Research Article

Interdisciplinary Project: "3D Printing" and Aortic Disease

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Background

The aortic disease involves a multitude of severe clinical conditions (aortic dissection, intramural hematoma, traumatic rupture, penetrating ulcer, aneurysm), characterized by a high mortality rate, if untreated.

Young patients can also be affected and the incidence varies between 15 and 20 cases per year every 100.000 inhabitants.

This disease can sometimes present underhanded symptoms that require targeted instrumental procedures aimed at the diagnosis. Early identification, often derived from a differential diagnosis from other conditions, is fundamental to reduce the timeframe that separates it from the treatment, which must be rapid and above all adequate.

In the majority of cases, surgical treatment represents the only therapeutic option possible. In the last decades, the development of technologies and materials, together with the increased “know-how” of dedicated specialists, ensured a greater improvement in the results, about both mortality and morbidity.

The correct “imaging”, the early diagnosis, the creation of diagnostic-therapeutic paths dedicated to these patients, including also the genetic screening, are key elements in providing patients the correct surgical indication, adequate timing and more and more precise and accurate procedural planning.

Even though medical imaging has overwhelmingly improved in the last years, thanks to the availability of machines, the speed of execution and their performance, it is not always possible to obtain a “real vision” of the condition.

If only a 2D data sequence (as in MRIs or MSCTs) or a single bidimensional data (as in X-rays) is available for the patient anatomy, the understanding of the clinical situation is undoubtedly limited compared to the analysis of a three-dimensional object.

3D printing solutions would allow visualizing and testing first-hand what might be found in the operating room, thus improving and optimizing the therapeutic approach, tackling more and more complex clinical and surgical scenarios.

In particular, with regards to aortic disease, a physical representation of the aorta would allow a tangible observation of the topographic anatomy, the origin and the angulation of the main arterial branches, the anatomical structure of the aortic arch, the location and origin of the lesions.

Moreover, a physical model, compared to a generic and impersonal video or image, would offer the patient a further element to better understand the condition and the possible recommended surgical procedure, allowing a more understandable and easy collection of the informed consent.

Materials and Methods

“The quality of the Rapid Prototyping/3D Printed models is highly dependent on the quality of the MSCT Angiogram imaging quality, the segmentation process, the 3D-printer model and the material used”.

A) MSCT Angiogram execution technique (extract from “Shared Protocol: CT-Angiogram Execution Technique in Patients with Aortic Disease”)

"Cardiac motion and breathing artifacts harm the segmentation and thus the printed volume. Typically, high-resolution scans are used in combination with electrocardiography gating, breath-hold, and/or respiratory gating".

• Direct phase

- Thickness 3 mm
- Thoracoabdominal extension

• Arterial phase with cardiac gating

- Slice thickness 0.4-0.6 mm
- Extension from the supra-aortic trunks emergence to the celiac trunk
- ROI in the aortic arch, scanning starts once the threshold is met (100 HU)
- 120 cc contrast medium, flow: 4 cc/sec.

•Late arterial phase

- Slice thickness 0.4-0.6 mm.
- Extension from the celiac trunk emergence to the femoral bifurcations
- Scanning starts right after the end of the previous one

• Venous phase

- Extension from the external auditory canals (including the carotid bifurcations) to the ischial tuberosities
- Scanning starts with a 30-second delay from the end of the previous scan (or 60 seconds after the threshold is met)
- Reconstruction from 1.5 mm at the level of the neck.

• Post-Processing

- Coronal MPR every 2 mm
- Oblique parasagittal MPR parallel to the aortic arch every 2 mm
- Sagittal MPR for the descending and abdominal aorta.

B) Use and conversion of *.DICOM to *.STL MSCT images edited by Carlo Campana

The images or the sequences of images are exported in a *.DICOM format and become anonymous via exchange of non-native software with the MSCT Angiogram elaboration software. Afterward, the images are imported into dedicated programs that can reconstruct the axial, coronal and sagittal sections. This particular software is equipped with plug-ins that can integrate the diagnostic imaging reading with 3D CAD-CAM modeling.

After identifying the imaging segmentation or the ideal DICOM image sequence, it is possible to perform the data segmentation. Every image is composed by pixel in grayscale; the operator selects an interval of threshold values of the grayscale that better highlights the area of interest.

This phase is named “THRESHOLDING” and it is aimed at the selection of pixels of the chosen images.

1st level 3D reconstruction

Once the pixels of interest are selected, the software can elaborate three-dimensional surfaces, described by the outlines of what was previously selected during the segmentation phase. The obtained 3D model, named “Mesh3D”, can be exported from the dedicated software in a *.STL format; this is the ideal format to interact with a 3D Printer, starting the rapid prototyping process.

2nd level 3D reconstruction

The first 3D file obtained directly from the MSCT Angiogram images will unlikely be printed or prototyped; a CAD-CAM 3D modeling phase will therefore be necessary; here the bio model of the aorta is corrected and refined from possible digital incongruities. In this phase, the Mesh 3D is “repaired, remodeled” and adapted to the use of Rapid Prototyping machines. The obtained

*.STL file is reimported in the starting software and it is overlaid to the MSCT DICOM images to verify their accuracy and compliance. The obtained *.STL file will be the definitive one, ready for printing.

C) File printing process description by STEFANPLAST

***.STL file processing**

The 3D printer, when taking into consideration the printing process management, has to be considered on a par with a traditional office printer.

The *.STL file is opened via Grab Cad Print program where, in the main screen, the palette is displayed on an X;Y plane; the component that has to be printed will be displayed in the same position of the CAD model created. After observing the characteristics of the component, the first operation consists of repositioning the virtual object in the most suitable position. This position is identified imagining the best compromise between the quality of the result and the layering by evaluating both the modeling strategy and, above all, the support that should sustain the component.

Once the best position is defined, the file is cleaned from possible breaches, errors, or imperfections via the automatic repair function.

Subsequently, the parameters are defined starting from the choice of the material that will be used to build the model. In case ABS is chosen, the program will allow different selections:

- The automatic thickness increase when the thickness is too thin
- The layer resolution that can reach ⅛ mm
- The type of grid used to build the support

If PLA, a translucid and biodegradable material, is chosen it will not be possible to select some options (for example, it will not be possible to define a resolution higher than ¼ mm) as this type of process does not consider the creation of the support with different materials.

It is important to recall that once the model obtained with two types of non-transparent ABS (solid for the model and soluble for the support) comes out of the printer, it has to be immersed in a chemical bath to obtain the complete dissolution of every part of the support, both inside and outside the component; in case of PLA models, it is necessary to perform some manual operations to remove those parts that, even if they are made with the same material, are extraneous to the component and operate as support. With PLA, the internal support can be removed only if it is possible to reach it from the outside.

Afterward, when adding the project to the print queue, the file is elaborated, displaying on the PC screen the printing preview with the expected material consumption and the process duration, furthermore it is possible to simulate on the monitor the layering progression to observe the strategy employed by the machine software.

Printing Process

Once the project is in the print queue (it is possible to select more than one project however they will not be executed without the voluntary intervention of the operator), the machine display previews the component located in the print board. The building process will therefore start.

First of all, a new print board needs to be positioned on the build platform and, as soon as **"start"** is selected, the machine waits for the chamber to reach 75°C, afterward the axis is monitored to verify the print board is planar and correctly mounted. During the building process, the machine uses two printing nozzles, one for the model material and the other one for the support; therefore, inside the same layer, the support layer will be deposited first and the model one later. Between the two operations, the model nozzle will self-clean by building a parallelepiped, in a separate position than the component, that will reach the same high of the higher point of the model. While printing, the machine display also shows the estimated time of realization.

The prototyping machines, as industry 4.0 devices, can be monitored remotely. It is possible to install the GrabCad app on a smartphone allowing the live monitoring of the last frame of the work in progress. Moreover, smartphones can provide further information regarding the working chamber and nozzles temperature as well as the percentage of the work performed.

Cleaning of the component

Once the machine completes the job, it is possible to open the door to extract the print board to remove the prototype. Depending on the material used for the construction, it will be necessary to perform the above-mentioned operations.

Final tests

At the end of the production, each prototype will be verified and catalogued by the project manager.

Possible uses of 3D printing

-Modern technology allows an accurate and real 3D printing, making possible the use of materials that resemble the properties of the heart and great vessels tissues;

-For educators, it can provide a wide variety of normal and pathological anatomical examples that would not normally be available;

-For patients, it can provide a better insight into the disease and recommended treatment options;

-Furthermore, prototyping can provide physicians a wider insight into the anatomy, favouring, indirectly, more accurate planning (especially in patients with "difficult" anatomies).

Legal Aspects

The printed product, the content of the present project, will be used exclusively for **DIDACTIC** purposes. As it is not a medical device, its use will not be regulated by the legislation displayed on the EU 745/2017 Regulation (medical device regulation).

Legend

MPR: Multi Planar Reformation MRI: Magnetic Resonance Imaging

MSCT: Multi-slice Computed Tomography STL: Stereolithography

PLA: Polylactic Acid - innovative bioplastic

ABS: Acrylonitrile-butadiene-styrene - thermoplastic polymer

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