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AngioLab—A software tool for morphological analysis and endovascular treatment planning of intracranial aneurysms

Ignacio Larrabide[a,b,*], *Maria-Cruz Villa-Uriol*[b,a], *Rubén Cárdenes*[b,a], *Valeria Barbarito*[b,a], *Luigi Carotenuto*[b,a], *Arjan J. Geers*[b,a], *Hernán G. Morales*[b,a], *José M. Pozo*[b,a], *Marco D. Mazzeo*[b,a], *Hrvoje Bogunović*[b,a], *Pedro Omedas*[b,a], *Chiara Riccobene*[b,a], *Juan M. Macho*[c], *Alejandro F. Frangi*[b,a]

[a] *Networking Biomedical Research Center on Bioengineering, Biomaterials and Nanomedicine, Barcelona, Spain*
[b] *Center for Computational Imaging & Simulation Technologies in Biomedicine (CISTIB), Universitat Pompeu Fabra, Barcelona, Spain*
[c] *Department of Vascular Radiology, Hospital Clinic i Provincial de Barcelona, Barcelona, Spain*

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ABSTRACT

Determining whether and how an intracranial aneurysm should be treated is a tough decision that clinicians face everyday. Emerging computational tools could help clinicians analyze clinical data and make these decisions. AngioLab is a single graphical user interface, developed on top of the open source framework GIMIAS, that integrates some of the latest image analysis and computational modeling tools for intracranial aneurysms. Two workflows are available: Advanced Morphological Analysis (AMA) and Endovascular Treatment Planning (ETP). AngioLab has been evaluated by a total of 62 clinicians, who considered the information provided by AngioLab relevant and meaningful. They acknowledged the emerging need of these type of tools and the potential impact they might have on the clinical decision-making process.

1. Introduction

Intracranial aneurysms (IAs) are abnormal focal dilations of cerebral arteries that may rupture and eventually cause a subarachnoid hemorrhage (SAH) [1]. Stroke is among the leading causes of death in the western world. SAHs correspond to 20% of all strokes with IAs accounting for 85% of all SAHs [2]. Over the last decade, great advances in interventional imaging and a new generation of therapeutic devices have provided major improvements in IA diagnosis and treatment. Currently, clinicians take into account patient age, presence of symptoms, and aneurysm size and shape when assessing the best treatment option [3]. There are two treatment strategies: Surgery (clipping or by-pass) and endovascular therapies (coil embolization, stent-assisted coil embolization, and flow diverter deployment). Both strategies aim to exclude the aneurysm from the blood circulation. However, particularly with endovascular devices, the outcome of IA treatment is difficult to predict.

Clinicians are becoming more interested in image quantification and personalized computational modeling; they demand tools to improve patient assessment and treatment planning. Therefore, the development and assessment of such

* *Corresponding author at*: Networking Biomedical Research Center on Bioengineering, Biomaterials and Nanomedicine, Barcelona, Spain. Tel.: +34 935422966.
E-mail address: ignacio.larrabide@upf.edu (I. Larrabide).
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tools is receiving increasingly more attention in recent years [4].

We can find general purpose libraries (e.g. Visualization Toolkit (VTK) [5] and Insight Toolkit (ITK) [6]), others specialized for vascular analysis (e.g. VMTK [7], TubeTK [8]) and commercial and non-commercial end-user applications which make use of the previous ones (e.g. 3D Slicer [9], Amira [10], Osirix [11]). This tool offers a set of advanced capabilities for segmenting and analyzing geometrical characteristics of patient-specific vasculature. In Table 1, we summarize the main features of these vascular analysis tools and those of the software we are presenting here. One important software initiative called the Vascular Modeling Toolkit (VMTK) [7] has been designed to perform 3D reconstruction, geometric analysis, mesh generation and surface data analysis of vascular models. However, the tool is not focused on a specific vascular disease and only part of its features have been integrated as a plugin into 3D Slicer [9] to provide a graphical user interface (GUI). Another important software package is OsiriX [11]. This package offers one plugin specifically designed for coronary vasculature segmentation from CTA images, called CMIV-CTA [12] that also allows multiple visualization capabilities. Other software, currently under development, is TubeTK [8], a software package without GUI, with capabilities to segment and extract vessel geometrical properties of vessels from medical images that can also be used for vascular atlas construction. Another similar tool is @neuFuse [13], which is an end-user application for the creation of 3D vascular models, morphological analysis, set-up and post-processing of hemodynamics simulations developed in the context of the @neurIST project [14]. Some of the algorithms and methods integrated in @neuFuse are available in the tool described in this work (e.g. vascular segmentation, morphological analysis and virtual stenting). For this reason, @neuFuse is the tool most similar to the one presented here. Finally, we mention Mimics [15], which is a medical image processing tool that forms part of a more general application called Mimics Innovation Suite. This tool offers a set of advanced capabilities for segmenting and analyzing geometrical characteristics of patient-specific vasculature.

The objective of this work is to present AngioLab, a software tool for the morphological analysis and endovascular treatment planning of IAs. Two workflows have been created and implemented in AngioLab for image-based management of IAs: 1. Advanced Morphological Analysis, and 2. Endovascular Treatment Planning, which are schematically represented in Fig. 1. These two workflows have been implemented in four plugins within the GIMIAS framework [20] described later. The included methods are a subset of those described by Villa-Uriol et al. [4].

AngioLab has also been brought into the hands of clinicians for their assessment during two hands-on workshops. Participants were mainly neuroradiologists and neurointerventionists who used the software for the first time and provided feedback through an anonymous survey. The survey inquired the participants about the usability and the clinical value of the methods presented in a normal use case. We would like to point out that the validation of the algorithms included in AngioLab is not in the scope of this study and has been addressed in the references cited herein.

The goal of AngioLab is to provide information to clinicians, engineers and computer scientists that help them to better evaluate IA patients and understand the effect of treatment. AngioLab is an end-user application, based on the mentioned libraries, that includes a complete set of features for a specific clinical application. So far, there is no distribution strategy for this software, because it is still in a prototype stage.

2. AngioLab description

AngioLab has been developed on top of GIMIAS (Graphical Interface for Medical Image Analysis and Simulation), a workflow-oriented software framework for medical image computing and computational physiology [19,20]. This framework allows building medical prototypes for clinical evaluation and simplifies the integration of tools for building new clinical workflows, by using open-source libraries to accomplish various tasks, including graphical editing, user interfaces, image analysis, anatomical modeling, computational physiology and visualization. Prototypes can be verified by research users, thus reducing the effort required to translate new concepts to the clinical environment. In this section, we briefly describe the GIMIAS architecture, how AngioLab was designed on top of it, and AngioLab's GUI.

2.1. *GIMIAS framework*

GIMIAS relies on a set of open-source libraries that are standards in biomedical imaging, such as VTK, ITK, the DICOM Toolkit (DCMTK), the Medical Imaging Interaction Toolkit (MITK), Boost, wxWidgets and CGNS. The integration of these libraries is obtained by leveraging a software infrastructure including routines to read and write different file formats, to support and optimize data handling, to provide consistent user interaction and visualize different data types (2D, 2D+t, 3D and 3D+t images, surface and volumetric meshes, signals, landmarks, contours, vector fields, etc.). The wide number of features provided by standard libraries are available through an Application Programming Interface (API), which permits to be easily extended and reused.

The GIMIAS extensibility stems from a modular architecture, which permits users such as scientific developers and bioengineering researchers to extend the framework with their own algorithms and methods, as depicted in Fig. 2. The architecture is implemented as a set of layers featuring different levels of abstraction. The architecture layers can be summarized as follows.

- The *library layer* contains widely used open-source libraries. The user can add new libraries, which can contain new algorithms and methods developed by her/him or can be third party ones.
- The *framework layer* provides an API through which the plugins interact with the library layer and with each other. It includes GUI components available to all plugins (widgets), facilities for user interaction with rendered data (interactors), readers/writers of various file formats, data handling functions.