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Post-EVAR aortic neck elongation: is a real phenomenon or a conformational change during the cardiac cycle?

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Abstract. – BACKGROUND: Stent-graft migration is a late-term complication of endovascular abdominal aortic aneurysm repair (EVAR). A recent published study suggests that stent graft migration could be explained only by aortic neck elongation, mimicking the appearance of distal stent graft migration. Several studies about the use of dynamic CT Angiography (CTA) in the evaluation of aortic conformation changes during the cardiac cycle demonstrate that axial aortic pulsatility exists. No studies have been carried out to evaluate if a longitudinal aortic pulsatility also exists, that could justify the aortic neck elongation previously reported.

AIM: To assess variations in length of proximal neck and infrarenal abdominal aorta in patients selected to undergo EVAR; to assess if longitudinal aortic pulsatility could modify EVAR planning.

PATIENTS AND METHODS: 40 patients with Abdominal Aortic Aneurysm (AAA) underwent both static and dynamic ECG-gated 64-CTA (0.625 mm-slice-collimation; 1.25 mm-reconstruction increment). Manual measurements of aortic neck length and infrarenal abdominal aorta were performed on modified coronal images to determine dynamic conformational changes.

RESULTS: Significant longitudinal pulsatility was demonstrated within aneurysm neck (19.1 ± 8.6%) and infrarenal abdominal aorta (6.6 ± 1.6%). When compared to dynamic measurements, the endograft previously selected according to static images in terms of fixation, would be potentially changed in 6/40 patients (15%) whereas 4/40 (10%) patients were not eligible for EVAR.

CONCLUSIONS: Dynamic ECG-gated CTA may provide information regarding longitudinal pulsatile motion that could change the EVAR planning based on static imaging. Reported post-EVAR elongation of infrarenal aortic neck could be an unreal phenomenon only due to a conformational change during cardiac cycle.

Key Words:
EVAR, Aortic neck elongation, Aortic Pulsatility

Introduction

Stent-graft migration is a late-term complication of endovascular abdominal aortic aneurysm repair (EVAR) with a reported prevalence of 9 to 45%, evidenced by downward slippage of the stent-graft and it should determine a type-I endoleak with an enlargement of the diameter of aneurismal sac and consequently an increased risk of rupture of aneurysm[1,2].

In a recent published study, patients undergoing EVAR with evidence of stent graft migration were studied[3] and two different subgroup of patients were identified and compared: in detail, patients with and without a total loss of the proximal seal zone. According to surgery literature, it was recognized that suturing a prosthetic graft in the infrarenal aorta poses a risk of subsequent proximal aortic neck dilation and proximal suture line pseudoaneurysm with consequent aortic neck dilation and elongation, thus creating the appearance of caudal displacement. It was supposed that in patients without loss of proximal fixation length, stent graft migration could be explained only by aortic neck elongation, that mimics the appearance of distal stent graft migration.

In the recent literature, there were some published studies about the use of dynamic CT Angiography (CTA) in the evaluation of changes in aortic conformation during the cardiac cycle and it was well evidenced that an axial aortic pulsatility exists[4-6]. But to the best to our knowledge, no studies have been carried out to evaluate if a longitudinal aortic pulsatility also exists, that could justify the aortic neck elongation previously reported.

On the basis of this background the primary purpose of our study was to assess the magnitude of variations in length of proximal neck of Abdominal Aortic Aneurysm (AAA) in patients se-

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lected to undergo EVAR by using dynamic ECG-gated CTA in order to evaluate if post-EVAR aortic neck elongation is a real phenomenon or a conformational change during cardiac cycle.

The secondary purpose was to assess if longitudinal aortic pulsatility could modify EVAR planning, in terms of indication to procedure and stent-graft selection.

Patients and Methods

Study Population

From November 2010 to November 2011, a prospective, single-center pilot study was carried out. A total of 40 consecutive patients older than 75 years old (32 men; mean age 79.8 ± 6 years, range 76-87), in order to reduce potential consequences due to increased exposure to ionizing radiation, with AAA detected with ultrasonography (US) who had been referred to our institution to undergo routine preoperative CTA were enrolled. The mean height and weight of the patients were 166.4 ± 5.4 cm (range 161-185) and 81 ± 8.7 kg (range 62-98), respectively. The mean body mass index was 25.28 ± 4.36 kg/m^2 (range 22-35.2). All patients underwent both standard static, as well as dynamic ECG-gated CTA performed with double CT acquisition and double contrast media injection. We excluded all patients younger than 75 years old and with a history of congestive heart failure, previous myocardial infarction, or severe disturbances in rhythm and patients with moderate or severe renal impairment (serum creatinine level > 1.5 mg/dl or creatinine clearance rate of < 60 ml/min/1.73 m^2).

The ethical conduct of the study was approved by our departmental Review Board (A. Gemelli Hospital-Catholic University of Sacred Heart, Rome, Italy) and was performed in agreement with the 1990 Declaration of Helsinki and subsequent amendments. All patients provided written informed consent for the surveillance protocol with specific acceptance of double CT acquisition.

MDCTA Examinations

All enrolled patients underwent double CT acquisition (i.e., standard static and dynamic ECG-gated CT angiography) by using a 64-detector row helical scanner (Light Speed VCT XT; GE Medical Systems, Milwaukee, WI, USA).

A double-phase static CT acquisition (including unenhanced and arterial contrast-enhanced phases) was firstly performed by using standard parameters: unenhanced CT images were obtained from the level of the diaphragm to the symphysis pubis, with 64 detector rows with 0.625-mm section thickness (64 x 0.625-mm – slice collimation) and a 5-mm reconstruction increment.

Contrast-enhanced images were obtained after intravenous bolus injection of 80 mL iomeprol (Iomeron-400; Bracco Diagnostics, Milan, Italy – 400 mg of iodine per milliliter) at a flow rate of 4 mL/sec, with 64 x 0.625-mm-slice collimation and reconstruction increments, a 0.5-second gantry rotation, and a pitch of 0.9-1.5 (120 kV). All contrast media injections were performed intravenously through an 18-gauge needle inserted into a brachial vein by using a power injector (Medrad Stellant Dual Head Injector; Medrad, Warrendale, PA, USA), and all were followed by a 40-mL saline flush injected at the same rate of 4 mL/sec. Arterial phase acquisition was performed from the suprarenal abdominal aorta to the common femoral artery. Scan delay was individualized per patient by using bolus-tracking software (SmartPrep; GE Medical Systems, Milwaukee, WI, USA) and a threshold level of 150 HU on the abdominal aorta at the level of the celiac trunk to trigger scanning and ensure a correct peak enhancement, with a diagnostic delay of 3 seconds.

Dynamic ECG-gated datasets were acquired with a low-dose acquisition protocol (100 kV) extending from the origin of the celiac trunk to the aortic bifurcation by using a 0.625-mm-slice collimation and a 1.25-mm reconstruction increment during injection of 40 mL of the same contrast medium as was used for static CTA, injected at the same flow rate. For dynamic imaging, the scanner acquired data in a nonstop helical mode, while an independent ECG tracing was simultaneously generated. Images were thus acquired both during systole and diastole, followed by standardized incremental 10% retrospective reconstructions performed from 5% to 95% of cardiac cycle at 10 equidistant times during the R-R interval of cardiac cycle. Adverse events related to the contrast medium injections were also recorded.

Image Evaluation

The data sets of each patient were loaded into a dedicated three-dimensional workstation (Advantage Workstation VolumeShare 4; GE Healthcare, Milwaukee, WI, USA) processed by using the cardiac review program function and randomly selected by the coordinator of the study (R.I, with 12 years of experience in vascular imaging), who was not involved in the analysis.

Both static scans and dynamic reconstructed scans were reviewed in random order by three independent readers (R.D., E.G.M.A., M.F.l.T., with 5, 4, and 2 years of experience in vascular imaging, respectively) during two reading sessions. The interval between reading sessions was at least 1 month. To minimize learning bias, reviewers were blinded to all patient identification and imaging parameters.

For the measurement of the aortic neck length, reformatted cross-sectional images longitudinal to the long axis of the aorta were obtained to create a "modified coronal" plane. The readers performed manual CTA measurements in order to evaluate the aortic neck length (defined as the distance between the lowest renal artery and the top of the aneurismal sac) and the distance between the lowest renal artery and the aortic bifurcation.

On dynamic reconstructed scans, minimum and maximum length during the cardiac cycle were determined in order to identify respectively systolic and diastolic length and to evaluate the longitudinal aortic pulsatility during cardiac cycle. The term "pulsatility" was defined as longitudinal displacement of the aorta lumen during a single cardiac cycle, and was calculated as the largest difference between maximum (diastolic) and minimum (systolic) neck length obtained on dynamic images.

For secondary purpose of our study, on the basis of selected standard static coronal images and also on systolic (minimum) and diastolic (maximum) lengths obtained on selected dynamic images, one experienced vascular surgeon (G.T.) and one experienced interventional radiologist (M.S.) in consensus assessed the stent-graft indication and selection, according to institutional recommended guidelines[7]. In detail, patients with the neck length <1.5 cm were considered not eligible to EVAR; for patients with the neck length ranged between 1.5-2 cm and >2 cm, stent-graft with suprarenal and iuxtarenal fixation respectively was selected. For dynamic images, the stent-graft planning was performed on the basis of minimum length obtained.

Stent-graft indication and selection assessed on standard static images were compared with those assessed on the basis of dynamic images, in order to calculate how often a different indication and selection would have been assessed if dynamic images were considered versus the standard measurements.

Statistical Analysis

Data on aortic length were reported as mean ± standard deviation (SD) for continuous variables, whereas categorical and ordinal data were reported as frequencies and percentages. Statistical analysis of changes in length were performed using a Student's *t* test; significance was assumed at $p < 0.05$. Analysis of measurement method comparison data according to Bland and Altman were performed to compare measurements by three readers. Statistical analyses were carried out using software (SAS release 9.2; SAS, Cary, NC, USA).

Results

Longitudinal Aortic Pulsatility

All static and dynamic CT acquisitions were considered technically adequate and excellent image quality was obtained in all patients. No adverse events were recorded. For each patient, aortic neck length obtained on static images was always longer than that obtained in systolic phase and shorter than that obtained in diastolic phase. The interobserver repeatability coefficient was 0.9 mm, without any significant differences between the observers ($p < 0.05$); therefore, the data from the three readers were pooled to obtain for each patient a final mean value of aortic neck length and of distance between lowest renal artery and aortic bifurcation.

Significant longitudinal aortic pulsatility was demonstrated during the cardiac cycle for the proximal aortic neck and for infrarenal abdominal aorta, from lowest renal artery to aortic bifurcation ($p < 0.05$). Overall, proximal neck length increased significantly during cardiac cycle, with a mean variation of 0.53 ± 0.18 cm and an absolute change of 19.1 ± 8.6%, whereas infrarenal abdominal aorta increased significantly with a mean variation of 0.59 ± 0.29 cm and an absolute change of 6.6 ± 1.6% (Table I).

Table I. Longitudinal pulsatility obtained for the proximal aortic neck and for infrarenal abdominal aorta.

Proximal neck lenght	
Static	3.03 cm ± 1.66
Diastolic/Maximum	3.26 cm ± 1.69
Systolic/Minimum	2.73 cm ± 1.68
Renal-bifurcation distance	
Static	11.77 cm ± 1.88
Diastolic/Maximum	12.13 cm ± 1.89
Systolic/Minimum	11.54 cm ± 1.85

Endograft indication and selection: Static vs Dynamic imaging

Stent-graft indication and selection, established on the basis of static images and compared with dynamic images, would be potentially changed in 6/40 patients (15%) whereas 4/40 patients (10%) were not considered eligible for EVAR in terms of aortic neck length.

In details in 6/40 patients, aortic neck length measured on static images (> 2 cm) suppose a selection of stent graft with infrarenal fixation, whereas an aortic neck length ranged between 1.5 to 2 cm was obtained on dynamic images (systolic phase) suggesting a selection of stent graft with suprarenal fixation.

In 4/40 patients, aortic neck length measured on static images (1.5-2 cm) suppose a selection of stent graft with suprarenal fixation, whereas an aortic neck length < 1.5 cm obtained on dynamic images (systolic phase) supposes that patients were not considered eligible for EVAR in terms of aortic neck length (Figure 1).

Discussion

EVAR has become a widely accepted, minimally invasive, alternative to open surgery in selected patients with abdominal aortic aneurysms, as a result largely of shorter hospital stays required and reduced morbidity in the short-term postoperative period[8,9]. However, despite excellent early results, many patients treated with EVAR require reintervention during middle- and long-term follow-up because of procedure related complications[10-12]. Stent-graft migration is a late complication of EVAR and refers to "slippage" or caudal movement of the proximal endovascular device in relation to the aortic neck below the lowest renal artery, leading to a type I endoleak with enlargement of the aneurysmal sac diameter and consequently increased risk of aneurysm rupture[13-15]. The occurrence of reported migration ranged between 9 to 45% and it is critically dependent on several variables: definition, relative length of follow-up, veracity of examination for migration and it may differ significantly among devices[1,2,16-18].

In a recent published study, authors tried to determine whether stent graft migration always represents a real phenomenon with real loss of the proximal stent graft seal zone or whether it is sometimes explained by simple aortic neck elongation. They studied patients undergoing EVAR with evidence of stent graft migration and identified and compared two different subgroup of patient: in detail, patients with and without a total loss of the proximal seal zone. On the basis of surgery literature, which recognized that suturing a prosthetic graft in the infrarenal aorta poses a risk of subsequent proximal aortic neck dilation and proximal suture line pseudoaneurysm with consequent aortic neck dilation and elongation, thus creating the appearance of caudal displacement, it was supposed that in patients without loss of proximal fixation length, stent graft migration could be explained only by aortic neck elongation, that mimics the appearance of distal stent graft migration[3,19].

Based on this background, it should be useful to understand if aortic neck elongation is a real phenomenon or simply a conformational change during the cardiac cycle. In the recent literature, there were some published studies about the use of dynamic CTA in which acquisition is synchronised to the patient's ECG. It provides informa-

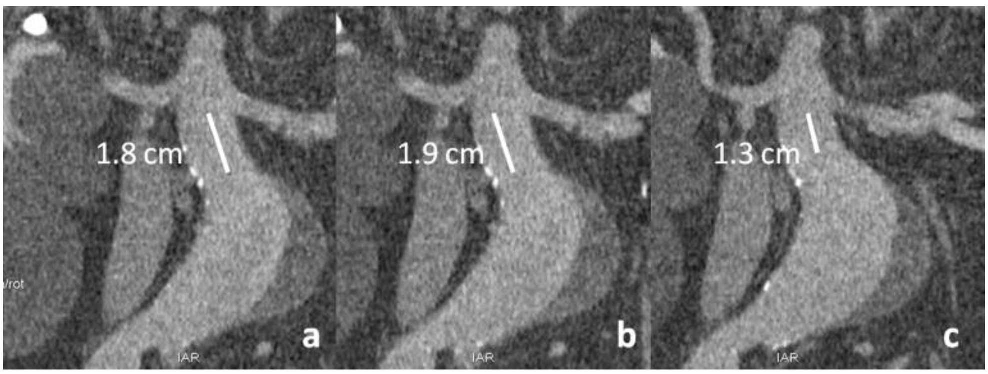

Figure 1. Aortic neck length was 1.8 cm on static images *(a)* supposing a selection of stent graft with suprarenal fixation. On dynamic images aortic neck length was 1.9 cm in diastolic phase *(b)* 1.3 cm in systolic phase *(c)*. In this case, on the basis of aortic neck measurement obtained in diastolic phase, the patient was no eligible for EVAR.

tion on aortic pulsatility and changes in aortic conformation that occur during cardiac cycle and it was well evidenced that an axial aortic pulsatility exists. But to our knowledge, there were no published studies to determine if a longitudinal aortic pulsatility also exists, that could justify the aortic neck elongation previously reported.

Moreover, the use of dynamic CTA could allow tailored selection of the stent-graft to the morphological, as well as dynamic, characteristics of the patient and could lead to more optimal endograft sizing and, subsequently, could improve procedural outcomes[4-6,20,21].

High-speed CT scanners provide dynamic ECG-gated images, allowing evaluation of aortic pulsatility. We used a 64-slice scanner capable of rapid, high-resolution image acquisition, together with a high-iodine-concentration contrast medium to maximise intra-arterial attenuation[22].

Our data confirm that significant longitudinal aortic pulsatility exists during cardiac cycle for proximal aortic neck and for infrarenal abdominal aorta, from lowest renal artery to aortic bifurcation. Proximal neck length increased significantly during cardiac cycle with a mean variation of 0.53 ± 0.18 cm while the infrarenal abdominal aorta increased significantly, with a mean variation of 0.59 ± 0.29 cm. As a matter of fact, the longitudinal pulsatility of proximal aortic neck was quite similar to that of infrarenal abdominal aorta, suggesting the quite exclusive pulsatility of proximal neck. This dynamic characteristic could justify the high rate of late term complication related to proximal neck. Understanding the dynamic properties in the region of the AAA could also have important effects on new stent-graft design's definition, focusing on the pulsatility of this aortic tract.

Furthermore, in our study we compared stent-graft indication and selection assessed on standard static images with those assessed on the basis of dynamic CT-angiographic measurements. Stent-graft indication and selection would be potentially changed in 15% of patients whereas 10% of patients were not considered eligible for EVAR in terms of aortic neck length. This mismatch between results obtained on the basis of static and dynamic measurements is caused by aortic pulsatility and by the fact that CT angiographic static images obtained with current high-speed CT acquisition times could represent any random moment during cardiac cycle.

The main criticism to our study was the relatively small number of patients examined; further investigations with large series of patients would be needed to confirm our findings. It could also be of potential concern that we limited the patients enrolled to those older than 75 years of age because aortic pulsatility may be age dependent and correlate with cardiac status, and, therefore, results obtained in this patient population may differ from those seen in younger patients. However, we decided to test our hypothesis only in patients older than 75 years to reduce any potential consequences from increased exposure to ionizing radiation.

There are lacking also long-term follow-up results. It would be interesting to demonstrate in such a follow-up if the existing longitudinal pulsatility of the infrarenal aortic neck could explain in all cases the post-EVAR elongation in patients in which it is reported. However, this investigation falls beyond the scope of this pilot study and remains a goal for future studies.

Conclusions

Dynamic ECG-gated CT-imaging may provide information regarding longitudinal pulsatility that could explain the previous reported post-EVAR elongation of the infrarenal aortic neck. It could be a unreal phenomenon simply due to a conformational change during the cardiac cycle and this longitudinal aortic pulsatility could change the EVAR planning based on static imaging in terms of stent graft indication and selection, in order to reduce the rate of EVAR late-term complication such as stent graft migration and to improve the outcome of patients.

Conflict of Interest

The Authors declare that there are no conflicts of interest.

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