative time and estimated blood loss (indeed we didn't record any significant difference in outcome comparing elective with urgent and emer-

gent interventions). Such dysfunctional response has the characteristics of an "all or nothing" phenomenon triggered by iatrogenic visceral ischaemia and subsequent reperfusion.

The perioperative neutrophil profile may be an important marker predicting a severe single or multiple organ failure and should be strictly monitored after visceral debranching.

References

1. Crawford ES, DeNatale RW. Thoracoabdominal aortic aneurysm: observations regarding the natural course of the disease. *J Vasc Surg* 1986; 3 (4): 578-82.
2. Webb TH, Williams GM. Thoracoabdominal aneurysm repair. *Cardiovasc Surg* 1999; 7 (6): 573-85.
3. Clouse WD, Hallett JW Jr, Schaff HV, Gayari MM, Ilstrup DM, Melton LJ, III. Improved prognosis of thoracic aortic aneurysms: a population-based study. *JAMA* 1998; 280 (22): 1926-9.
4. Miller CC 3rd, Porat EE, Estrera AL, Vinnerkvist AN, Huynh TT, Safi HJ. Number needed to treat: analyzing of the effectiveness of thoracoabdominal aortic repair. *Eur J Vasc Endovasc Surg* 2004; 28 (2): 154-7.
5. Etheredge ME, Yee J, Smith JV, Schonberger S, Goldman MJ. Successful resection of a large aneurysm of the upper abdominal aorta and replacement with homograft. *Surgery* 1955; 38 (6): 1071-81.
6. De Bakey ME, Cooley DA, Crawford ES, Morris GC, Jr. Clinical application of a new flexible knitted dacron arterial substitute. *AMA Arch Surg* 1958; 77 (5): 713-24.
7. Crawford ES, Crawford JL, Safi HJ, et al. Thoracoabdominal aortic aneurysms: preoperative and intraoperative factors determining immediate and long-term results of operations in 605 patients. *J Vasc Surg* 1986; 3 (3): 389-404.
8. Cina CS, Clase CM. Coagulation disorders and blood product use in patients undergoing thoracoabdominal aortic aneurysm repair. *Transfus Med Rev* 2005; 19 (2): 143-54.
9. Coselli JS, LeMaire SA, Miller CC III, et al. Mortality and paraplegia after thoracoabdominal aortic aneurysm repair: a risk factor analysis. *Ann Thorac Surg* 2000; 69 (2): 409-14.
10. Etz CD, Di LG, Bello R, et al. Pulmonary complications after descending thoracic and thoracoabdominal aortic aneurysm repair: predictors, prevention, and treatment. *Ann Thorac Surg* 2007; 83 (2): S870-S876.
11. Safi HJ. Role of the BioMedicus pump and distal aortic perfusion in thoracoabdominal aortic aneurysm repair. *Artif Organs* 1996; 20 (6): 694-9.
12. Hassoun HT, Miller CC, III, Huynh TT, Estrera AL, Smith JJ, Safi HJ. Cold visceral perfusion improves early survival in patients with acute renal failure after thoracoabdominal aortic aneurysm repair. *J Vasc Surg* 2004; 39 (3): 506-12.
13. Sueda T, Morita S, Okada K, Orihashi K, Shikata H, Matsuura Y. Selective intercostal arterial perfusion during thoracoabdominal aortic aneurysm surgery. *Ann Thorac Surg* 2000; 70 (1): 44-7.
14. Safi HJ, Miller CC, III, Carr C, Iliopoulos DC, Dorsay DA, Baldwin JC. Importance of intercostal artery reattachment during thoracoabdominal aortic aneurysm repair. *J Vasc Surg* 1998; 27 (1): 58-66.
15. Safi HJ. How I do it: thoracoabdominal aortic aneurysm graft replacement. *Cardiovasc Surg* 1999; 7 (6): 607-13.
16. Coselli JS, Bozinovski J, Lemaire SA. Open surgical repair of 2286 thoracoabdominal aortic aneurysms. *Ann Thorac Surg* 2007; 83 (2): S862-S864.
17. Safi HJ, Estrera AL, Azizzadeh A, Coogan S, Miller CC, III. Progress and future challenges in thoracoabdominal aortic aneurysm management. *World J Surg* 2008; 32 (3): 355-60.
18. Cambria RP, Clouse WD, Davison JK, Dunn PF, Corey M, Dorer D. Thoracoabdominal aneurysm repair: results with 337 operations performed over a 15-year interval. *Ann Surg* 2002; 236 (4): 471-9.
19. Estrera AL, Miller CC III, Chen EP, et al. Descending thoracic aortic aneurysm repair: 12-year experience using distal aortic perfusion and cerebrospinal fluid drainage. *Ann Thorac Surg* 2005; 80 (4): 1290-6.
20. Cowan JA, Jr, Dimick JB, Henke PK, Huber TS, Stanley JC, Upchurch GR, Jr. Surgical treatment of intact thoracoabdominal aortic aneurysms in the United States: hospital and surgeon volume-related outcomes. *J Vasc Surg* 2003; 37 (6): 1169-74.
21. Rigberg DA, McGory ML, Zingmond DS, et al. Thirty-day mortality statistics underestimate the risk of repair of thoracoabdominal aortic aneurysms: a statewide experience. *J Vasc Surg* 2006; 43 (2): 217-22.
22. Harward TR, Welborn MB 3rd, Martin TD, Flynn TC, Huber TS, Moldawer LL, Seeger JM. Visceral ischemia and organ dysfunction after thoracoabdominal aortic aneurysm repair. A clinical and cost analysis. *Ann Surg* 1996; 223 (6): 729-34; discussion 734-6.
23. Huynh TT, Miller CC, III, Estrera AL, Porat EE, Safi HJ. Thoracoabdominal and descending thoracic aortic aneurysm surgery in patients aged 79 years or older. *J Vasc Surg* 2002; 36 (3): 469-75.
24. Jacobs MJ, Mommertz G, Koeppel TA, et al. Surgical repair of thoracoabdominal aortic aneurysms. *J Cardiovasc Surg* (Torino) 2007; 48 (1): 49-58.
25. Coselli JS, Lemaire SA. Tips for Successful Outcomes for Descending Thoracic and Thoracoabdominal Aortic Aneurysm Procedures. *Semin Vasc Surg* 2008; 21 (1): 13-20.
26. Quiñones-Baldrich WJ, Panetta TF, Vescera CL, Kashyap VS. J .Repair of type IV thoracoabdominal aneurysm with a combined endovascular and surgical approach. *Vasc Surg* 1999; 30 (3): 555-60.
27. Donas KP, Czerny M, Guber I, Teufelsbauer H, Nanobachvili J. Hybrid open-endovascular repair for thoracoabdominal aortic aneurysms: current status and level of evidence. Eur J Vasc Endovasc Surg 2007; 34 (5): 528-33. Epub 2007 1. Review.

28. Resch TA, Greenberg RK, Lyden SP, et al. Combined staged procedures for the treatment of thoracoabdominal aneurysms. *J Endovasc Ther* 2006; 13 (4): 481-9.
29. Zhou W, Reardon M, Peden EK, Lin PH, Lumsden AB. Hybrid approach to complex thoracic aortic aneurysms in high-risk patients: surgical challenges and clinical outcomes. *J Vasc Surg* 2006; 44 (4): 688-93.
30. Black SA, Wolfe JH, Clark M, Hamady M, Cheshire NJ, Jenkins MP. Complex thoracoabdominal aortic aneurysms: endovascular exclusion with visceral revascularization. *J Vasc Surg* 2006; 43 (6): 1081-9.
31. Bockler D, Schumacher H, Klemm K, et al. Hybrid procedures as a combined endovascular and open approach for pararenal and thoracoabdominal aortic pathologies. *Langenbecks Arch Surg* 2007; 392 (6): 715-23.
32. Lee WA, Brown MP, Martin TD, Seeger JM, Huber TS. Early results after staged hybrid repair of thoracoabdominal aortic aneurysms. *J Am Coll Surg* 2007; 205 (3): 420-31.
33. Chiesa R, Tshomba Y, Melissano G, et al. Hybrid approach to thoracoabdominal aortic aneurysms in patients with prior aortic surgery. *J Vasc Surg* 2007; 45 (6): 1128-35.
34. Welborn MB, Oldenburg HS, Hess PJ, et al.The relationship between visceral ischemia, proinflammatory cytokines, and organ injury in patients undergoing thoracoabdominal aortic aneurysm repair. *Crit Care Med* 2000; 28 (9): 3191-7.
35. Adembri C, Kastamoniti E, Bertolozzi I, et al. Pulmonary injury follows systemic inflammatory reaction in infrarenal aortic surgery. *Crit Care Med* 2004; 32 (5): 1170-7.
36. Supraceliac, but not infrarenal, aortic cross-clamping upregulates neutrophil integrin CD11b. Hill GE, Mihalakakos PJ, Spurzem JR, Baxter TB. *J Cardiothorac Vasc Anesth* 1995; 9 (5): 515-8.

Accepted: May 5th 2011
Correspondence: Dr. Lukla Biasi
Unit of Vascular Surgery, University Hospital of Parma
Ospedale Maggiore - Via Gramsci, 14
Parma 43100, Italy
Tel. 0039 340 2695946
Fax. 0521 992019
Email: luklabiasi@gmail.com