

Characterization of Vessel Deformations During EVAR: A Preliminary Retrospective Analysis to Improve Fidelity of Endovascular Simulators

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OBJECTIVE: During endovascular aneurysm repair (EVAR), vessel deformations occur due to the insertion of tools and deployment of stent grafts in the arteries. We present a method for the characterization of vessel deformations during EVAR, and its application on patient datasets for a preliminary retrospective analysis that may be used to improve fidelity of endovascular simulators.

DESIGN: The method provides the extraction of vessel profiles from intraoperative fluoroscopic images and the calculation of a tortuosity index in the 2D fluoroscopy view (τ_{2D}) used to quantify the vessel deformations ($\delta\%$) during EVAR caused by the stiff guidewire insertion ($\delta\%_{Stiff}$) and the stent graft deployment ($\delta\%_{Graft}$), when compared with the undeformed vessel configuration (no device inserted). We applied the method to analyze retrospectively 7 EVAR patient datasets, including vasculature anatomies with different grades of vessel tortuosity or calcification: 2 patients (Pts) with absent tortuosity and mild calcification, 2 with mild tortuosity and mild calcification, 2 with severe tortuosity and mild calcification, and 1 with severe tortuosity and severe calcification. The analysis was focused on deformations of the left common iliac artery (LCIA), which is one of the arterial segments most affected by deformations.

RESULTS: In patients with mild LCIA calcification, the vessel straightening effect due to the stiff guidewire insertion increases as the severity of LCIA tortuosity increases ($\delta\%_{Stiff} = 0 \pm 2\%$, $-19 \pm 2\%$, $-45 \pm 2\%$ for absent, mild, and severe tortuosity, respectively). In patients with mild/severe LCIA tortuosity, the artery with the deployed graft seems to retain part of the straightening effect caused by the stiff guidewire ($\delta\%_{Graft} = -9 \pm 3\%$, $-31 \pm 2\%$, for mild and severe tortuosity, respectively). In case of severe LCIA calcification, the stiff guidewire causes only a slight straightening effect ($\delta\%_{Stiff} = -12\%$) despite the severe vessel tortuosity.

CONCLUSION: The method was effective in characterizing real vessel deformations during EVAR. Results gave evidence of a relationship between the obtained deformations and the anatomical vessel conformation. These results may be useful to drive predictive models of vessel deformations during EVAR to be implemented in endovascular patient-specific simulators for improving their fidelity. (J Surg Ed ■■■■-■■■. © 2017 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: image processing, vessel deformation, EVAR, fluoroscopy, patient data, endovascular simulator

COMPETENCIES: medical knowledge, practice-based learning and improvement

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INTRODUCTION

The endovascular aneurysm repair (EVAR) is a well-established technique, which involves the endovascular implantation of stent grafts to repair aneurysms.¹ During EVAR, both the introduction of guidewires and the deployment of the stent graft into the vessels make them deform, in particular, the iliac arteries.² These arterial deformations may depend on multiple factors, such as the tortuosity of the arteries, the grade of calcification of the arterial wall, and the types of devices used.

Accurate prediction of vessel deformations during EVAR may be extremely useful during the preoperative planning to derive clinically relevant data such as the length of the stent graft to be deployed or the displacement of reference anatomical points. Indeed, before intervention, the surgeon must choose the stent graft model and size to ensure that the aneurysm is completely sealed without covering important collateral arteries, particularly renal arteries and internal iliac arteries. Straightening of tortuous arteries due to the interaction with the procedural devices may lead to shrinkage of the arterial segments compared to the preoperative anatomy, thus requiring the change of the initial sizing of the graft, or it may induce movements of anatomical reference markers that alter the planned landing zones for the graft.³

Currently, arterial deformations during EVAR are not objectively taken into account at the time of the procedural planning to determine which stent graft size is the most suitable for the patient. This is because the stent graft sizing is carried out on the undeformed preoperative CT image, while in the intraoperative setting, the graft is deployed inside a vessel deformed by the insertion of procedural devices that may not have the same length as that measured on CT. The physician may predict the changes in the graft sizing due to vessel deformations just relying on his own experience.

In recent years, endovascular virtual reality (VR) simulation has evolved to support the surgeons in EVAR preoperative planning. Particularly, the latest developments include VR simulations based on preoperative patient-specific anatomy: computed tomography or magnetic resonance angiographic images are used to generate patient-specific 3D models that are uploaded on the simulator.⁴⁻⁶ Although several studies have demonstrated that these systems are effective tools for boosting the learning curve in vascular surgery,⁷⁻⁹ their major limitation remains the inadequate modeling of vessel biomechanical properties and vessel deformations caused by the endovascular equipment.⁴ This affects the fidelity of simulation and its efficacy for preoperative planning, since vessel morphology in simulation may not match the real intraoperative morphology, especially in the case of noncalcified, tortuous iliac arteries.

Finite-element models (FEM) have been recently developed to predict vessel deformations during EVAR,¹⁰⁻¹⁸ and they seem to be promising tools to improve the fidelity of

patient-specific endovascular VR simulators. In many models, the geometry of the arteries is based on standard values found in the literature, and only few of them^{10,18} use a parametrization based on patient-specific data (i.e., mechanical properties of vessels are adapted according to the arterial wall quality of the patient's arteries). Moreover, few works provide the matching of the simulation results with patient-specific intraoperative data to validate the models used.^{10,17,18}

Many of the proposed FEM models take into account vessel deformations caused by the introduction of stiff guidewires,¹⁰⁻¹⁴ while prediction of vessel deformation after the stent graft deployment is poorly studied.^{15,16} Only 2 studies^{15,16} are focused on FEM simulation of virtual deployment of stent grafts in an abdominal aortic aneurysm, but they are not specifically addressed to predict arterial deformations after the graft deployment. Some other FEM applications have been proposed to study the placement of a stent in an aortic aneurysm or in the peripheral or coronary vessels,¹⁹⁻²³ but their main purpose was to analyze the mechanical stress between the stent and vessel wall during the stent placement.

In this study, we present a method for the characterization of vessel deformations during EVAR by processing intraoperative fluoroscopic images, and its application on patient datasets for a preliminary retrospective analysis.

The presented analysis can be systematically applied to a wider patient database to provide a full characterization of real deformational behavior of the aortoiliac structure during EVAR, in relation to different grades of vessel tortuosity and calcification. The collected data may be useful to develop predictive models for vessel deformations during EVAR to be implemented in endovascular VR simulators, in order to improve their fidelity. Particularly, a VR simulation able to replicate the real deformational behavior of vessels due to the interaction with EVAR devices may help to select the optimal stent graft size for implantation.

MATERIALS AND METHODS

Description of the Method

The proposed method provides the extraction of vessel profiles by processing intraoperative fluoroscopic images and calculates a tortuosity index in the 2D fluoroscopy view (τ_{2D}) which is used to quantify the percentage of vessel deformations ($\delta\%$) caused by the interventional devices, when compared with the undeformed vessel configuration (no device inserted). Negative $\delta\%$ values correspond to straightening deformations, while positive $\delta\%$ values to bending deformations.

For image processing functions and τ_{2D} calculation, the software MATLAB 2010 (Mathworks, Natick, MA) was used.

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