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Abstract

In this paper, we present our global image processing frameworkof interventional planning
and assistance for ascending aorta dissections.

The preoperative stage of that framework performs the extraction of aortic dissection features
in Computed Tomography Angiography (CTA) images. It mainly consists ofa customized fast
marching segmentation.

The intraoperative stage of that framework realizes medical images registration and proposes
data visualization enhancement; standard X-ray fluoroscopic images are used as the reference
modality. We use our recently introduced registration method based on image transformation
descriptors (ITDs) and usual 3D/2D techniques (based on digitally reconstructed radiographs).
The first stage provides aortic dissection features and is to help clinicians for the planning.
The second stage provides an augmented reality visualization and would be used for
assistance during the intervention.

As far as we know, this is the first complete image processing framework which focuses on
the ascending aorta dissection (minimally invasive) endovascular treatment.

1. Introduction

Aortic dissection is an uncommon yet potentially catastrophic clinical event. The annual
incidence has been estimated at 5-30 cases per million [1]. Aortic dissection is a medical
emergency and can quickly lead to death. The thoracic aorta is divided into four anatomic
segments (Fig. 1 left): the *aortic root*, the *ascending aorta*, the *aortic arch*, and the

descending aorta. The aorta is made up of three layers: the *intima* (in direct contact with the blood flow), the *media* and the *adventitia* (farthest from blood flow). Aortic dissections are caused by one or more aortal tissue perforations issued from tissue weakness and high blood pressure. It consists of one or several *intimal tears* and a clear separation between layers of the aortic media, resulting in two separate blood flow channels: the *true lumen* (the primary aorta bed of blood flow) and the *false lumen* (a channel inside the splitted media occuring during an aortic dissection). The layer of detached aorta tissues between lumens is called *intimal flap*.

According to both patient's condition and the extent of the dissection, the treatment can be done in three ways: open heart surgery, minimally invasive endovascular intervention with endoprosthesis landing, or medical management. This decision is made following a preoperative 3D Computed Tomography Angiography(CTA) examination (Fig. 1 right). In the case of an endovascular treatment, one of the most used modalities is intraoperative 2D X-ray (fluoroscopic, by a monoplane C-arm system) angiographic images.

Our motivation consists in studying the endovascular treatment of ascending aorta dissections which could be more adapted for certain patients. This study follows recent publications about treatments of this segment of aorta [3, 4] and new prosthesis design. The detailed framework, proposed here, is made up of the two following main steps:segmentation (Sect. 2) from CTA data,3D/2D registration (Sect. 3) of the 3D segmented data onto the intraoperative 2D X-ray angiographic images. This framework gives the opportunity to assist and help clinicians during their diagnosis (features extraction) and to enhance angiographic intraoperative images. Moreover, due to this augmented angiographic rendering, this study also aims to decrease irradiation dose and to reduce injected contrast quantity.

As far as we know, this is the first complete image processing framework which focuses on the aortic dissection endovascular treatment. Other works concern only segmentation stage in the case of aortic dissections (by example [5]).

2. Segmentation

In this section, we describe the pipeline of image processing operators (Fig. 2) that enables us to separate and distinguish the two lumens inside a CTA image of an aortic dissection. These features will be used in our registration stage (Sect. 3).

Region of interest definition. In order to speed up the image processing, the initial CTA volume I_1 including the dissected aorta is truncated, yielding I_2. Then, we construct aparametric model I_3 of the aorta. That model is a 3D mesh interactively built [6]by delineating the outer aortic wall into I_2.

Lumens retrieval. We want to extract and separate the two lumens, with a segmentation process.

- PREPROCESSING. The interior of the model inside I_3 is filled with the corresponding grayscale values of I_2. Then, to improve the image quality, a Gaussian filter is applied ($\sigma=1.0$).

- MODIFIED FAST MARCHING. Fast marching segmentation method (FM) [7] is an efficient implementation of level set deformable models. It consists of a propagation process inside a grayscale volume according to a speed function, an initial surface and a number of iterations.Due to intimal tears between lumens, this algorithm would yield the two interconnected lumens on our aortic dissection images.

  To obtain separated lumens during the segmentation step, we have adapted FMby modifying the speed function [8]. The new speed function must be such thatthe propagation front should spread over homogeneous regions (we use a Gaussian

density probability); the propagation should stop at the neighborhood of flap and lumens borders (we have proposed an intermediate labelling image). That labelling image, constituted by such candidate points, is computed from both gradients and initial grayscale values.

- APPLICATION. This algorithm extracts each lumen by a single voxel initialization. Note that the propagation occurs inside the parametric model therefore no other organs nor vessels are retrieved.By repeating this process twice, we obtain the separated lumens imageI_4.

Lumens distinction. Intensity values of blood mixed with contrast are usually higher inside the true lumen for our images.A straightforward operator (mean intensity inside each lumen) enables us to distinguish the true and false lumens; we obtainI_5.

3. Registration

The goal of our proposed registration framework is to provide an alignment of pre- and intraoperative images. The pipeline is composed of two steps(Fig. 3): the first one −based on the recently introduced descriptors (ITDs) −yields a coarse registration providing a quick initialization for the second step −an iterative precise algorithm.

3.1. Fast ITD-based registration

This original method [9] quickly provides a relatively accurate 3D pose estimation$T_{\sim}$.

Input.

We have recently introduced a technique called *fluoroscopy amplification* [10]: it processes the angiographic sequence J_1 to extract contrast agent, thus to increase the visibility of the aorta; the obtained image isJ_2. As input for this registration, we use the binarizedamplification image J_3as a reference; and the parametric model of the aorta I_3 as a target.

Method.

Our registration approach uses a new technique of 2D images alignment, based on the *image transformation descriptors* (ITDs). Our 3D/2D registration technique is driven by such a 2D approach carried out for an estimated best orientation, obtained through a 3D pose estimation and a rotation sampling. The three major stages of the method are described below:

- ITD 2D/2D FLAT ALIGNMENT.

ITDs enable us to obtain a 2D similaritytransformation T' between two 2D images M_1 and M_2 (Fig. 4)without any iterative optimization process [11].

- 3D/2D REGISTRATION FOR A GIVEN ORIENTATION.

(Cf. Fig. 5.)At this stage, we assume we have a projection Proj(N_2) of the 3D imageN_2 with a correct volume orientation (relatively to the referenceN_2). A *3D pose estimation* algorithm computes a 3D pose update as a function of both the current volume 3D transformation$T_{i-1}$and the 2D output T'_i of our 2D/2D ITD-based method [9]. Such a volumetransformation update is repeated (e.g. 3 times), until the projection image Proj(N_2) is coherent with its 2D referenceN_1.

- COMPLETE ALGORITHM.

If the correct projection orientation is known, the pose is directly obtained by the previously described 3D/2D stage. Otherwise, starting with a roughly computed initializationT_0, we perform a sampling overthe selected orientations range,choosing the best parameters from a similarity measure (Dice coefficient) issued from the projections for each sample. The optimal 3D orientation$T$ is chosen for the sample with maximum similarity measure.The resultingcoarse transformation parameters are given after carrying out the final 3D/2D ITD algorithm for the best volume orientation (see [6] for further details).

3.2. Precise DRR-based registration

(Cf. Fig. 3.) The last stage of the registration framework is an iterative method, based on digitally reconstructed radiograph (DRR). DRR is an approximation of an X-ray image from CTA data [12].

Input.

The algorithm takes as inputs the 2D image J_2 (reference image) obtained by the amplification technique, and the 3D volume (target image)combining both the image $I_5$of the two lumens (obtained by the segmentation approach described in Sect. 2)whose intensity is increased (after experimentations), and the initial CTA volume I_1.The algorithm is initialized with the transformation$T$issued from our fast ITD-based algorithm.

Method.

The registration is achieved by matching the reference imageJ_2 to generated DRR images, derived from the 3D CTA volumetric data I_1.Reference image and the DRR image are compared by measuring the similarity between the images using the value of the Mattes mutual information. The transformation is estimated using the evolutionary 1+1 optimizer [13].

The preliminary visual results are presented in Fig. 6.

4. Conclusion

In this paper, we presented our whole framework concerning interventional planning and assistance. As far as we know, this is the first attempt to propose such an image processing framework to treat ascending aorta dissections.Future works will be devoted to improve our pipeline: retrieve all aortic dissection characteristics (intimal tears, flap …), perform a deformable registration using the aorta parametric model, provide endoprostheses sizingand elaborate a clinical protocol, etc.

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Figure 1- Left: (A) The aortic root, (B) the ascending aorta, (C) the aortic arch, (D) the upper part of the descending aorta; (1), (2) and (3) respectively intima, media and adventitia layers; (a) an intimal tear, (b) the false lumen; (c) the true lumen [2]. Right: One 2D grayscale Computed Tomography Angiography slice (T: true lumen, F: false lumen).

Figure 2 - Aortic dissection segmentation. In I_5: in red the true lumen, in blue the false lumen.

Figure 3 - Complete 3D/2D registration framework.

Figure 4 - ITD-based 2D/2D registration.

Figure 5- ITD-based 3D/2D registration for a known 3D orientation T_0.

Figure 6 - Enhanced intraoperative images. Upper row: the X-ray amplification image (left) and the two lumens superposed (right). Lower row: a selected frame of the X-ray angiographic sequence (left) followed by its augmented view.

I_1 Volume cropping I_2 Interactive parametric model construction I_3 Modified fast marching I_4 Lumens distinction I_5

Amplification
(image processing)

Binarisation

J_1

J_2

J_3

Reference

Initialization

T_0

ITD-based
3D/2D registration

Target

$T_\sim$

Interactive
parametric model
construction

I_1

I_3

I_5

Super-
position

Reference

Initialization

DRR-based
3D/2D registration

Target

T_*

Iterations $i = 1, 2, \ldots n$

Reference

N_1 (2D)

Reference

ITD based
2D/2D registration

Initialization

Target

T_0 (3D)

Target

N_2 (3D)

Proj(N_2) (2D)

T_{i-1} (3D) T'_i (2D)

3D pose
estimation

Projecting

T_i (3D)

T_n (3D)

$T_\sim$ (3D)