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Aneurysm identification by analysis of the blood-vessel skeleton

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ABSTRACT

At least 1% of the general population have an aneurysm (or possibly more) in their cerebral blood vessels. If an aneurysm ruptures, it kills the patient in up to 60% of cases. In order to choose the optimal treatment, clinicians have to monitor the development of the aneurysm in time. Nowadays, aneurysms are typically identified manually, which means that the monitoring is often imprecise since the identification is observer dependent. As a result, the number of misdiagnosed cases may be large. This paper proposes a fast semi-automatic method for the identification of aneurysms which is based on the analysis of the skeleton of blood vessels. Provided that the skeleton is accurate, the results achieved by our method have been deemed acceptable by expert clinicians.

1. Introduction

An aneurysm is a localised, blood-filled dilation of a blood vessel caused by disease or weakening of the vessel wall. Cerebral aneurysms most commonly occur in arteries at the base of the brain. The danger of cerebral aneurysms lies in their risk of rupture – this can result in a severe bleeding, which may lead to death. Statistics have shown that the mortality rate is about 30–60% [1,2] depending upon the severity of the bleeding. According to [1,3], aneurysms develop in 2–6% of adults; women are more susceptible than men (by a factor of 2), and people with high blood pressure are especially vulnerable.

The current treatment involves: use of medicament to reduce the blood pressure; surgical clipping, which consists of opening the skull, exposing the aneurysm and closing the base of the aneurysm with a clip; endovascular coiling, in which a platinum coil is directed through the vessel and the neck of aneurysm to fill the aneurysm sac; and inserting a stent, which requires placing the stent in the vessel with the aneurysm to help to redirect the blood flow into healthy arteries. None of these treatments can be used in all cases. The medical treatment is not available for ruptured aneurysms or aneurysms that either grow rapidly or have a high risk of rupture. Similarly, coiling cannot be used if the aneurysm neck is too wide. As inserting a stent may temporarily increase the bleeding, this treatment is often not an option for large ruptured aneurysms. Surgical clipping is associated with a higher risk of consequent complications [4], though some surgeons disagree with it and are convinced that surgery is the best.

In order to decide which treatment should be used, simple geometrical measurements of aneurysms such as depth, ostium diameter, volume and aspect ratio (AR, computed as the dome maximum depth/the ostium diameter) must be calculated. Nowadays, these measurements are typically obtained manually by clinicians either from digital subtraction angiography or from single or multiple CT scans [5]. Depending

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upon the imaging modality, the detection and quantification of aneurysms can be imprecise and observer dependent [5].

Not many research papers proposing automation of this process have been published [6–9]. Fully automatic or semi-automatic detection of aneurysms is based mainly on the segmentation of CT scans (or angiography images) followed by a probabilistic classification of the segmented regions [6,8] exploiting the fact that voxels corresponding to the aneurysm have a different intensity than voxels of blood vessels or the surrounding mass [9]. The accuracy of these methods varies, in accordance with the screening resolution and the kind of segmentation algorithm used. As precise measurements are not performed by these methods, their use for the identification of changes (of the aneurysm volume or of the neck perimeter) over time is at least difficult, if not impossible.

Recently, a more accurate approach for fully automatic detection of aneurysms was proposed [7]. Instead of searching for aneurysms in the image data, it constructs a 3D surface model of blood vessels and performs the identification of aneurysms in this model. In order to do so, the skeleton of blood vessels is found and, afterwards, the so-called "writhe number" is calculated for every point on the surface. This calculation takes into account the mutual location of this point and points in its neighbourhood, and also the relationship of their normal vectors. The neighbourhood is defined as a sphere with centre at the skeleton point closest to the point being inspected and radius equal to the distance between these two points multiplied by $\sqrt{2}$. The authors prove that, unlike the points on the aneurysm, the points belonging to the healthy blood vessel should have zero writhe number. According to the published information, however, we suspect that the method is inaccurate for aneurysms with wide necks.

The accurate detection of aneurysms for the identification of at-risk individuals with higher chances for developing brain aneurysms and their rupture was tackled in @neurIST [10], a large integrated project financed by the European Commission (EC), in the context of which we developed (independently) an approach similar to [7]. We also analysed the mutual relationship of points of the surface model and its underlying skeleton, though our analysis is completely different from that in [7]. The most important feature of our semi-automatic method is that, instead of concentrating on the detection of aneurysms, it focuses on the precise supervised identification of the aneurysm neck and, hence, the extraction of the aneurysm. This approach provides additional benefits because, by comparing the size of the aneurysm to that obtained from the previous tomography, the clinician can determine if the aneurysm has increased in size, in which case, a non-medicament treatment would normally be preferred.

The remainder of the paper is structured as follows. The next section describes the background of our research and the @neurIST project [10] in more detail. We then provide the proper definition of the neck of an aneurysm enriched with an explanation of the low usability of curvatures for neck identification. Section 4 presents our probabilistic method that is based on the analysis of mutual location of surface points and the underlying 3D skeleton. In Section 5, we describe the results of the experiments performed, and Section 6 concludes the paper and discusses the possible future work.

2. Background

The natural history of cerebral aneurysms is complex and, to a large extent, still unknown, given that genetic, physical and environmental factors are thought to play a key role in their pathogenesis and progression. The identification of at-risk individuals with a greater chance of developing brain aneurysms and the aneurysms that are most likely to rupture are two extreme decision-making situations in the screening and/or handling of this condition, in which health professionals have a great need of integrative decision support tools.

A large integrated project financed by the EC (@neurIST, FP6-2004-IST-4-027703) addresses this problem in a broader systemic context; the project started in 2006 and ended in March 2010. @neurIST developed an information technology (IT) system for the diagnosis, management, prognosis, risk assessment and epidemiological studies of aneurysms. This system includes several software suites, each belonging to a specific field of application (genetics and data mining, risk assessment, medical imaging, treatment planning), and an IT infrastructure that provides a secured access to clinical and research databases, medical imaging, simulations data and to computing facilities.

@neuFUSE is the software suite that provides access to clinical data, such as the anonymised patient's record and images. It also builds computational models of cerebral aneurysms, interfaces off-the-shelf simulation software, makes available to the clinician an environment for the treatment planning and populates research databases in order to foster a knowledge basis for a more sophisticated rupture risk assessment of cerebral aneurysms.

@neuFuse integrates a complex information tool-chain that allows the extraction of a set of indices from medical images stored in the databases to provide help with the understanding of the mechanisms that rule the process of growth and lead to aneurysm rupture. The tool chain involves a number of processing steps (either automated or interactively manual); these are represented in Fig. 1.

2.1. *Segmentation*

From medical images, a geometrical representation of boundaries of the vasculature enhanced by the contrast agent on the images is automatically extracted [11] by a multimodal implementation of a geodesic active regions level set method.

2.2. *Surface healing*

Due to lack of resolution, a situation typical in routine clinical images, the extracted surface presents many artefacts that should be removed either automatically or interactively by an operator.

2.3. *Centreline extraction*

From the topologically correct surface, a representation of the vasculature centreline is extracted by an automatic method (so-called "skeletonisation"). The output centreline gives a topological representation of the arterial tree and is used in the