

VICTORIA

An interactive online tool for the Virtual neck Curve and True Ostium Reconstruction of Intracranial Aneurysms

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Abstract. For the characterization of intracranial aneurysms, morphological and hemodynamic parameters provide valuable information. To evaluate these quantities, the separation of the aneurysm from its parent vessel is required by defining a neck curve and the corresponding ostium. A fundamental problem of this concept is the missing ground truth. Recent studies report strong variations for this procedure between medical experts yielding increased interobserver variability for subsequent evaluations. To make further steps towards consensus, we present a web application solution, combining a client based on HTML and JavaScript and a server part utilizing PHP and the Matlab Runtime environment. Within this study, participants are requested to identify the neck curve of five virtual aneurysm models. Furthermore, they can manipulate the ostium surface to model the original parent artery. Our application is now available online and easily accessible for medical experts just requiring an internet browser.

1 Introduction

The assessment of intracranial aneurysm (IA) rupture risk increasingly depends on morphological as well as hemodynamic parameters that are calculated based on the aneurysm sac [1,2]. Furthermore, therapy planning requires a detailed knowledge of the individual IA neck size to select an appropriate treatment strategy and device, respectively [3]. In addition, a virtual separation of the IA from the parent vessel allows for the extraction of parameters from a 3D model rather than 2D projected images in the clinical routine that suffer from increased user- as well as image (i.e. the viewing angle of the 2D projections) dependency [4].

However, the separation between parent vessel and aneurysm sac (i.e. the ostium) strongly varies, which might lead to insufficient analyses and in conse-

quence to unreliable conclusions. The separation of the IA from the healthy parent vessel is often realized using a (planar) cut-plane [5,6], which might be error-prone for complex IA shapes. In previous work, we developed a semi-automatic extraction of an anatomical, bent neck curve [7], but the question about the correct neck curve remains unanswered.

Therefore, VICTORIA (Virtual neck Curve and True Ostium Reconstruction of Intracranial Aneurysms) aims at a standardization of IA neck curve and ostium reconstruction. For the definition of these neck curves and ostia, highly experienced physicians are required. Since their availability for user studies is limited due to the clinical work load, we developed an easy accessible framework solely requiring a web browser. Thus, we can gather expert-knowledge from physicians as well as biomedical engineers. The study has been successfully launched at <https://VICTORIA.cs.ovgu.de/>.

2 Materials and methods

Within the VICTORIA study, participants are requested to identify the neck curve of patient-specific IA models extracted from 3D digital subtraction data. The extraction of surface models is described in our previous work [8].

2.1 VICTORIA web application

The study is conducted using a specialized web application, consisting of two parts: a client part (written in HTML and JavaScript), and a server part (written in PHP and using Matlab runtime environment). The VICTORIA study can be accessed via the internet using a web browser. Between client and server, the data is exchanged in the JSON format. The server stores user-submitted data in a relational database, thus allowing for easy sorting and filtering of the data, see Figure 1.

In order to keep the motivation to participate high, the user is directly presented with five datasets and two tasks, respectively. For both tasks, a surface

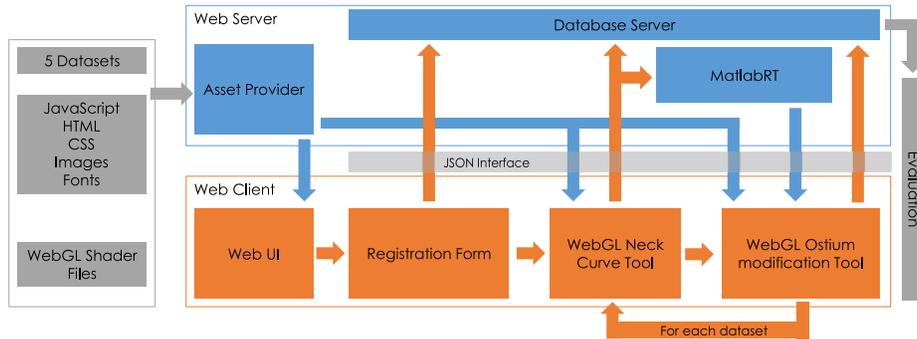


Fig. 1. Illustration of the different parts of the VICTORIA web application

mesh of an IA and its parent vessel is shown. The rendering is performed using the WebGL2 API, thus allowing it to run in most current desktop browsers. The mesh is illuminated using the Phong lighting model to increase shape perception. The user has limited control over the camera (rotation, zoom and panning), ensuring that the neck region is always visible and centered in the image.

2.2 Neck curve definition

First, the user draws a neck curve onto the vessel mesh by selecting surface vertices, see Figure 2. To connect the selected vertices into a circular path, the surface triangle mesh is interpreted as a bidirectional graph. The shortest paths between the selected points are then calculated using the A* algorithm by Hart et al. [9]. However, the A* algorithm is only designed to find the shortest path between two points, not the shortest path connecting a list of unordered points. To prevent having to force users to select the points in order and thus sacrificing usability, the list of points has to be sorted automatically. Here, a distance matrix stores the length of the shortest path between all points. Whenever a new point is added to the matrix, the distances to all other points are determined using A*. To sort the list of points, we begin with a list containing only one randomly chosen point. As long as there are points that have not been added to the list, we take the last entry, look up the closest point (based on the distance matrix)

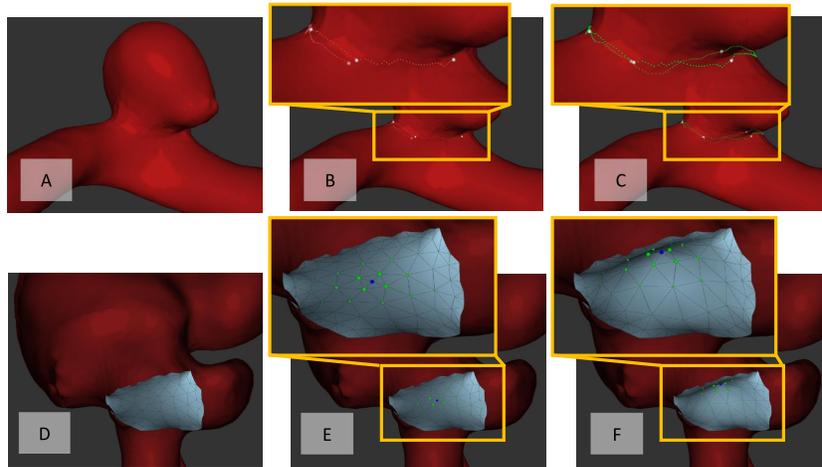


Fig. 2. The different steps of the ostium definition. (A) 3D visualization of the surface model with WebGL. (B) The user can interactively select points on the aneurysm surface. The points are automatically selected (see also inset). (C) If the points are close to each other, the neck curve is automatically closed. (D) In the second step, an automatic ostium triangulation is provided. (E) The user can hover over the points and the active point is highlighted. (F) the point can be moved (including a reduced movement of its neighbors) until the user is satisfied with the ostium shape.

that has not been added yet, and add it to the back of the list. After all points have been processed, the resulting list contains the shortest path connecting all neck points selected by the user. The last and first point in the list will only be connected if their distance is shorter than the longest path between any of the other adjacent points in the list. This prevents the neck curve from closing before the user has finished adding all desired points. In case the resulting neck curve does not match the users' expectation additional points can be added.

The sorting and path finding algorithm are implemented in JavaScript and are performed entirely on the client side. Even on less powerful devices, they run interactively without any noticeable delay.

2.3 Ostium creation and manipulation

After submitting the neck curve, the server calculates the associated ostium surface mesh. This step is implemented in Matlab, motivated by previous work [7] as well as to provide additional geometric functionalities and to spare the client's PC performance. To ensure the general applicability, we use the Matlab runtime environment and provide it at our linux server. The Matlab script receives the previously selected surface meshes and downsamples them to a predefined threshold. The process is illustrated in Figure 3. For the illustration, the neck curve points are resampled to 32 points. The ostium triangulation is analytically defined and centered around the origin (z -coordinates equal 0). Next, the analytically defined border points are replaced by the neck curve points and simple Laplacian smoothing (50 iterations, $\sigma = 1.0$) is applied to all vertices except the border points, resulting in the smooth ostium surface (Fig. 3).

The second task consists of the adjustment of the previously calculated ostium surface. This is important to better approximate the inflow area for further postprocessing steps in order to better approximate the parent vessel's original geometry. During this task, only the backfaces of the vessel are rendered to reveal the ostium. The user can grab and drag any vertex of the ostium surface that is not part of its border. To keep the interaction as simple and straight-forward as possible, the vertices can only be moved in the direction of the average surface

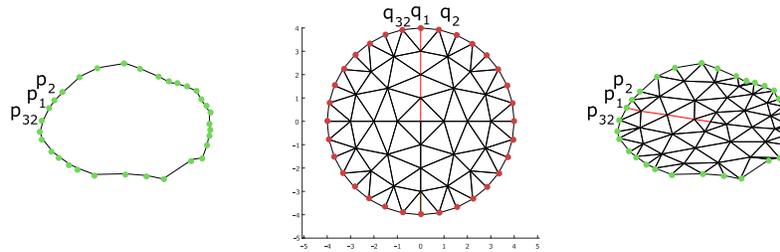


Fig. 3. Illustration of the ostium triangulation. The neck points are resampled to 32, $p_1 - p_{32}$ (left). The pre-defined triangulation is centered around 0 with border points $q_1 - q_{32}$ (center). Next, $q_1 - q_{32}$ are replaced by $p_1 - p_{32}$ and all points undergo Laplacian smoothing yielding the triangulated ostium surface.

normal of the ostium. As moving one vertex at a time would be tedious, dragging one vertex by a distance of v also moves the surrounding vertices by a distance of v_n based on their normalized Euclidean distance d_n to the original vertex. The parameter a controls the size of the affected area. We empirically determined a value of $\frac{1}{3}$ to result in an interaction that feels natural.

$$v_n = v \cdot (\max(0, d_n - (1 - a)) * a^{-1})^{0.75}$$

The second task can be considered optional, as it is possible for the user to directly accept and submit the ostium surface generated by the server without performing any modifications.

Finally, we implemented a registration form combined with a questionnaire. Users enter their name, e-mail address, occupation and employer, as well as answer questions about their experience with IAs. Thus, an examination of differences between user groups (e.g., physicians vs. engineers) can be conducted in the future.

3 Results

The VICTORIA study was implemented at the Otto-von-Guericke University, Magdeburg, Germany, and can be easily assessed at <https://VICTORIA.cs.ovgu.de/>. We tested this interactive survey successfully with three medical cooperation partners. They requested more hints and icons regarding the controlling of the application which we included. The neck curve definition requires approximately two minutes per case and less than ten minutes overall. The study requires the use of Mozilla Firefox or Google Chrome. Other, less commonly used browsers, such as Apple Safari or Microsoft Edge do not support the required WebGL technologies. The evaluation of the submitted ostia segmentations is not part of this work but ongoing research. In this work, the implementation of the web-based study is presented and the prototype does fulfill its purpose.

4 Discussion

Currently no ostium ground truth is available, yet it is required for many post-processing steps of IA models. We presented an approach that allows for an easy participation of international field experts and physicians by utilizing a combination of JavaScript, PHP and Matlab-programs, including 3D visualizations, editing and modification options.

Based on a ground truth ostium definition, a precise morphological evaluation of the 3D IA shape is further promoted, and it is highly beneficial for the quantification of hemodynamic flow simulations [10]. Furthermore, a 3D neck curve determination and subsequent parameter evaluation is superior to 2D analysis [4]. Particularly, since relevant blood flow parameters that are associated with rupture (e.g., normalized wall shear stress, shear concentration index, oscillatory shear index [11]) need to be calculated with high accuracy, wrong

aneurysm-vessel-separation or high user-dependency can lead to clear variations regarding the analysis.

Furthermore, we expect our survey results to be utilized as ground truth data for deep learning-based ostium extraction approaches, e.g. similar to the MeshCNN network [12]. Finally, our architecture can be easily adapted to other medical image processing questions that require 3D models and user interaction.

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