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The phenomenon of stent-graft "shortening" during implantation of endovascular stent-graft in an abdominal aortic aneurysm in cases involving significant tortuosity of the aorta and iliac arteries

Bartosz Pacewski, Piotr Słowiński, Grzegorz Madycki

Department of Vascular Surgery and Angiology CMKP, Bielański Hospital, Warszawa, Poland

Abstract

Introduction: *One of the main problems with the implantation of stent-graft (STG) in the abdominal aortic aneurysm (AAA) remains its proper fit. Minor differences in distances from the relevant structures can result in life-threatening complications. This article aims to show the problem of aortic stent-graft shortening during implantation. This occurs in the case of significant tortuosity of the abdominal aorta vessels and iliac arteries. Our study has found a significant correlation between vessel tortuosity and erroneous results of preoperative sizing (using the centerline). The new measurement system developed (along long curves) seems to correlate better with intraoperative images.*

Material and methods: *The study involved the evaluation of 70 patients sized classically and with the use of the described technique, and then operated on with the EVAR technique. In all patients, stent-grafts were sized classically (using the central lumen line) and along the curvature line of the sized vessels. The dimensions of the stent-graft were selected according to the standard method (classical sizing), and the fit of the STG in relation to the calibrated catheter ("pigtail"), and the final postoperative result was considered to be the final result. There were 44 men (62,8%) and 26 women (37,2 %) in the study group. The mean age of patients was 74 years. Eighty-nine percent of patients were classified as NYHA (Class I-II) and 11 % of patients as NYHA Class III.*

Results: Average measurement of the aorta and iliac arteries using the centerline was 201.8 mm, and average measurement based on the curvature of vessels was 222.2 mm. Average measurement using calibrated catheter was 218.1 mm. The results of the analysis showed significant differences between the measurements (centerline and long curvature of vessel): $Z = 7.17$; $p < 0.001$; $r = 0.87$.

Conclusions: The measurement made along the long curves is more accurate than the measurement made with the centerline. The measurement made with the centerline is underestimated (it indicates a smaller value than the actual measurement).

Key words: abdominal aortic aneurysm AAA, EVAR management, measurement of EVAR device, kinking (tortuosity) of iliac arteries in AAA

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Address for correspondence: Bartosz Pacewski, Department of Vascular Surgery and Angiology CMKP, Bielański Hospital, 80 Cegłowska Street, 01–809 Warszawa, Poland, e-mail: barpac@gazeta.pl

Introduction

Techniques of surgery for abdominal aortic aneurysms have changed dramatically over the past 15 years. The traditional technique of aortic prosthesis implantation has gradually become limited due to the development and expansion of indications for endovascular surgery to stent-graft implantation.

Graft implantation into the abdominal aorta is a relatively simple and minimally invasive operation. However, the prevailing problem remains proper stent-graft fitting, with particular consideration of anatomical problems related to the course of the abdominal aorta and the location of its important branches (e.g. renal arteries, visceral trunk, superior mesenteric artery). The proper selection (sizing) of the graft is crucial in the process of endovascular treatment of AAA. Small differences in the distances to relevant structures may result in life-threatening complications (e.g. insufficiently long "aortic neck", excessively long iliac branches which may cut off the internal iliac branch, and others).

The preoperative evaluation to match the stent-graft to the anatomy of the aneurysm is based on imaging studies, mainly computed tomography or, less frequently, vascular magnetic resonance imaging. Detailed anatomical sizing and selection of equipment are carried out with the help of specialized computer programs that allow for graphic processing and spatial reconstruction of abdominal organs. The most useful feature is the ability to draw a centerline for the vessels under evaluation and determine the precise dimensions of the aneurysm [1–3].

Such measurements are taken preoperatively to select the equipment used for the operation. It is necessary to take into account not only the width of the vessels at particular locations but also their length. The correct sizing and the subsequent selection of equipment based on the obtained measurements is the prerequisite to avoiding some postoperative complications, e.g. leakage into the aneurysm sac, undesirable covering of arterial branches from the aorta or iliac arteries, displacement of stent-graft elements, or thrombosis of the prosthesis [4–6].

One of the anatomical phenomena occurring in a significant proportion of patients during the process of formation and enlargement of aneurysms of the abdominal aorta and iliac arteries is the tortuosity of these vessels.

When the examined vessels are kinked or coiled, the measurement using the centerline may not reflect the actual length of the vessel that needs to be covered with the stent-graft because the stent-graft material must fit tightly to the curvature of a given vessel. This may cause the intraoperative "shortening" of the stent-graft, which, in turn, may result in the distal end of the stent-graft after implantation being closer than planned preoperatively.

The shortening of stent-graft length in tortuous vessels has been described in reports of earlier studies. Lee et al. [3] described stent-graft shortening by more than 15 mm in patients with severe aortic and iliac vessel tortuosity. Based on this report, the phenomenon of stent-graft shortening and the mechanism of complications, such as internal iliac artery coverage or leakage resulting from insufficient distal landing zone coverage, can be better understood.

The aim of the study included:

1. To compare the accuracy of the two methods used to size STGs in patients with AAA: the traditional, commonly used, central axis-based sizing and the measurement based on vessel curvature.
2. To evaluate the usefulness of the method of sizing based on the curvature of vessels, especially in patients with tortuosity of the aorta and iliac arteries, as a method complementary to the one previously used.

Material and methods

Seventy patients with abdominal aortic and possibly iliac artery aneurysms who underwent stent-graft surgery were enrolled in the prospective study. In all patients, the aortic tortuosity index (ATI) and iliac artery index (IAI) were calculated, and the obtained results were used to analyze the results of vessel tortuosity measurements with the use of both methods (Fig. 1).

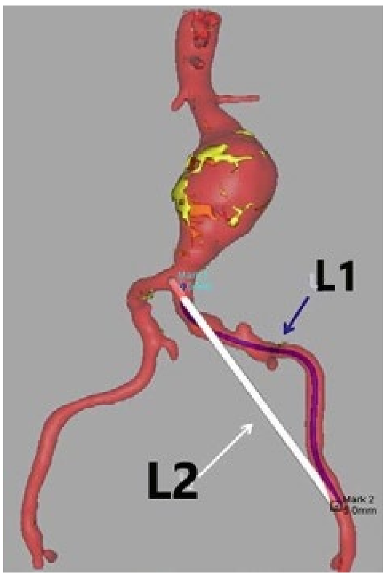

Figure 1. Calculating the aortic tortuosity index: L1 — length of the central line, L2 — the distance between the end and the beginning of the measured artery. Curvature index = L1/L2

To achieve the objectives, two sizings of the aorta were used for STG selection in all patients:

1. The standard central axis-based method.
2. The assessment method based on the curvature of the vessel edge.

The findings were compared against intraoperative evaluation with a calibrated "pig-tail" catheter.

A comparative scheme of the classic technique of measuring aortic aneurysm length (Fig. 2A) versus the technique including the ATI (Fig. 2B).

Both groups of patients underwent surgical implantation of a nitinol, polyester-coated, multiple overlapping stent-graft. Preoperative angio-CT examinations of the aorta and iliac arteries were conducted with the use of Endosize computer software and after carrying out anatomical measurements of the aneurisms, appropriate stent-graft components were selected according to the manufacturer's recommendations. In each patient, the actual vessel length was additionally assessed intraoperatively with the use of calibrated catheters and on this basis, irrespective of earlier calculations, in case of discrepancies, the length of iliac stent-graft extensions was finally adjusted.

Correct stent-graft sizing confirmed by arteriography after stent-graft implantation was considered the primary endpoint. To enhance the accuracy of the evaluation of stent-graft sizing (arteriography), it is advisable to carry out an additional intraoperative verification with the use of a calibrated catheter to have a comparison with the measurements obtained preoperatively.

To answer the research questions and test the hypotheses, statistical analyses were performed using the IBM SPSS Statistics package version 25. The software was used to analyze basic descriptive statistics. Then, the Wilcoxon signed-rank test was used to compare the differences between centerline measurements and outer curvature measurements with the actual artery length. Correlation analysis was used to determine the relationship between the tortuosity index and the difference between the actual lenght of the artery and its measurement with the centerline. The prediction model for the difference based on the tortuosity index was then checked using linear regression. The value of $\alpha = 0.05$ was used as the significance level for the interpretation of the analyses.

Results

The outer curvature measurement was found to be more accurate than the measurement along the central axis. The results of the analysis showed significant differences between the measurements: $Z = 7.17$; $p < 0.001$; $r = 0.87$. The mean difference for the centerline measurement compared with arteriography was $M = -16.31$ ($SD = 15.08$), whereas the difference for the outer curvature measurement was $M = 4.10$ ($SD = 2.79$). The outer curvature measurement is, therefore, more accurate than the centerline measurement. The centerline measurement is underestimated (it indicates a lower value than the actual measurement), while the outer curvature measurement is overestimated (it

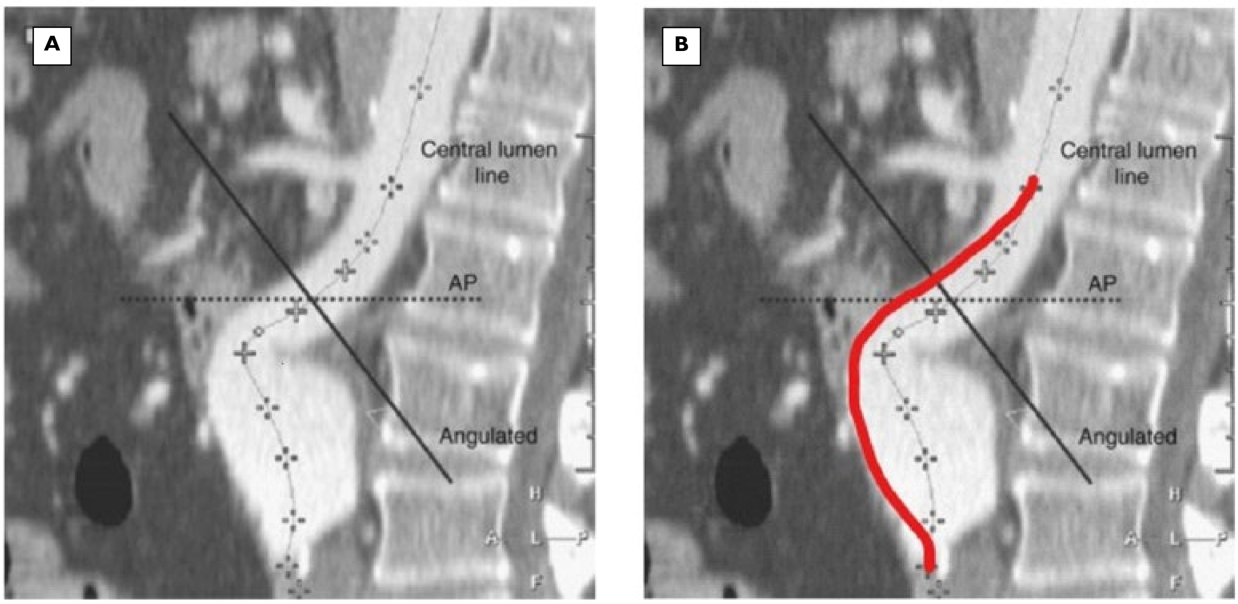

Figure 2 A — the classical technique for measuring aortic aneurysm length; **B** — the technique for measuring aortic aneurysm length with the ATI

indicates a higher value than the actual measurement). The differences between the measurements are illustrated in Figure 3.

Discussion

The mechanism of stent-graft "shortening" is related not only to the anatomy of the aneurysm but also to its structure. The metal skeleton is covered with material in such a way that it forms rings with gaps between them, in which there is only the stent-graft material. On the one hand, it enables the stent-graft element to adapt to the curvature of the vessel during implantation; on the other hand, it allows the metal elements of the prosthesis to come closer together or even overlap, which is responsible for its physical "shortening" in relation to the long axis of the vessel (Fig. 4).

Our study shows that the greater the angle of vessel kinking and the greater the number of kinks in the vessel, the more pronounced is the phenomenon of shortening of the prosthetic component. This observation coincides with the results obtained by other researchers [1–3].

This study shows a statistically significant difference between preoperative length assessment and intraoperative actual stent-graft length needed to cover the planned vessels to achieve the desired seal. The higher the value of the tortuosity index, the higher the difference between the centerline measurement and the actual length. Thus, in patients with an index value below 1.3, the differences in length measurements do not exceed 10%; with the index above that value, they may quickly reach 20%.

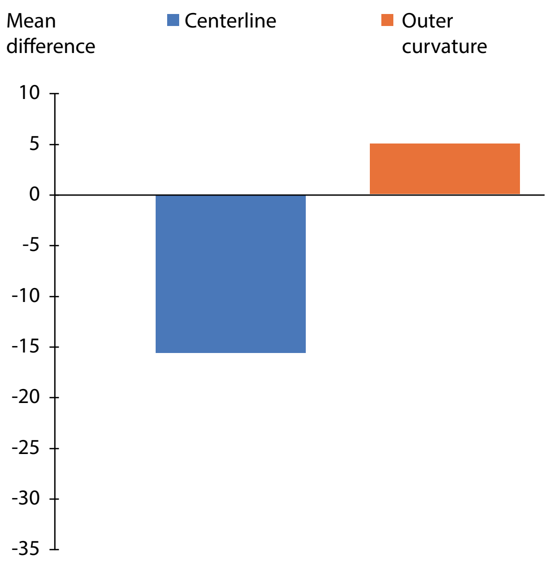

Figure 3. Mean and standard deviation for the differences in centerline and outer curvature measurements versus actual measurement

Figure 4. Stent-graft in a straight and tortuous vessel

In practice, intra-implantation shortening of the stent-graft by approximately 2-3 cm was observed in patients with the highest tortuosity index. Taking into account the structure of the stent-graft, the 2–3 cm length is equivalent to two nitinol rings, which, according to the manufacturer's recommendations, are the minimum length needed to properly seal the stent-graft termination site [1, 2]. At the same time, the study shows that in patients with a low tortuosity index, there is no shortening of the stent-graft and the preoperative length assessment coincides with the intraoperative assessment.

Moreover, like other authors, we have observed a decrease in vessel tortuosity after stent-graft implantation. The reason for this phenomenon is the stiffness of the metal components of the implanted stent-graft, which causes the vessels to "straighten" in most patients. This may explain why there is a need to implant unplanned iliac extensions of the stent-graft only in some patients.

In practice, shortening of the stent-graft during implantation in patients with significant vascular tortuosity means the necessity to prepare preoperatively different lengths of iliac extensions. In addition to preparing for unplanned implantation of another extension, it may also entail adding another element if coverage of the planned vessel segment fails the first time. This increases the cost of surgery and the number of steps, which results in its prolongation. Nowadays stent-graft manufacturers offer ready-made elements of various lengths, and elements ordered individually cannot be used for another patient. Therefore, in patients with a large tortuosity of vessels, if we have a selection of various extension lengths, we often opt for extensions of a longer length than suggested by our measurements. Most often, however, while preparing for the operation, we order different lengths of extensions, and during the implantation, depending on the vessel's susceptibility to straightening under the influence of the stent-graft's rigid elements, we decide on the length of the implanted extension.

Conflict of interest

None.

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