[11] Zipfel B, Bauer M, Schaffarczyk R, Hetzer R. Operative repair of traumatic aortic rupture with extracorporeal circulation — management and outcome. Thorac Cardiovasc Surg 1999;43(Suppl. I):260—1.
[12] Hunt JP, Baker CC, Lentz WL, Rutledge RR, Oller DW, Flowe KM, Nayduch DA, Smith C, Clancy TV, Thomason MH, Meredith JW. Thoracic aorta injuries: management and outcome of 144 patients. J Trauma 1996;40:547—56.
[13] Nicolosi AC, Almassi GH, Bousamra M, 2nd, Haasler GB, Olinger GN. Mortality and neurologic morbidity after repair of traumatic aortic disruption. Ann Thorac Surg 1996;61:875—8.
[14] Grabenwoger M, Fleck T, Czerny M, Hutschala D, Ehrlich M, Schoder M, Lammer J, Wolner E. Endovascular stent graft placement in patients with acute thoracic aortic syndromes. Eur J Cardiothorac Surg 2003;23:788—93.
[15] Jamieson WRE, Janusz MT, Gudas VM, Burr LH, Fradet GJ, Henderson C. Traumatic rupture of the thoracic aortic: third decade of experience. Am J Surg 2002;183:571—5.
[16] Rousseau H, Soula P, Perreault P, Bui B, Janne d'Othee B, Massabuau P, Meites G, Concina P, Mazerolles M, Joffre F, Otal P. Delayed treatment of isthmic aortic rupture. Circulation 1999;99:498—504.
[17] Langanay T, Verhoye LP, Corbineau H, Agnino A, Derieux T, Menestret P, Logeais Y, Leguerrier A. Surgical treatment of acute traumatic rupture of the thoracic aorta a timing reappraisal? Eur J Cardiothorac Surg 2002;21(2):282—7.
[18] Fabian TC, Richardson JD, Croce MA, Smith JS, Rodman Jr G, Keaney PA, Flynn W, Ney AL, Cone JB, Luchette FA, Wisner DH, Scholten DJ, Beaver BL, Conn AK, Coscia R, Hoyt DB, Morris JA, Harviel JD, Peitzman AB, Bynoe RP, Diamond DL, Wall M, Gates JD, Asensio JA. Prospective study of blunt aortic injury: multicenter trial of the American Association for the Surgery of Trauma. J Trauma 1997;42:374—83.
[19] Amabile P, Collart F, Gariboldi V, Rollet G, Bartoli LM, Piquet P. Surgical versus endovascular treatment of traumatic thoracic aortic rupture. J Vasc Surg 2004;40:873—9.
[20] Zipfel B, Hammerschmidt R, Krabatsch T, Buz S, Weng Y, Hetzer RJ. Maxwell Chamberlain memorial paper for adult cardiac surgery: stent-grafting of the thoracic aorta by the cardiothoracic surgeon. Ann Thorac Surg 2007;83:441—9.
[21] Rousseau H, Dambrin C, Marcheix B, Richeux L, Mazerolles M, Cron C, Watkinson A, Mugniot A, Soula P, Chabbert V, Canevet G, Roux D, Massabuau P, Meites G, Tran Van T, Otal P. Acute traumatic aortic rupture: a comparison of surgical and stent-graft repair. J Thorac Cardiovasc Surg 2005;129:1050—5.
[22] Ott MC, Stewart TC, Lawlor DK, Gray DK, Forbes TL. Management of blunt thoracic injuries: endovascular stent versus open repair. J Trauma 2004;56:565—70.
[23] Kühne CA, Rucholtz S, Voggenreitter G, Eggebrecht H, Paffrath T, Waydhas C, Nastkolb D. Traumatic aortic injuries in severely injured patients. Unfallchirurg 2005;108:279—87.
[24] Hoornweg LL, Dinkelman MK, Goslings JC, Reekers JA, Verhagen HJM, Verhoeven EL, Schurink GWH, Balm R. Endovascular management of traumatic ruptures of the thoracic aorta: a retrospective multicenter analysis of 28 cases in The Netherlands. J Vasc Surg 2006;43(6):1096—102.
[25] Idu MM, Reekers JA, Balm R, Ponsen KJ, de Mol BA, Legemate DA. Collapse of a stent-graft following treatment of a traumatic thoracic aortic rupture. J Endovasc Ther 2005;12(4):503—7.

Appendix A. Conference discussion

Dr D.C. Miller (*Stanford, California, USA*): Nine of the 31 had the left subclavian covered? Is it correct that 9 of the 31 patients required covering the left subclavian artery covered by the stent graft?

Dr Buz: Yes. In 9 of the 31 patients, the origin of the left subclavian artery was primarily overstented; 5 of them later needed bypass.

Dr Miller: Five needed revascularization?

Dr Buz: Yes.

Dr Miller: Because of arm claudication or posterior fossa cerebral insufficiency?

Dr Buz: The arm symptoms, i.e. arm ischemia at exercise or at rest, were the main indications for revascularization.

Dr Miller: It should be remembered that you cover the left subclavian ostium when you have to in an emergency situation, but you can get burned by a posterior fossa stroke if the left vertebral is large and the right vertebral is hypoplastic or occluded. We use the pre-procedure CTA to assess the vertebral artery anatomy and size to determine whether to revascularize (transposition preferred over carotid—subclavian bypass) the left subclavian system before or during the stent graft. Also remember that the left vertebral artery originates directly from the arch in about 2% of patients — a four-vessel arch — which can be very important.

Dr Buz: In patients with polytrauma, especially with severe head injury, the distinction of neurological complication related to occlusion of the left subclavian artery is difficult. But in this series with 31 patients we have not shown any neurological complication because of LSA occlusion. (Comment: In an oral presentation in Stockholm, we reported 31 patients treated with endovascular stent grafting. After the update of all patients until 2007, the paper reports on 39 patients (endovascular group). In this series we have two patients with neurological complications following LSA occlusion, reported in the paper).

Dr Miller: Yet. . . . As your experience gets larger it will happen. Believe me, this is a tricky and controversial subject.

Dr T. Sundt (*Rochester, Minnesota, USA*): I may have missed this. In your conventional group, how was the repair performed? Was it performed with left heart bypass? Did you give any heparin? Or did you use full cardiopulmonary bypass? I am concerned about your conclusions, because you seem to have an extraordinarily high CVA rate in your control group of conventional surgery. I'm concerned about how much heparin was administered in the control group.

Dr Buz: We had five patient deaths on intracranial hemorrhage in this group. In all patients who were operated on with cardiopulmonary bypass, systemic heparinization was established.

Dr Sundt: In your control group, how was the operation done? Was full bypass with full heparinization used?

Dr Miller: Two were off-pump, or clamp and sew. What perfusion strategy for spinal cord and lower body protection was used for the others in the conventional surgery control group — left heart bypass, total bypass?

Dr Buz: We had only two patients without cardiopulmonary bypass in the conventional group. Except for two patients who were operated on without cardiopulmonary bypass, in all patients femorofemoral bypass was established. Out of them in 9 patients circulatory arrest and deep hypothermia were performed.

Editorial comment

Management of traumatic aortic rupture: endovascular is the winner

Massive deceleration either horizontal or vertical can cause rupture of the aorta typically at the level of the ligamentum arteriosum (the aortic isthmus) distal to the origin of the left subclavian artery. The moment of inertia displaces the relatively mobile heart together with the aortic arch, while the descending aorta tethered to the spine via the intercostals pedicles remains fixed. With the vast majority of these injuries incurred through car crashes, nearly 80% of the victims die at scene of the accident as a result of complete aortic transection including the adventitia and attached connective tissue [1]. Approximately 20% reach the hospital alive due to an incomplete disruption of the

tunica intima and media. Tensile strength is provided by the intact adventitia, and the parietal pleura contain the hematoma. However, if left untreated, 5—20 % of these patients are at risk of secondary rupture and intrapleural exsanguination within the first week [2]. In surgically untreated survivors, the natural course of aortic rupture is false aneurysm formation with secondary rupture after months or years.

For decades the treatment of choice has been immediate repair by a left thoracotomy, aortic cross clamping and direct suturing, or prosthetic graft interposition. The outcome has been constantly improved and in particular, the risk of paraplegia resulting from open surgery has been decreased to 2% by the use of partial cardiopulmonary bypass, active distal perfusion, and heparin-bonded circuits. However, mortality remains high with 12—26% due to associated injuries [3,4].

Since the first report of an endovascular treatment of traumatic aortic rupture in 1997 [5], numerous studies including our own experience [6,7] demonstrate a high degree of technical success and low complication rates, although based on a small number of patients. The recent report of Buz and co-workers [8] represents the largest series to date, and corroborates the results of the previous studies. It gives, once again, supporting evidence of an improved early outcome following endovascular repair. The literature gives clear proof of a shift in the management from open surgical to endovascular repair. Although endovascular aneurysm repair was first introduced 16 years ago, and a decade from the first stent graft repair of an acute traumatic rupture, no prospective randomized trial has been performed so far. Endovascular repair has several obvious advantages over open repair:

Increased efficiency: operative trauma load is minimal with a relatively short operating time of 60—90 min.
Improved outcomes: overall early mortality seems to be lower by 3—6%, as well as procedure-related morbidity including pulmonary complications. Heparin administration, even if necessary, is minimized and, therefore, less dangerous in patients with cerebral injuries. The endovascular repair is usually performed in a supine position, which is preferable in the presence of instable spine fractures.
Lower risk: paraplegia as an inherent and tragic complication of open repair, is *not* associated with endovascular repair, as aortic cross clamping is avoided.
Minimized delay: the endovascular approach removes the issue of delaying the repair due to its minimal invasiveness.

While the techniques and technology used in endovascular repair will continue to improve, there are a number of challenges that remain, namely:

Design improvement: there is a demand for smaller device diameters (20 or 22 mm) in these mostly younger patients with a small aorta and a tight aortic arch. Improvements of the devices are likely to mitigate device-related complications such as endoleaks and device collapse. Enhanced flexibility in order to better accommodate the steep inner curve of the aortic arch and a covered flap at the proximal end of the device designed to fully appose the inner aortic curve, will enable tight sealing of the aortic tear. A scallop at the outer proximal end of the device could avoid covering the left subclavian artery orifice. However, its covering by the actually available devices is necessary in about one third of the cases, and is rarely associated with impaired perfusion of the extremity. Finally the risk of iliac artery laceration could be decreased by smaller introducer sheaths.
Embolization risk: an inherent risk is the possibility of cerebral embolization resulting from manipulations within the aortic arch, although most of these trauma victims are young and their aortas free of atheroma.
Repair suitability: certain types of lesions are not favorable to an endovascular repair. There is such a circumferential disruption with pseudocoarctation because of the risk of dissection of the aortic arch by endovascular manipulations, or an impending instability of the device because of insufficient anchorage. An aortic disruption with extension into the arch also requires an open repair.
Device durability: the main argument against the endovascular repair, or indeed in favor of a randomized trial, is the unknown outcome in the long term. There are some concerns about device collapse, compression of the left main stem bronchus or aortoesophageal fistula, however, they seem to be very rare, and mid-term results are encouraging [9,10].

In summary, reduced early mortality and procedure-related morbidity, combined with the absence of paraplegia, are strong arguments in favor of an endovascular repair. Although early results are favorable, long-term outcome is still lacking. Considering the very encouraging experience we have to date, it is difficult to recommend prospective randomized trials. In the challenging management of traumatic rupture of the aorta, the endovascular approach with a record of improved outcomes, is a winning strategy.

References

[1] Parmley LF, Mattingly TW, Manion WC, Jahnke EJ. Nonpenetrating traumatic injury of the aorta. Circulation 1958;XVII:1086—101.
[2] Pate JW, Fabian TC, Walker W. Traumatic rupture of the aortic isthmus: An emergency? World J Surg 1995;19:119—26.
[3] Cook J, Salerno C, Krishnadasan B, Nichols S, Meissner M, Karmy-Jones R. The effect of changing presentation and management on the outcome of blunt rupture of the thoracic aorta. J Thorac Cardiovasc Surg 2006; 131:594—600.
[4] Jahromi AS, Kazemi K, Safar HA, Doobay B, Cina CS. Traumatic rupture of the thoracic aorta: Cohort study and systematic review. J Vasc Surg 2001;34:1029—34.
[5] Kato N, Dake MD, Miller DC, Semba CP, Mitchell RS, Razavi MK, Kee ST. Traumatic thoracic aortic aneurysm: Treatment with endovascular stent-grafts. Radiology 1997;205:657—62.
[6] Lettinga-van de Poll T, Schurink GWH, De Haan MW, Verbruggen JPAM, Jacobs MJ. Endovascular treatment of traumatic rupture of the thoracic aorta. Br J Surg 2007;9:525—33.

[7] Marty B, Tozzi P, Ruchat P, Huber C, Doenz F, von Segesser LK. An IVUS-based approach to traumatic aortic rupture, with a look at the lesion from inside. J Endovasc Ther 2007;14:689—97.
[8] Buz S, Zipfel B, Mulahasanovic S, Pasic M, Weng Y, Hetzer R. Conventional surgical repair and endovascular treatment of acute traumatic aortic rupture. Eur J Cardiothorac Surg 2008;33:143—9.
[9] Hoornweg LL, Dinkelman MK, Goslings C, Reekers JA, Verhagen HJM, Verhoeven EL, Schurink GWH, Balm R. Endovascular management of traumatic ruptures of the thoracic aorta: A retrospective multi-center analysis of 28 cases in The Netherlands. J Vasc Surg 2006;43: 1096—102.
[10] Marcheix B, Dambrin C, Bolduc J-P, Arnaud C, Hollington L, Cron C, Mugniot A, Soula P, Bennaceur M, Chabbert V, Otal P, Cérène A, Rousseau H. Endovascular repair of traumatic rupture of the aortic isthmus: Midterm results. J Thorac Cardiovasc Surg 2006;132:1037—41.

Bettina Marty*
Department of Cardiovascular Surgery, University Hospital, Rue du Bugnon 46, 1011 Lausanne, Switzerland

*Corresponding author. Tel.: +41 26 426 7185; fax: +41 26 426 7314
E-mail address: martyb@h-fr.ch

Available online 3 December 2007

doi:10.1016/j.ejcts.2007.10.018