ARTICLE IN PRESS
IRBM:458

Disponible en ligne sur
ScienceDirect
www.sciencedirect.com

Elsevier Masson France
EM|consulte
www.em-consulte.com

IRBM ••• (••••) •••–•••

IRBM

RITS 2017

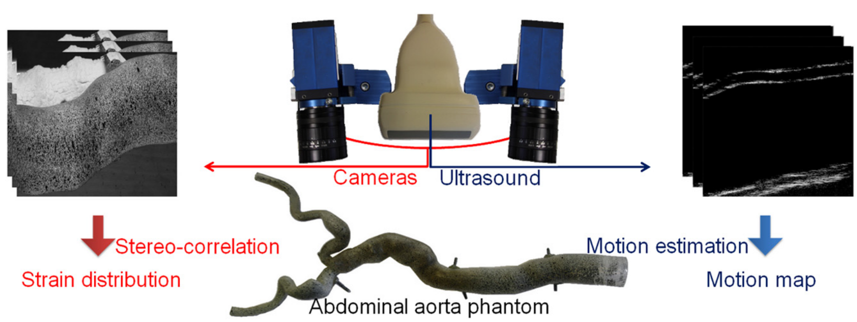
Biofidelic Abdominal Aorta Phantom: Cross-Over Preliminary Study Using UltraSound and Digital Image Stereo-Correlation

V. Perrot [a,*], S. Meier [b], A. Bel-Brunon [b], H. Walter-Le Berre [b], B. Bou-Saïd [b], P. Chaudet [b], V. Detti [a], D. Vray [a], H. Liebgott [a]

[a] *Univ. Lyon, INSA-Lyon, Univ. Claude Bernard Lyon 1, UJM-Saint-Étienne, CNRS, Inserm, CREATIS UMR 5220, U1206, F-69621, Lyon, France*
[b] *Univ. Lyon, INSA-Lyon, LaMCoS UMR CNRS 5259, F-69621, Villeurbanne, France*

Received 13 March 2017; received in revised form 12 July 2017; accepted 13 July 2017

Graphical abstract



Abstract

Purpose: EndoVascular Aneurysm Repair (EVAR) can be indicated to prevent Abdominal Aortic Aneurysm (AAA) breaking. However, several complications may occur during and after surgery, such as endoleaks or migration. The aim of this work is to develop and validate an experimental set-up designed to reproduce the comportment of an abdominal aorta with aneurysm. Consequently, this paper presents the proof of concept of the experimental set-up.

Materiel and methods: We have developed an experimental set-up based on a patient-specific aorta phantom with an aneurysm. Physiological conditions that are influent for EVAR (blood flow and mechanical support) are applied. The set-up combines UltraSound (US) and Digital Image Stereo-Correlation (DISC) measurements to evaluate the vascular structure motion due to blood flow and EVAR.

Results: Preliminary results show that our experimental set-up allows measuring local surface deformations on the phantom using DISC as well as motions in the vessel wall thickness using US without surgical material. The measurements from the two techniques are consistent with the applied pressure, realistic and complementary.

Conclusion: The set-up and methods in this paper are validated and our proof of concept is established. Future work will focus on the simultaneous use of the two measurement tools (US and DISC) and the introduction of stent-grafts inside the phantom during pulsed cycles. Such measurements of local deformations and motions will help understanding possible complications of EVAR.

* Corresponding author.
E-mail address: vincent.perrot@creatis.insa-lyon.fr (V. Perrot).

http://dx.doi.org/10.1016/j.irbm.2017.07.002
1959-0318/© 2017 AGBM. Published by Elsevier Masson SAS. All rights reserved.

Keywords: Biofidelic; Phantom; AAA; EVAR; UltraSound; Digital Image Stereo-Correlation; Biomechanical; Biomedical

1. Introduction

EndoVascular Aneurysm Repair (EVAR) is a minimally-invasive technique that is commonly used to treat Abdominal Aortic Aneurysms (AAA). It relies on the exclusion of the aneurysm sac by introducing one or more stent-grafts through the femoral arteries and deploying them inside the aneurysm. During the procedure, several tools of varying stiffness are introduced to enable the delivery of the stent graft to its deployment site, in particular by straightening the often tortuous iliac arteries. During this process, the vascular structure undergoes major deformations [1]. It has been shown [2] that these deformations are mainly regulated by the mechanical support provided by the connections between the aorta and the rachis. Moreover, in the same paper [2], it has been proved that these deformations could put into question the initial preoperative sizing of EVAR. Therefore, it is important to take them into account.

Once the stent-graft has been deployed, several other complications can occur, including migration and endoleaks. Migration consists in a displacement of more than 10 mm of the prosthesis from its initial position; endoleak consists in a permeability of the prosthesis, for different reasons including an incorrect contact between the prosthesis and the aortic wall. However, there is no clear evidence of the mechanisms leading to these complications.

Investigating experimentally the vascular structure response to EVAR is the main goal of this project: it consists in studying (1) its deformations and (2) its interactions with the prosthesis, using a biofidelic phantom of a patient-specific vascular structure placed in physiological conditions in terms of blood flow and mechanical support. Full-field measurement by Digital Image Stereo-Correlation (DISC) and UltraSound (US) are associated to the set-up to investigate points (1) and (2) respectively. They can provide quantitative data in terms of 3D displacements and relative speeds. This paper presents the set-up and its measurements capability.

2. Material and methods

2.1. Experimental set-up

The set-up is designed to reproduce physiological conditions that are relevant for stent-graft deployment. As described in Gindre et al. [2], the tortuosity and the mechanical support of the vascular structure to the spine are the two most influent factors on the structure deformation during EVAR. Therefore, the set-up is based on a silicon phantom vascular structure designed from a patient-specific geometry (© Segula Technologies, SA, Nanterre, France). While its behavior is linear, the silicon used for the phantom is similar to the aortic wall in terms of stiffness (about 1.5 MPa); however, it does not include stiffer parts to represent calcifications. The set-up is presented on Fig. 1; the phantom is attached to a 3D-printed curved spine using springs to mimic the secondary arteries mechanical support as suggested in Gindre et al. [3]. The descending aorta is connected to a pump through a solenoid valve controlled by a LabView (© National Instruments, Inc., Austin, Texas, United States) program to create a pulsed flow. Pressure and flow can be measured using a pressure sensor (0.2 bars) and a flow meter. A manual valve is mounted on the iliac arteries output to control the pressure inside the vascular structure and a second pressure sensor is mounted there as well.

The phantom can be immersed to mimic abdominal pressure. However, the results presented in this paper are obtained without filling the aquarium for the DISC measurements, while US acquisitions are performed with water immersion. Indeed, water is necessary for US acquisition (air is a poor medium for US wave propagation) whereas it is not a requirement for DISC. Since our purpose is to establish a proof of concept of the set-up, the water was not taken into account for DISC. However, DISC measurements into a filled aquarium is possible as long as calibration is performed in the same condition.

2.2. Ultrasound

During this study an US research scanner, named Ula-Op (Ultrasound Advanced Open Platform) [4] is used, which allows to program personalized US sequences through a MATLAB interface (© MATLAB, The MathWorks, Inc., Natick, Massachusetts, United States). A 1D linear US probe (LA 523, © Esaote, Inc., Florence, Italy), composed of 192 elements for a total width of view of 47.04 mm corresponding to a pitch of 0.245 mm, is also used. An example of the ultrasound images obtained with the scanner is shown on Fig. 2.

A particular US sequence was implemented on this scanner to acquire at high frame rate images of the wall motion of the phantom along time. With the chosen sequence, high framerate imaging is reached, up to 5 000 images per second during two seconds (resulting to 10 000 saved images) to appreciate each subtle displacement of the vessel wall. In order to achieve this framerate, a plane wave sequence is implemented. In plane wave imaging, all elements of the probe are excited simultaneously in order to produce a wave front close to a plane wave [5]. For our specific mode, 64 elements located at the center of the probe and corresponding to a total width of 15.68 mm are successively activated in emission and reception. The probe ultrasound frequency was 9.4 MHz and signal was sampled at 50 MHz (scanner clock). One line per element was beamformed, the resulting pixel resolution is 0.0141×0.245 [mm^2] in axial and lateral directions, respectively.

The received single element raw US signals (RF images) are collected after each plane wave transmission/reception. Afterwards, RF images are migrated/beamformed to obtain images [6]. Motion is estimated on the migrated images. Our motion estimator is based on a 2D phase shift measurement between

Please cite this article in press as: Perrot V, et al. Biofidelic Abdominal Aorta Phantom: Cross-Over Preliminary Study Using UltraSound and Digital Image Stereo-Correlation. IRBM (2017), http://dx.doi.org/10.1016/j.irbm.2017.07.002