Biomechanical and histologic analysis in aortic endoprosthesis using fibrin glue

Marcelo José Almeida, PhD, Winston Bonetti Yoshida, PhD, Ludvig Hafner, PhD, Julio Sequeira, PhD, Juliana Henriques dos Santos, MD, Ana Paula Batista Masseno, MS, José Bitu Moreno, PhD, and **Sílvia de Sá Lorena, PhD,** *Botucatu, São Paulo, Brazil*

Background: **The absence of incorporation between endoprosthesis (EP) and the arterial wall may lead to device migration and endoleaks around the stent graft. Alternatives have been tested aiming to improve this incorporation. Fibrin glue is used in many operating procedures promoting adhesion and tissue regeneration; however, its use to improve EP incorporation by arteries is unknown.**

Objective: **The objective of this study was to analyze dislodgement forces needed to extract the EPs implanted in pig aorta, compare different oversizing and fibrin glue injections, and to analyze histologic changes among groups.**

Methods: **Straight EPs were implanted in the thoracic aorta of pigs using 10% oversizing plus fibrin glue in the interface between the EP and the artery (group 1), using 20% oversizing (group 2), and 10% oversizing (group 3). Fourteen days after the implant, the animals were killed to enable biomechanical analysis of the EP and to verify histologic changes of the aortic wall and its interface with the EP.**

Results: **Group 1 showed a dislodgement force of 21.9 ± 5.3 Newton (N) being higher than the other groups and statistically significant when compared to group 3 (15.6 ± 3.6N), $P = .003$%. Group 2 had a higher dislodgement force and statistically more significant than group 3 (19.5 ± 7.8N). Histologic analysis showed tissue reaction with inflammatory cells and fibroblasts higher in group 1 and group 2 compared to group 3.**

Conclusion: **This study reports a large animal survival model of thoracic aortic stent graft placement by testing the impact of fibrin glue on EP incorporation. Compared to oversizing alone, fibrin glue placed between the stent graft and the arterial wall increases EP incorporation. Additional studies are needed to determine the potential utility of fibrin glue in the setting of human arterial endografts. (J Vasc Surg 2011;53:1368-74.)**

Clinical Relevance: **The incorporation of stent grafts never occurs and migration is a common problem. The EP resource fixation is oversizing, which has been empirically determined to be between 10% and 30%. In this article, biomechanical studies provided an evaluation about the oversizing and the forces for displacement of the EP. Moreover, successful initiatives have been done to improve the incorporation of the stent grafts. Our study used fibrin glue to improve the incorporation and fixation of stent grafts. Fibrin glue applied to the interface of the EP/aorta promoted better fixation of EPs, induced a more intense inflammatory reaction, and could be a very promising alternative in the development of new materials.**

Since the introduction of the aortic stent by Parodi et al[1] in 1990, there have been great developments in the treatment of aortic aneurysms. There has been consistent improvement in both the stent graft materials and surgical technique. Endovascular aneurysm repair has become less invasive and is a safe alternative, particularly for high-risk patients.[2]

Despite advancements in material science and surgical techniques, not all patients have optimal outcomes after surgery. This may be associated with structural graft problems, the morphology of the aortic aneurysm, progression of the disease after surgery, or the hemodynamic forces and healing at the surgical site, and may lead to migration and leakage.[3,4] Complex mathematical calculations have revealed that the hemodynamic drag force of endoprostheses (EPs) implanted in the aorta is about two Newtons, suggesting that the stent graft must have fixation forces greater than this threshold to prevent migration.[5-7] Although endovascular aneurysm repair has minimized the surgical impact, the aortic neck may still undergo expansion over time.[3] This enlargement is due to the remodeling process and progression of the disease and seems to be more frequent in endovascular repair. The high incidence of enlargement is typically attributed to the fact that EPs are self-expandable and continuously exert a radial force on the aortic neck, which in turn dilates this structure. To reduce the migration, the addition of bare suprarenal stent, barbs, and hooks have improved the devices.[8,9] Another resource of EP fixation is oversizing, which has been empirically determined to be between 10% and 30%. Clinical studies have shown that <10% is insufficient, 20% is ideal, and 30% is excessive.[8] Oversizing of >30% may increase neck dilatation and folding of the EP, which can lead to

From the Department of Vascular and Orthopaedic Surgery of Faculdade de Medicina de Botucatu, Universidade Estadual Paulista Júlio de Mesquita Filho - UNESP and Faculdade de Medicina de Marília, São Paulo, Brazil.

The study was sponsored by the FAPESP foundation (Fundação de Amparo à Pesquisa do Estado de São Paulo).

Competition of interest: none.

The editors and reviewers of this article have no relevant financial relationships to disclose per the JVS policy that requires reviewers to decline review of any manuscript for which they may have a competition of interest.

0741-5214/$36.00

doi:10.1016/j.jvs.2010.11.112

Table I. Presentation of animals and endoprosthesis distribution

	P1	*P2*	*P3*	*P4*	*P5*	*P6*	*P7*	*P8*	*P9*
EP1	10%	20%	10%	20%	20%	20%	10% + G	10% + G	10% + G
EP2	20%	10%	20%	10% + G	10%	10% + G	20%	20%	10%
EP3	10% + G	10% + G	10% + G	10%	10% + G	10%	10%	10%	20%
EP4	10%								

EP, Endoprosthesis position in thoracic aorta; *G,* glue; *P,* pigs.
Exclusion criteria = P1 and P4 represent the animals that died 6 hours after the procedure.

endoleaks, enlargement of the aneurysm, and subsequent complications associated with migration.

The interface between the EP and the aorta is a critical aspect associated with migration. The degree of incorporation varies depending on the material used to cover the stent graft. Polyurethane has a higher degree of incorporation in a vascular wall, but this material also quickly degenerates within the human body. Polyester (Dacron) is a material widely accepted for use in vascular surgery, it induces the ingrowth of vascular cells from the aorta, and it is a material that presents resistance in the long-term. Polytetrafluoroethylene (PTFE) is used in several different types of stents and is widely used in vascular surgery as an arterial graft. However, PTFE has a hydrophobic surface, and, therefore, this material has very little tissue interaction.[10-12] Successful initiatives have been done to improve the incorporation of the stent grafts using growth factors, collagen, and nitrite with chondroitin sulfate.[13,14] To improve tissue adhesion strength and reduce excessive bleeding, fibrin sealants have been used in bypass surgery, the repair of septal atrial defects, type A aortic dissections, prosthetic patches, and in several other cardiovascular procedures.[15,16]

Despite the frequent use of fibrin glue in cardiovascular surgeries, no empiric studies have been conducted to evaluate the effect of fibrin glue on the incorporation and fixation of stent grafts. Therefore, the purposes of this study were to (1) establish a large animal model of aortic EP delivery, survival, and explantation, and (2) to determine if different prosthesis oversizing and use of fibrin glue improves fixation of EPs.

METHODS

The experiment was previously approved by the Ethical Committee on Animal Research and Experiments of Botucatu Medical School – Universidade Estadual Paulista. A pilot study with 3 pigs was performed and six EPs were implanted in their thoracic aorta (two per pig). The sample size of the present study was calculated based on the pilot work. Nine Landrace pigs weighing 41 to 53 kg (mean weight 50 kg), and aged 4 to 5 months (mean age 4.5 months) were previously obtained. The mean thoracic aortic diameter was 20 mm (ranging from 17-22 mm) and mean length was 180 mm (ranging from 168-190 mm). Two pigs called P1 and P4 died 6 hours after surgery, and biomechanical tests were done but were not included in statistical analysis (see exclusion criteria). Seven pigs were used and three EPs were implanted in each, with a total of 21 EPs (ranging from 18-26 mm) and were included in this study (Table I).

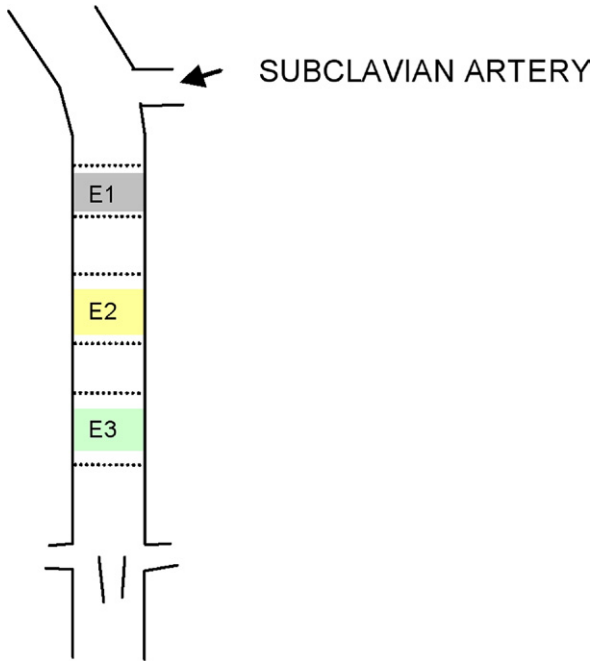

Fig 1. Endoprostheses implantation in positions E1, E2, and E3.

The criteria for exclusion were death, thrombosis of the aorta, or if there were any technical problems with the implant procedure. The EP used in each animal was oversized by either 10% or 20%, depending on the group. Three groups were defined for the final analysis: EP with 10% oversizing + glue, EP with 20% oversizing without glue, and EP with 10% oversizing without glue (group 1, group 2, and group 3, respectively). Each pig received three stents in their thoracic aorta: one proximal, one in the middle, and one in the distal site on a random allocation (E1, E2, and E3, respectively; Fig 1).

The EPs used were manufactured in diameter from 16 mm up to 30 mm, in increments of 1 mm, but all had a fixed length of 40 mm; Z-nitinol stents were completely covered by Dacron. None of the EPs had barbs or hooks (Braile Biomédica, São José do Rio Preto, São Paulo, Brazil).

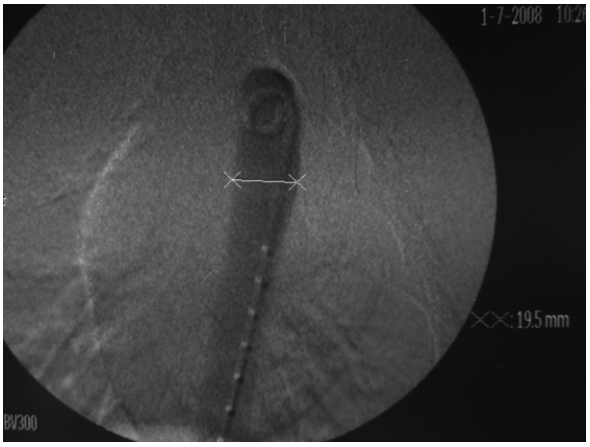

Fig 2. Aorta diameter measurement obtained by placing the software marks over the border of artery walls delimited by angiography contrast.

After an adjustment period of 7 days, a laparotomy was performed and vascular access through the abdominal aorta of pigs was obtained. The delivery system consisted of a catheter with the stent graft inside, which was released through the traditional pull-back system. The procedures in pigs were performed while they were under general anesthesia with isoflurane, after premedication with acetopromazine (Acepran; UNIVET, São Paulo, Brazil), xylazine (Rompun; Bayer Schering Pharma, Wuppertal, Germany), and ketamine (Ketalar; Pfizer, Guarulhos, São Paulo, Brazil).

Angiography and evaluation of the EP implantation was obtained using a Philips BV-300 (Philips, Miami, Fla). The size of each portion of the thoracic aorta was determined from the angiograms using built-in software, which was calibrated in a standardized manner using a pig-tail catheter with 11 marker bands spaced 1 cm apart (Performa Merit Medical, Salt Lake City, Utah). Based on these measurements, the oversizing of each stent graft was chosen (Fig 2).

To implant the EP with adhesive tissue, a 12F (Arrow, Hampton, Va) hemostatic valve was introduced through aortotomy with the insertion of two catheters of the 5F 90 cm (Merit Medical), which were positioned in the thoracic aorta. This valve was then removed and the applicator system of the EP was inserted and then released. The catheters were tractioned and repositioned at the upper end of the prosthesis under fluoroscopy. Contrast injections (1-3 mL) were used to assess the positioning of the catheter at the EP-aorta interface. After this procedure, fibrin glue (Tissucol; Baxter, Deerfield, Ill) was injected. The Duplojet intracatheter system, which consisted of two syringes with a Y connection, was used. One syringe contained fibrinogen and aprotinin and the other contained Thrombin 4U and $CaCl_2$; 2.5 mL of fibrin glue was injected through each catheter. In the postoperative period, no antiplatelets or anticoagulants were given.

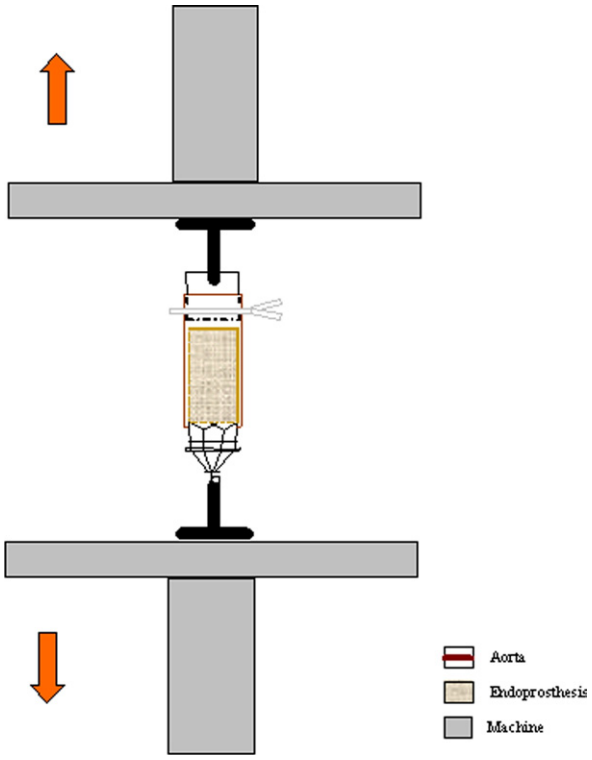

Fig 3. Diagram – Universal Machine for Mechanical Testing.

After 14 days, the animals were killed by bleeding while under anesthesia. The thoracic aorta was perfused with heparinized saline and removed en bloc. The aorta was divided into three segments corresponding to the positions of E1, E2, and E3, and each segment consisted of the entire device plus 10 to 20 mm of aorta on either end.

For histologic analysis, a foam cylinder was placed inside the artery with the EP and 2-mm sections were removed. The cylinder provided support during the removal of the sample and prevented fragmentation and damage of the vessel. The samples were fixed in 10% tamponated formaldehyde solution, processed in the tissue processor (102 Leica, Wetzlar, Germany), and prepared on paraffin blocks using the Leica EG 1160. A total of 5-μm sections were made using a microtome (Leica RM 2155) and stained with hematoxylin and eosin. Analyses were performed by a veterinary pathologist who was blinded to the group assignment.

Next, biomechanical tests were performed using a Universal Testing Machine (Model EMIC, São José dos Pinhais, Paraná, Brazil). Each aortic segment was connected to a rough metallic cylinder on the machine system and a parachute was made in the distal portion of the EP, which was tied to the base of the equipment. Tension was applied at a constant rate of 30 mm/minute until the EP was detached from the aorta (Fig 3). A load-deformation plot was automatically generated by the computer software. Two parameters were extracted

Table II. Results from tensile testing on pig 1 and pig 4 obtained 6 hours after endoprostheses implant

Animals	*Maximum force*	*Maximum deformation*
Pig 1[a]	2.4N	14.0 mm
E1 (10%)		
E2 (20%)	3.8N	7.6 mm
E3 (10% + G)	7.2N	4.6 mm
E4 (10%)	2.6N	3.8 mm
Pig 4[a]	4.0N	8.0 mm
E1 (20%)		
E2 (10% + G)	7.6N	12.0 mm
E3 (10%)	2.5N	4.6 mm

G, Glue; *N*, Newton.
[a]Pig 1 and Pig 4 died 6 hours after surgery and, therefore, they were not included in the statistical analysis.

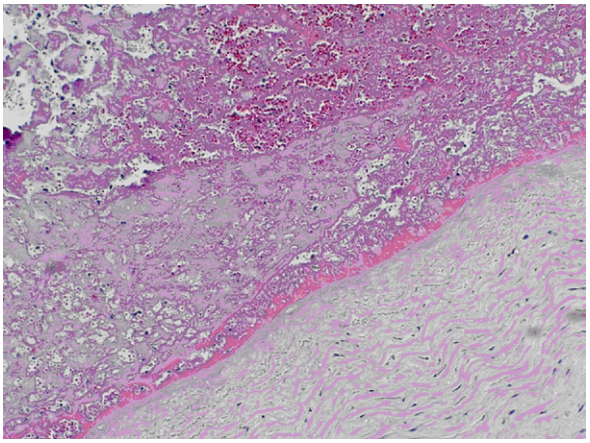

Fig 4. Aorta – 10% group – Space between the vessel wall and the prosthesis filled with thrombotic mass constituted by thick layers of fibrin, red blood cells, and leukocytes (hematoxylin and eosin, ×20).

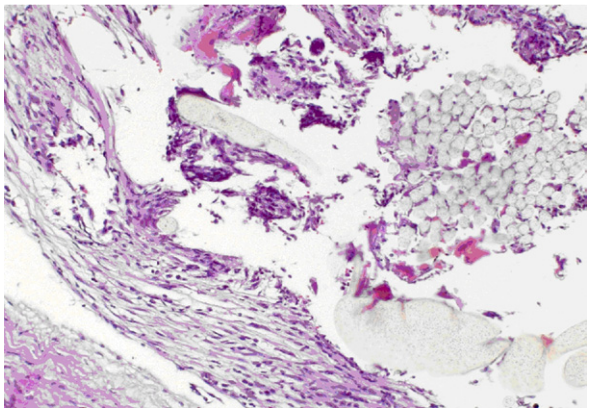

Fig 5. Aorta – 20% group – Dacron covered by the organization process next to the vessel intima (hematoxylin and eosin ×20).

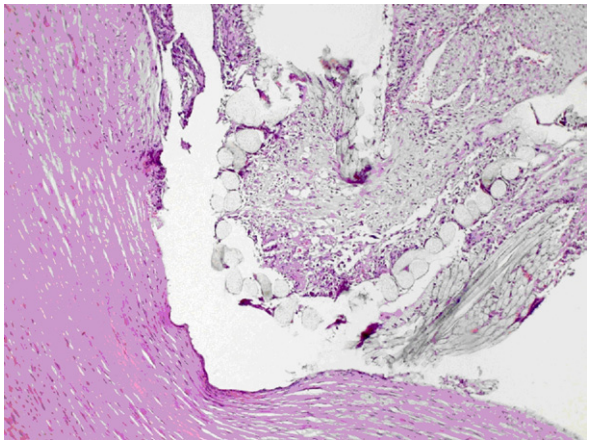

Fig 6. Aorta – 10% group with glue – Dacron was covered by fibroblasts and macrophages and incorporated to the organization process next to the vascular wall depression area that goes deep to the media layer (hematoxylin and eosin, ×10).

from the load deformation data: maximum force – load maximum value for displacement of the EP (Newtons [N]) and maximum deformation – maximum elongation of aorta before displacement from the EP (millimeters [mm]).

A repeated measures analysis of variance was used to assess the biomechanical data between groups and vessel positions, followed by Tukey's posthoc tests when appropriate. A *P* value of .05 or less was considered significant. A qualitative analysis was made for histologic results.

RESULTS

Two pigs called P1 and P4 died 6 hours after surgery. In total, 7 pigs were used in the final analysis and three EPs were implanted in each animal, giving a total of 21 EPs (ranging from 18-26 mm; Table I). Transient paraplegia of the pelvic limbs of all animals with complete recovery in 3-hour to 8-hour periods was observed in the postoperative period. Biomechanical tests were performed to assess the force needed to displace the EPs of the 2 animals that died (Table II), but the results from these animals were not included in the final statistical analysis. Fourteen days after the implant, the thoracic aortas were removed and biomechanical and histologic analyses were performed. When the aortas were removed, the presence of a detachable thin brilliant layer covering the internal surface of the EP was observed, and the stent grafts were firmly fixed to the arteries.

Histologic analysis showed thrombotic masses consisting of thick layers of fibrin and leukocytes between the vessel wall and the prosthesis. There was no sign of endothelization of the luminal side of the prosthesis. In the 10% group, the organization level of the thrombus was less intense and restricted to small base areas adjacent to the intima (Fig 4). In the 20% group (Fig 5) and in the 10% group with glue (Fig 6), Dacron was covered with fibro-

Table III. Mean and SD related to the variables: maximum force and maximum deformation, according to the group

Group number	*Maximum force*	*Maximum deformation*
1 (10% + G)	21.9 ± 5.3N	16.0 ± 5.8 mm
2 (20%)	19.5 ± 7.8N	15.4 ± 6.2 mm
3 (10%)	15.6 ± 3.6N	15.1 ± 4.7 mm
P value	.003*	.95

*Statistically significant value = $P < .05$. Number per group = 7.
G, Glue; *N*, Newton.

blasts and macrophages and incorporated to this reaction. There was evidence of neorevascularization at the base of the thrombus, and these neoformed vessels were lined by hypertrophic endothelial cells.

No differences in maximum force and maximum deformation were found between graft location in positions E1, E2, and E3 ($P = .97$ and $P = .85$, respectively). Differences were found between groups for maximum force. Maximum force for group 1 and group 2 was higher than maximum force for group 3 ($P < .05$). In group 1 (10% + glue), maximum force was statistically equal to group 2 (20%). There was no difference in the maximum deformation variable among the groups ($P > .05$; Table III).

DISCUSSION

Despite technological development of stent grafts, migration still remains a clinical problem. In a survey of several articles, migration rates ranged from 2% to 45% of cases.[3,8,9] The incidence of migration depends on many variables, including the criteria used to define migration, the time to follow-up, and the specific measurement technique used to assess the presence of migration. The Society for Vascular Surgery has recommended that migration be defined as 10 mm dislodgement, although this value is not yet a consensus among all physicians.[17]

Experimental evaluations have led to improvement in prosthetic incorporation and biomechanical interactions. Lambert et al[4] implanted EPs in cadaveric aortas and evaluated their biomechanics. Based upon those findings, it was recommended that a greater overlap of the EP on the artery improves fixation. The authors also observed that a bigger oversizing would result in an increase of radial force. Malina et al[18] observed that hooks and barbs further increased anchoring force. Despite these investigations that led to important clinical advancements, the interaction between the living organism and the EP was not evaluated. In our study, implantation of the prostheses in pigs better simulated conditions observed in clinical practice, including blood flow during implantation, and interactions with the thermal conditions, coagulation factors, and inflammatory processes in the organism. The subsequent evaluation of prosthetic incorporation in a living organism expanded upon the current understanding of stent grafts in vivo. In addition, the displacement tests conducted on the Universal Tensile Machine provided more precise evaluations of the biomechanical properties after implantation.

Significant increases in the anchoring strength of the EP observed in all groups at 2 weeks of postimplantation showed that the inflammatory process, even at an early phase, is an important element in EP fixation.

In our study, we used oversizing of 10% to 20% to simulate current clinical techniques of endovascular graft implantation. Differences between group 2 and group 3 could be explained by the greater radial force of the metallic stent graft in group 2, which penetrated deeper into the tunica media of the vascular wall and increased anchorage. However, because of equipment sensibility and the parallax effect, the oversizing measurement can result in less accurate results, particularly when a small size aorta is used. To avoid this, we used Landrace pigs weighing 50 kg (mean weight) and the stent graft was placed in the thoracic aorta, as close as possible to the subclavian artery.

Some authors[19] have reported that larger oversizing increases the inflammatory response in the vessel wall. In small arteries, such as the coronary arteries, a larger oversizing intensifies the inflammatory process, intimal hyperplasia, and early arterial thrombosis.[20,21] In larger arteries such as the aorta, a severe inflammatory process would increase prosthesis fixation and reduce the chance of migrations. In our study, histologic findings confirmed that the 20% group (group 2) had a greater fibroblastic reaction and inflammatory response compared to the 10% group (group 3).

The aortic wall in aneurysmal diseases shows structural alterations caused by transmural inflammatory processes, particularly destruction of elastic and collagen fibers caused by the proteases. These alterations make the arterial wall more fragile[22-24] and thus the additional force from oversizing could promote a dilation of the aortic neck and consequent migration of the EP.[3,25] The ideal EP would have a greater capacity to incorporate into the artery without requiring excessive oversizing. Therefore, efforts have been made to promote adhesion and migration of fibroblasts and smooth muscle cells in a surface of endografts.

Lerouge et al[13] impregnated the polyester and PTFE fabric of the prostheses with nitrogen-rich polymerized plasma, and in another group with chondroitin sulfate, which is described as a mediator of vascular inflammatory response. Using fibroblast and smooth muscle cell cultures, the authors observed a significant increase in the ingrowth of these cells into the impregnated prostheses when compared to the control group of standard prostheses. van der Bas et al[14] implanted EPs impregnated with basic fibroblast growth factor and collagen in swine aortas and compared the histologic results to non-impregnated prostheses. At 4 to 8 weeks after implantation, histologic analyses with optical and transmission electron microscopy showed a greater ingrowth reaction in the impregnated group, characterized by foreign body type giant cells, formation of neointima, and myofibroblasts. The authors concluded that this method could be

a feasible alternative to increase ingrowths of the EPs and a consequent improvement of anchoring strength. In our study, we found that the group with 10% oversizing with fibrin glue had greater displacement forces compared to the other groups. Compared to the 10% group without glue, this difference was statistically significant ($P < .003$), suggesting that endoprosthetic fixation can be increased without excessive oversizing.

Cardon et al[26] reported moderate intimal hyperplasia and intense thickening around the prosthesis in pigs 14 days after implantation of open aortobifemoral grafting impregnated with fibrin glue. The fibrin matrix acts as a pathway that facilitates the migration of inflammatory cells. These granulocytes, in turn, release cytokines with angiogenic potential and stimulate migration of fibroblasts and smooth muscle cells related to the incorporation process. The use of substances that expedite tissue synthesis and improve the efficiency of the graft is an attractive idea.[27] In our study, Tissucol fibrin glue, which is a biological concentrate made of plasma-derived components, was used. Its action is similar to the last phase of the physiological coagulation and the formation of stable fibrin. The clot created by the glue is a component for tissue repair and it differs from the other types of glues, such as cyanoacrylate, which results in hard and inelastic fibrosis via foreign body type reaction.[28] Despite the benefits of commercial fibrin glue, this product is obtained from a great group of donors, increasing the potential risk of infectious diseases or "prions."[29] Glue obtained from a single donor reduces these risks, and recently autologous tissue fibrin glue has been produced by machines in a short time.[30] Future advances in fibrin technology may offer optimal treatment options for patients requiring endoprosthetic treatments.

In conclusion, animals who received grafts with 10% oversizing + fibrin glue had a more intense inflammatory reaction and fibrosis with greater fixation than the group with 10% oversizing alone. Fibrin glue applied to the interface of the EP and aorta may improve EP fixation. Impregnated EPs would potentially promote better fixation and could be a very promising alternative in the development of new materials. However, in this study, tests were performed in thoracic aortas and data extrapolation to abdominal aorta should be done carefully. Further evaluations and clinical studies are required to confirm these results.

The authors thank Braile Biomédica, Brazil, for endovascular material donation (endografts).

Animal care and all procedures were approved by Ethical Committee for Animals Researches of Faculdade de Medicina de Botucatu, Universidade Estadual Paulista Júlio de Mesquita Filho, UNESP, Botucatu, São Paulo, Brazil.

AUTHOR CONTRIBUTIONS

Conception and design: MA, WY
Analysis and interpretation: LH, JM
Data collection: MA, JS, AM, JS, SL
Writing the article: MA, WY
Critical revision of the article: WY, JM, LH
Final approval of the article: WY
Statistical analysis: WY
Obtained funding: MA, WY
Overall responsibility: MA

REFERENCES

1. Parodi JC, Palmaz JC, Barone HD. Transfemoral intraluminal graft implantation for abdominal aortic aneurysms. Ann Vasc Surg 1991;5:491-9.
2. Zarins CK, White RA, Schwarten D, Kinney E, Diethrich EB, Hodgson KJ, et al. AneuRx stent graft versus open surgical repair of abdominal aortic aneurysms: multicenter prospective clinical trial. J Vasc Surg 1999;29:292-305.
3. Resch T, Ivancev K, Brunkwall J, Nyman U, Malina M, Lindblad B. Distal migration of stent-grafts after endovascular repair of abdominal aortic aneurysms. J Vasc Inter Radiol 1999;10:257-64; discussion 265-6.
4. Lambert AW, Willians DJ, Budd JS, Horrocks M. Experimental assessment of proximal stent-graft (InterVascular) fixation in human cadaveric infrarenal aortas. Eur J Vasc Endovasc Surg 1999;17:60-5.
5. Canic S, Ravi-Chandar K, Krajcer Z, Mirkovic D, Lapin S. Mathematical model analysis of Wallstent and AneuRx: dynamic responses of bare-metal endoprosthesis compared with those of stent-graft. Tex Heart Inst J 2005;32:502-6.
6. Li Z, Kleinstreuer C. Blood flow and structure interactions in a stented abdominal aortic aneurysm model. Med Eng Phys 2005;27:369-82.
7. Fillinger MF, Marra SP, Raghavan ML, Kennedy FE. Prediction of rupture risk in abdominal aortic aneurysm during observation: wall stress versus diameter. J Vasc Surg 2003;37:724-32.
8. Sternbergh WC 3rd, Money SR, Greenberg RK, Chuter JA; Zenith Investigators. Influence of endograft oversizing on device migration, endoleak, aneurysm shrinkage, and neck dilation: results from the Zenith Multicenter Trial. J Vasc Surg 2004;39:20-6.
9. Tonnessen BH, Sternbergh WC 3rd, Money SR. Mid- and long-term device migration after endovascular abdominal aortic aneurysm repair: a comparison of AneuRx and Zenith endografts. J Vasc Surg 2005;42:392-400; discussion 400-1.
10. Szilagyi DE. The problem of healing of endovascular stent grafts in the repair of abdominal aortic aneurysms. J Vasc Surg 2001;33:1283-5.
11. Cejna M, Virmani R, Jones R, Bergmeister H, Loewe C, Schoder M, et al. Biocompatibility and performance of the Wallstent and the Wallgraft, Jostent, and Hemobahn stent-grafts in a sheep model. J Vasc Interv Radiol 2002;13:823-30.
12. Marty B, Leu AJ, Mucciolo A, von Segesser LK. Biologic fixation of polyester- versus polyurethane-covered stents in a porcine model. J Vasc Interv Radiol 2002;13:601-7.
13. Lerouge S, Major A, Girault-Lauriault PL, Raymon MA, Laplante P, Soulez G, et al. Nitrogen-rich coatings for promoting healing around stent-grafts alter endovascular aneurysm repair. Biomaterials 2007;28:1209-17.
14. van der Bas JM, Quax PH, van den Berg AC, Visser MJ, van der Linden E, van Bockel JH. Ingrowth of aorta wall into stent grafts impregnated with basic fibroblast growth factor: a porcine in vivo study of blood vessel prosthesis healing. J Vasc Surg 2004;39:850-8.
15. Guilmet D, Bachet J, Goudot B, Laurian C, Gigou F, Bical O, et al. Use of biological glue in acute aortic dissection. Preliminary clinical results with a new surgical technique. J Thorac Cadiovasc Surg 1979;77:516-21.
16. Matras H. Fibrin seal: the state of the art. J Oral Maxillofac Surg 1985;43:605-11.
17. Chaikof EL, Blankensteijn JD, Harris PL, White GH, Zarins CK, Bernhard VM, et al. Reporting standards for endovascular aortic aneurysm repair. J Vasc Surg 2002;35:1048-60.
18. Malina M, Lindblad B, Ivancev K, Lindh M, Malina J, Brunkwall J. Endovascular AAA exclusion: will stents with hooks and barbs prevent stent-graft migration? J Endovasc Surg 1998;5:310-7.

19. Marty B. Quantification of radial pressure caused by bare and covered Wallstents. Endovascular aneurysm repair-from bench to bed. Darmstadt, Germany: Steinkopt Verlag; 2005. p. 11-8.
20. Strauss BH, Serruys PW, de Scheerder IK, Tijssen JG, Bertrand ME, Puel J, et al. Relative risk analysis of angiographic predictors of restenosis within the coronary Wallstent. Circulation 1991;84:1636-43.
21. Gravanis MB, Roubin GS. Histopathologic phenomena at the site of percutaneous transluminal coronary angioplasty: the problem of restenosis. Hum Pathol 1989;20:477-85.
22. Cohen JR, Keegan L, Sarfati I, Danna D, Ilardi C, Wise L. Neutrophil chemotaxis and neutrophil elastase in the aortic wall in patients with abdominal aortic aneurysms. J Invest Surg 1991;4:423-30.
23. Sukhova GK, Shi GP, Simon DI, Chapman HA, Libby P. Expression of the elastolytic cathepsins S and K in human atheroma and regulation of their production in smooth muscle cells. J Clin Invest 1998;102:576-83.
24. Gacko M, Chyczewski L. Activity and localization of cathepsin B, D and G in aortic aneurysm. Int Surg 1997;82:398-402.
25. Sonesson B, Hansen F, Stale H, Länne T. Compliance and diameter in the human abdominal aorta – the influence of age and sex. Eur J Vasc Surg 1993;7:690-7.
26. Cardon A, Chakfé N, Thaveau F, Gagnon E, Hartung O, Aillet S, et al. Sealing of polyester prostheses with autologous fibrin glue and bone marrow. Ann Vasc Surg 2000;14:543-52.
27. Yoshida WB, Naresse LE, Rodrigues AC, Fabris VE, Angeleli AY. End-to-end arterial anastomosis with fibrin glue in larger arteries: histology, hydroxyproline concentration and tensile strength study in carotidas of rabbits. Acta Cir Bras 2002;17:4-11.
28. Ronis ML, Harwick JD, Fung R, Dellavecchia M. Review of cyanoacrylate tissue glues with emphasis on their otorhinolaryngological applications. Laryngoscope 1984;94(2 Pt 1):210-3.
29. [No authors listed] Revocation of fibrinogen licenses. FDA Drug Bull 1978;8:15.
30. Dresdale A, Rose EA, Jeevanandam V, Reemtsma K, Bowman FO, Malm JR. Preparation of fibrin glue from single-donor fresh-frozen plasma. Surgery 1985;97:750-5.

Submitted Jul 19, 2010; accepted Nov 19, 2010.