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RESEARCH ARTICLE

Digital Fracture: New Approach for 3D Organ Modelling

Gabriela Mendes da Rocha Vaz[1,2], Luciano Paulino Silva[1,2*]

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Abstract

Biofabrication emerged a few years ago as a new research field with a set of promising technologies that have the potential to impact multiple sectors. In this field, the idea of 3D bioprinting originated from rapid prototyping (additive manufacturing) technology. This technology consists of some steps or stages, the first of which is the development of virtual computer models. However, there are some challenges to be overcome in order to develop reliable models for bioprinting purposes. Here, we present the proposal of a workflow using free and open-source software to produce reliable organ models from computerized tomography (CT) and magnetic resonance imaging (MRI) scans. We also propose the concept of digital fracture as a novel approach applicable to generating computer-aided design (CAD) models, especially for 3D bioprinting processes. This novel strategy can be used as an organic way to create smaller organ models compatible with some limitations of the current bioprinters, including relatively low speed, limited spatial resolution, and low accuracy.

Key Words: *3D bioprinting; Biofabrication; Bioimaging; CAD; Modelling; STL*

Introduction

Rapid prototyping, often called 3D printing or additive manufacturing [1] is a technology idealized back in 1983 by Charles W. Hull [2]. Today, it is one of the most promising technologies capable of shaping the future, arousing growing interest from numerous companies, researchers, and even artists. These people are truly delighted with the potential of this tool, and they often call themselves and are recognized as makers. Overall, Hull's idea was to develop a method to quickly make prototypes [2] in order to decrease the time of product development, and from that simple idea, the technology was born and is currently enabling mass customization. In the beginning, in the 1990s and early 21st century, the range of applications included the production of functional technical parts, medical models, microfabrication approaches, and others, but the main application envisaged was still the

[1]*Embrapa Genetic Resources and Biotechnology, Laboratory of Nanobiotechnology (LNANO), Brasília 70770-917, DF, Brazil*

[2]*University of Brasília, Postgraduate Program in Biological Sciences (Molecular Biology), Brasília 70910-900, DF, Brazil*

[*]*Corresponding author: Luciano Paulino Silva, Professor, Embrapa Genetic Resources and Biotechnology, Laboratory of Nanobiotechnology (LNANO), Brasília 70770-917, DF, Brazil, Tel: 55 (61) 3448-4755; E-mail: luciano.paulino@embrapa.br*

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prototype development [3]. After almost three decades, 3D printing promises to change the way we create and use industrial products [4] with a wide range of possible applications in surprising fields and sectors like bioprinting (exploring the idea of using living cells to print whole organs) [5] food printing (exploring the demanding gourmet market and even the aerospace sector) [6], house printing (exploring the speed made possible in the ever-pulsating sector of civil engineering), [7] among others, which make this technology greatly researched today.

The development of rapid prototyping is directly related to the development of computers and the software industry. This scenario happens because 3D printing processes include one essential stage that consists of creating a virtual computer model, called computer-aided design (CAD) that is then 3D printed. From the initial CAD model to the final printed object, several intermediate steps are involved. These steps encompass converting the model to a suitable format, adjusting optimal printing parameters, digitally segmenting the model, selecting the appropriate material, layer-by-layer fabrication, and carrying out post-processing on the completed construct [1]. Therefore, creating a reliable model is a critical step at the core of this technology. In order to create a CAD model, there are some possible approaches: one can create a model ab initio, using basic shapes available in stereolithography (STL) format, or after scanning an object using 3D laser scanning, computerized tomography (CT), and magnetic resonance imaging (MRI) [1]. Despite the recent advances, when it comes to designing specifically for bioprinting, there are several challenging issues that represent bottlenecks for the achievement of practical uses. The building of reliable 3D biomodels is still a non-trivial task that limits the widespread application of this technology for researchers working in bioengineering laboratories [8].

The aim of this study was to explore free and open-source software tools and show how they can be used for modelling biostructures and how they can be useful in the 3D bioprinting field. Another goal was to develop a protocol to create feasible models of organs from bioimages (CT scans) using exclusively free and open-source software and a normal computer, not a high-performance one. In order to prove the feasibility of using such tools to create models for bioprinting purposes, here we introduce the new concept of digital fracture and compare it to common modelling approaches. Exploring these modelling tools, it is possible to adapt CAD models according to the biofabrication process, especially when it comes to 3D bioprinting. Current 3D bioprinters have some limitations related to speed and resolution. This means that to our knowledge, there is not any available commercial or lab-made equipment that is suitable to print a full human organ considering its size, cell viability, tissue integrity, and viable structure for the medical field of transplants. The available printers would take too much time, which makes unfeasible this final goal. Bearing this in mind, tools that perform segmentation can be really useful. Through digital segmentation tools, it is possible to generate or adapt models and make them a feasible technology for the tissue engineering field.

File Conversion and Model Regeneration

In order to obtain .STL files for testing our modelling approaches, four steps were followed using different software for multiple file conversions and processing (Figure 1).

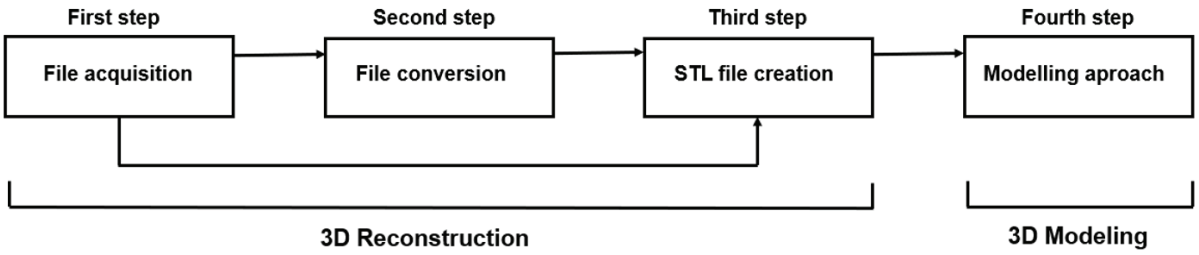

Figure 1) *Computational tools used to convert bioimages into CAD models useful for bioprinting processes. The first step was based on an online database available on a website, and the others are open-source software used in this study.*

First step: Images from a human CT scan were downloaded from Embodi3D (The Biomedical 3D Printing Community). On this site, the search terms were: "chest CT scan", "abdominal CT scan" and "full abdominal CT scan". The common formats for these scans were DICOM or NRRD.

Second step: If the format was NRRD, these scan files needed to be converted to DICOM. For this conversion, the software Slicer 4.9.1 [9] was used. The DICOM series tool was used in order to obtain all files in DICOM format.

Third step: Thus, from each DICOM file, it is possible to create a 3D model (STL file format) on the software InVesalius 3 through the create mesh tool. This tool offers the possibility of selecting parts of the CT scan by selecting shades of grey. And after the selection and mesh creation, it is possible to export the model as .STL file.

Fourth step: Finally, open the .STL file on Blender 2.7.9 [10] and choose the desired modelling approach (Bissect, Knife, and Add-on Cell Fracture). Every tool was applied to the same model.

Results and Discussion

On the website Embodi3D, there are several bioimaging files currently available for download. Among them were CT image files with different resolution levels. So, the final conversion from these bioimaging files to STL files (Figure 1) resulted in models with different accuracies and internal architectural details (Figure 2). In addition, the software 3D Slicer was used only for conversion and showed itself as a useful and fast tool for this end when compared to some online tools, which mostly resulted in errors that made conversion impossible. There were common errors where files were too big for the online tool and could not be uploaded, and when we did upload them, the converted files were corrupted when downloaded. Although the software InVesalius is very accurate when creating bone models, when it comes to soft tissue models, it shows some limitations. To generate STL files of soft tissue, it is necessary to manually select the band that includes the shades of grey related to the target organ. To ensure that the band is correctly assigned, it is necessary to review both the front and back of the images.

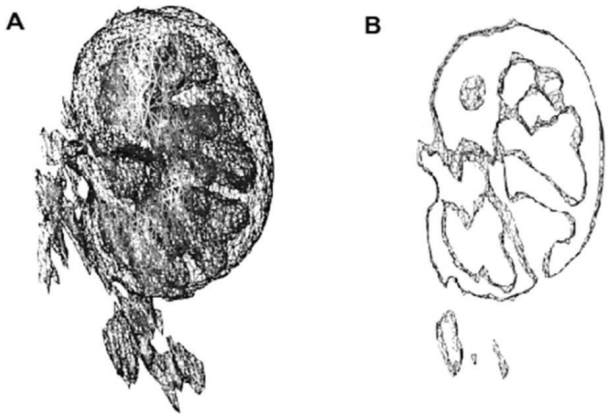

Figure 2) *Kidney 3D model created from a CT scan using the software InVesalius and rendered on Blender. A) Kidney wireframe visualized on Blender. B) Slice of the Kidney where is possible to see some internal structure.*

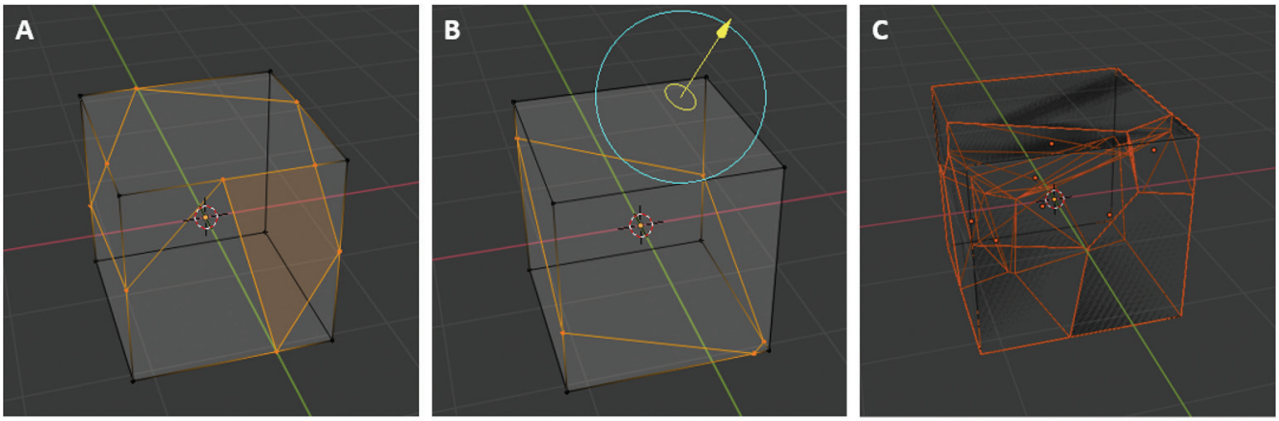

Figure 3) *Presentative examples of different tools used on Blender in order to perform the modelling on the generated STL files. A) Knife tool. B) Bissect tool. C) Cell fracture tool.*

Blender is a suitable tool for 3D structure modelling, as it is already widely used in 3D modelling of movies and game animation [11]; medical modelling [12,13]; and even in the biology research field with protein modelling [14]. To evaluate this hypothesis, three different tools available in Blender were explored to create a consistent organ model compatible with the final purpose of 3D bioprinting. Exploring the Blender Knife tool is akin to using a scalpel to dissect a real organ bit by bit, layer by layer (Figure 3a). Depending on the original model's resolution, there may be varying levels of detail in the organ's internal architecture, making it more challenging to use this tool for cutting. The second approach evaluated was the Blender Bisect tool, which allows cutting through the entire organ in a manner similar to using a scalpel for a single precise motion (Figure 3b). Therefore, with the Bissect tool, it is possible to cut the entire pathway through the resolution of the CAD model. Finally, the third approach chosen was the Blender Cell Fracture Toll, which allows the user to randomly break the model into several smaller pieces (Figure 3c). By applying this tool to the small-sized models generated by current bioprinters, the purpose is to designate this novel strategy as computerized (digital) fracture, a technique comparable to cryofracture. Similar to how cryofracture is commonly used in scanning electronic microscopy studies in order to create smaller pieces of biological tissues, this digital fracturing process also generates smaller pieces, but in CAD models.

On the Blender Cell Fracture tool, there are several possible configurations to create different patterns of small or big pieces (Figure 4). This tool is guided by the geometric construct following Voronoi diagrams. Decades ago, people making use of computational geometry had an increasing interest in this type of geometric construct [15]. According to Aurenhammer, this interest emerges for many reasons, from the fact that it happens in nature to its surprising mathematical properties and even its use in solving unrelated computational problems [15]. Therefore, this novel suggested approach for 3D model generation in the bioprinting field can be explored. Agreeing, Figure 5 shows what happens when this tool is applied to a simple cube model.

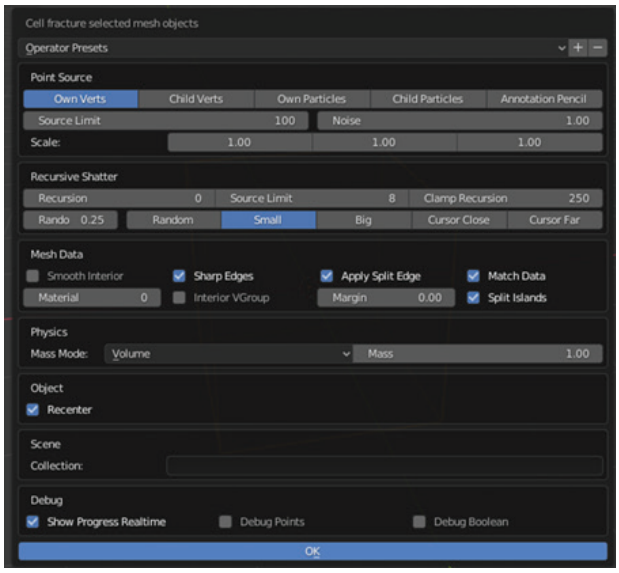

Figure 4) *Cell fracture configurations applied to the created organs models in order to achieve satisfactory sizes pieces for bioprinting processes.*

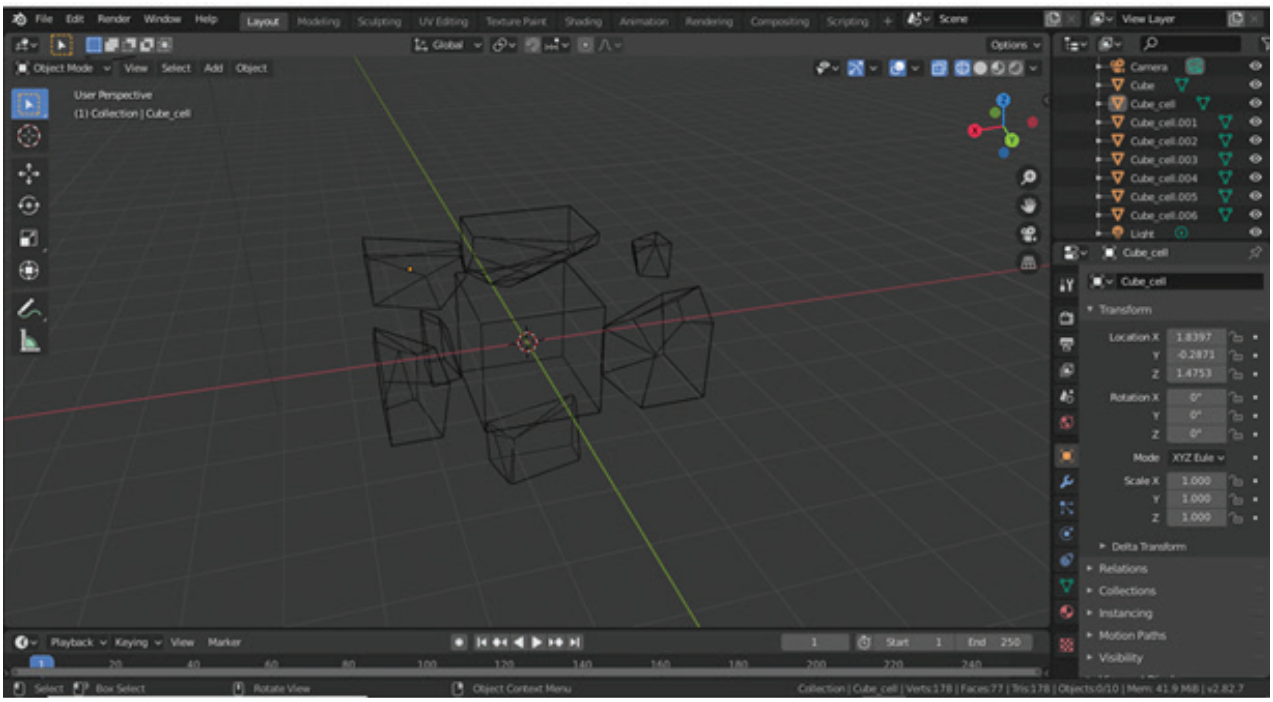

Figure 5) *Cell fracture tool applied on a cube, generating 8 random pieces with different size and shapes.*

Conclusion

Given the findings of this study, it is possible to propose a workflow based on the use of free and open-source software for CT/MRI conversion on 3D CAD models and a new concept in biomodelling when it aims to generate organ models compatible with current bioprinters.

Acknowledgement

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