Web based 3D quantitative measurements of Abdominal Aortic Aneurysms

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We tested a novel approach for the quantitative remote analysis of Abdominal aortic Aneurysm by reconstructing their 3D geometry and topological structure (i.e. centerline path) and put them on the web as VRML97 models including specialized code enabling the user to perform guided inspection and measurements useful for surgical planning.

1. Methods

1.1. Image retrieval

A DICOM server based on the Mallinckrodt CTN have been used to receive and store the CT data received from the diagnostic center.

1.2. Segmentation

Deformable models have been used for segmentation: we developed a software tool with an user friendly interface that can be used to control two different segmentation procedures used to recover the geometrical structure of the aorta. The first method consists of generating single vessel branches from series of 2D contours arbitrarily oriented in the 3D space and then joining them with basic operations. Contours are extracted from 2D slices using region growing or balloon snakes [7,8] algorithms, and can be modified and controlled through the user interface. Vessel surfaces are finally built in the following way: first point correspondence on successive contours is found, then a triangulated surface is generated and a centerline (a spline joining the centers of mass of the contours) is also built. The operations introduced to join the contours are three: simple joint, anastomosis and bifurcation. The first connects two segments at their extrema, the second joins two intersecting vessels, the third joins three different branches in a bifurcation structure.

The same procedure of the balloon evolution, can be performed directly in 3D starting from a small sphere first put inside the vessel region in the data set and then making it grow driven by an internal pressure, regularizing forces and voxel based forces. We found a good 3D geometrical structure to be used as a basis to implement the balloon in the Simplex Meshes [9]. Simplex Meshes are very simple surface meshes where each node is connected exactly to three neighbors. This makes very easy to write the code for the dynamics and the algorithms obtained are simple and fast. This method can be more accurate near bifurcations, but it is less easy to control when, for example, the presence of plaques or local structures makes convenient to correct locally the reconstruction or to tune the segmentation parameters. Furthermore it requires the use of another algorithm to recover the vessel centerline (we implemented a voxel coding method [10]. In any case, the final result is still a file including both the surface of the arterial lumen and its centerline. The same techniques can be obviously used also to extract other interesting structures, such as the external surface of the thrombotic region. Geometric operations and the file structure is based on the XOX Shapes Microtopology library [14].

1.3. Web-based measurable models generation

VRML97 and ECMA scripting are used to obtain 3D models that are not only viewable from any VRML97 enabled browser, but that also allow users to interact with them, to navigate along the vessel lumen and to perform guided measurements of distances and angles. The segmented data are automatically converted in VRML97 worlds hiding scripting code that enables the measurement of the geometrical parameters relevant for surgical planning directly from standard web browsers. The conversion tool has been realized as a perl script and generates the geometric object nodes, several viewpoints, an user interface with clickable buttons, guided navigation paths, an image display and the measurement support. Using ECMA scripting we implemented methods to measure parameters of surgical interest. The first gives the 3D coordinates and the distance from the centerline for an arbitrary point on the surface selected with the mouse. A plane perpendicular to the centerline is also shown. Another one consists of measuring the distance traveled by a point moving along the centerline between two user selected reference points. This is an extremely useful value, since usual measurements of vessel length done with 2D imaging or endoscopy are often wrong due to the effect of vessel curvature [11]. Furthermore, it is possible to measure angles defined selecting three points on the centerline. Other options introduced in the VRML97 worlds are introduced to perform a guided navigation inside the vessel lumen ("Virtual endoscopy") or to perform a test to verify if a probe of given radius can be inserted through the vessel lumen. During the measurement phase, images corresponding to a section of the CT dataset passing through the clicked point of the surface and perpendicular to the vessel centerline are also represented inside the browser interface. Images have been obtained from the CT data by selecting planes perpendicular to the centerline in sampled points and using linear interpolation to compute the pixel values. These images are saved as gif files and used as texture of a plane in the VRML model.

Using these tools the end user can perform many useful computations on realistic models that can be distributed worldwide a few hours after the image acquisition and can be accessed and analyzed in the same moment by different consulting centers just using a standard web browser. This means that, once fully validated, this technology could be used by specialized service centers to provide, in a cost-effective way, surgical support through 3D based measurements. Fig. 1 shows the expected service model: the diagnostic center can send DICOM3 datasets through the net to the elaboration center, and after a few hours, the surgeons can browse, from their standard PC, the resulting VRML97 model and perform guided measurements. Differently from other similar services currently available [1], this new system is based on open standards, does not require specialized software on the client side and it is specifically designed to operate within Internet.

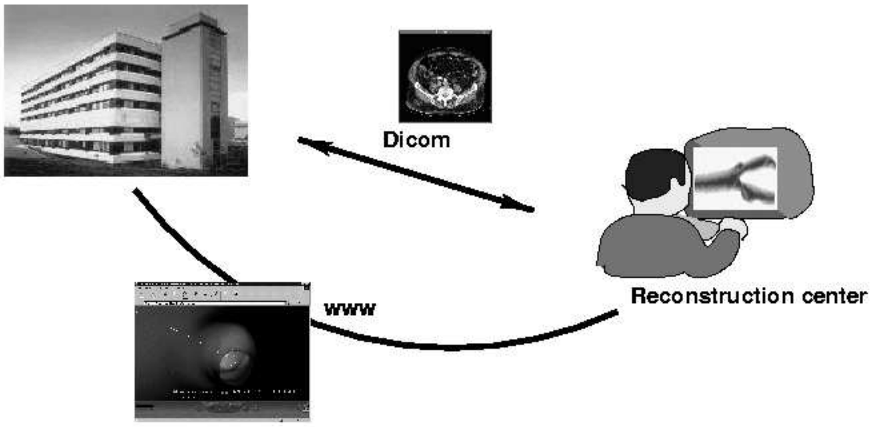

Figure 1. The VRML97 measurable model service: a diagnostic center can send images to the reconstruction center, and a few hours after, a 3D model with guided measurement support is available on the net.

2. Abdominal Aortic Aneurysms

To test on a really useful application the idea described in the previous sections, we applied our method to measure the geometrical parameters describing aortic aneurysms. The aortic aneurysm is a progressive, pathological dilation of the aorta. The fate of all aneurysms is the rupture. This condition is almost always fatal. Thus aggressive surgical approach is warranted. Therapeutic approaches include open surgery and/or endovascular exclusion. The latest procedure involves the endovascular placement of a complex prosthesis. A correct geometrical evaluation of the aneurysm structure is fundamental to have a successful implant. Moreover, [11] knowledge of the true aneurysm diameter, proximal aortic neck diameter and its distance from renal arteries is necessary in order to evaluate the surgical risk. CT is the most accurate technique [12] to evaluate abdominal aortic aneurysm. The useful measures to plan the endovasal procedures are often performed on the volumetric data. However, this is usually done with empirical techniques: selecting some slicing planes and making ad hoc corrections to measures performed on the 2D projections. If the parameters are estimated from these projections or from the trajectory of a catether a large amount of error due to the curvilinear structure of the vessel is introduced both in diameter and length measurements.

3. Results

Eight cases of Aortic Aneurysms already treated with the placement of an endovascular stent by our vascular surgeons have been acquired by the CRS4 PACS. Vascular geometrical structures have been reconstructed using the contour based method and VRML models have been generated. Two trained vascular surgeons performed blind measurements on the model using a simple web browser with the Cosmo Player 2.1 plugin, as if he had to choose the design of the stent and to plan the procedure. The aneurysm neck,length and sac diameter has been measured. Particular attention has been paid to the presence of calcified plaques at the level of the bifurcation and iliac arteries. Operators computed also the intra-aortic angle and the aortic-iliac angles. The results obtained were always compatible with the previous values used by the surgeons who planned the intervention, who had to recover the parameters from 2D images and correct them with ad hoc methods.

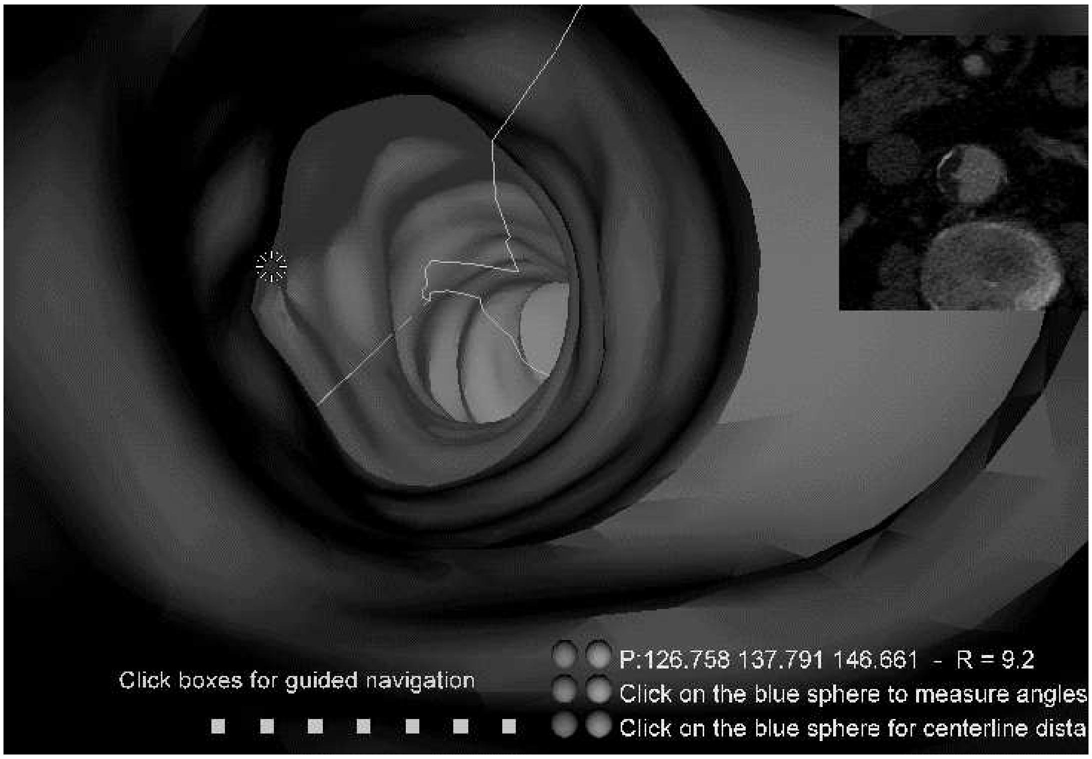

Figure 2. The VRML97 model can be inspected, navigated and measured from any pc with a web browser and a plugin. Here a "virtual endoscopy" with radius measurement is shown.

4. Conclusion

The results obtained show that the system described here can be effectively useful to obtain reliable measurements and support for collaborative work. The same method can be applied also for other clinical applications, i.e. colonoscopy, where measurements of 3D structures and a collaborative diagnosis can be extremely helpful for a correct diagnosis.

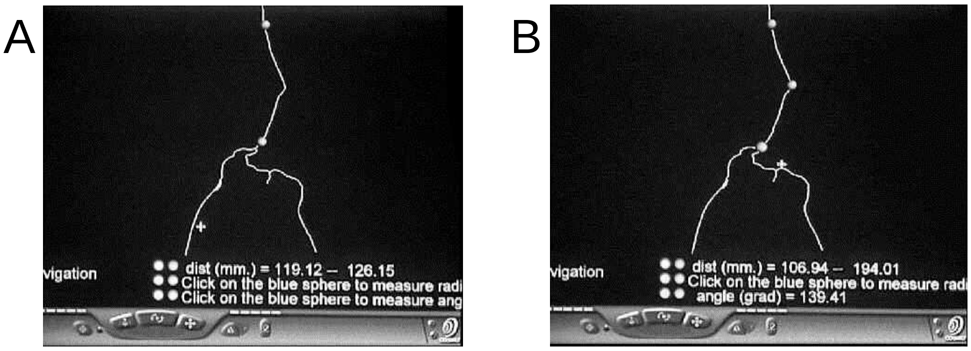

Figure 3. Measurement of centerline distances (A) and angles (B): the user can place the two or three reference points just by clicking with the mouse on the centerline, and the distance or angle is automatically shown.

We plan to improve the quality of the reconstructions and the functionality of the system in the near future, especially with regards to the support of collaborative work.

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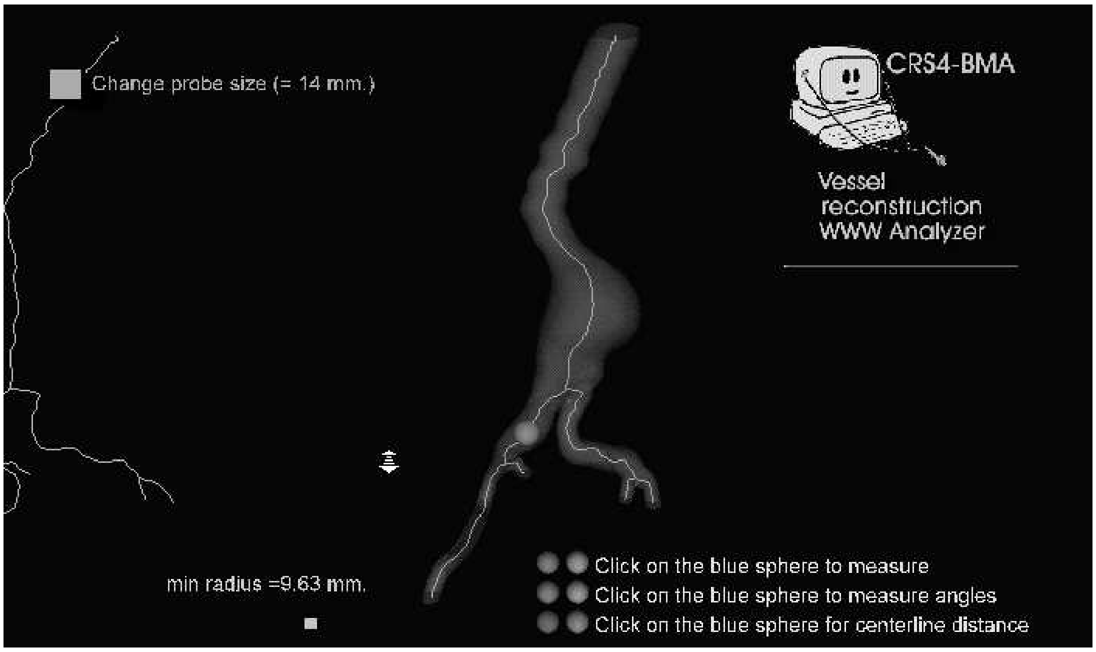

Figure 4. Testing the insertion of a probe of fixed size inside the vessel.

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