ORIGINAL PAPER

Integration of Three-dimensional Technologies in Orthopedics: A Tool for Preoperative Planning of Tibial Plateau Fractures

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ABSTRACT

Background: There is a growing scientific interest in the use of three-dimensional (3D) technologies in orthopedic surgery. Digitalization makes research in orthopedics more accurate and quantitative. Scientific literature describes an overview of current 3D technologies applications in orthopedics, without any emphasis on integrating available technologies as a clinical workflow. **Objective:** To develop a clinical workflow integrating 3D technologies for patient-specific applications in orthopedics validated in practice by employment of a free 3D software solution with the aim of minimizing the intervention. **Method:** By exploring the applications of 3D technologies in orthopedic surgery, we have created a clinical workflow integrating 3D technologies for patient-specific applications in orthopedics. It is validated in practice for preoperative planning of a 49-year-old male patient who had a tibial plateau fracture of Schatzker type VI in his right leg. The software solution we have used is Democratiz3D, from Embodi3d platform, which allows patient-specific modeling and surgical planning. **Results:** By using the proposed methodology we obtained the model of the tibial plateau fracture Schatzker type VI, as a "solid" representation in stl type files, which represents a numerically defined geometry of the bones fragments. It helps surgeons in planning the surgical approach. The time from the beginning to the end of the analysis was 193 min, which is 15% lower than times reported in similar studies. **Conclusion:** The planning potential of the 3D solution is a valuable instrument for surgeons in exploring the nature of tibial plateau fractures and the formulation of a suitable surgical plan for surface alignment, design and screw fixation guides, strength calculations of bone fragments, and printing surgical objects.

Keywords: orthopedic surgery, tibial fracture, workflow, three-dimensional printing.

1. 1. INTRODUCTION

Over the very recent past there has been a growing trend for publications related to three-dimensional (3D) printing applied in orthopedic surgery (1) and connected fields like cartilage repair (2). 3D printing technology is used by orthopedic surgeons with great success for whole body interventions (3). Digitalization makes research in orthopedics more accurate and quantitative, promotes a depth of orthopedics, and assists in better summarizing and analysis of data (4). It allows to simulate a wide variety of tissue and organ dynamics, which is predicted to become valuable and versatile clinical tools (5).

The research in mechanics of cartilage contact layers supports diagnosis and treatment planning specific to the patient (6). Computational mechanics and constitutive modeling has been considerably advanced, but many challenges still exist in 3D joint simulations (7). There are some reservations about the usefulness of patient-specific orthopedic implants, and it is necessary to demonstrate the clinical efficacy of this customized technology in future clinical trials (8).

The widespread use of current 3D technology in hospitals is currently limited by the high costs and the time duration required to produce patient-customized devices (9). At the same time, the additive manufacturing industry will have to deal in the future with tougher medical regulations and with the adoption of integrated quality control procedures for patient-specific implants (10).

Scientific literature (11, 12) describes an overview for the 3D technologies and their current applications in orthopedics, without any emphasis on the integration of available technologies in a clinical workflow.

In particular, the reconstruction of the tibial plateau fractures can be supported by 3D technologies, with the aim of minimizing the intervention (13), as visual and printed models are capable to provide both tactile feedback and tangible depth information about anatomic and pathologic states (14, 15), to obtain optimal fixation results with screws (16, 17), to reduce the surgical time, the blood loss and the radiation exposure (18), to improve the mechanical alignment in total knee replacement (19, 20, 21), to support a patient-specific implant that fits perfectly and has unlimited geometric mobility (22).

Orthopedic surgery planning can be supported by various virtual 3D reconstruction and segmentation software, like VoXim© (23), or implemented as an OsiriX plugin (24). But this topic requires further study, for the identification of software solutions which make the duration of the process more efficient (25).

This paper is written to help the orthopedic surgeons and the medical engineers to adopt the workflow of 3D technologies in orthopedic for patient-specific applications and to develop further clinical applications.

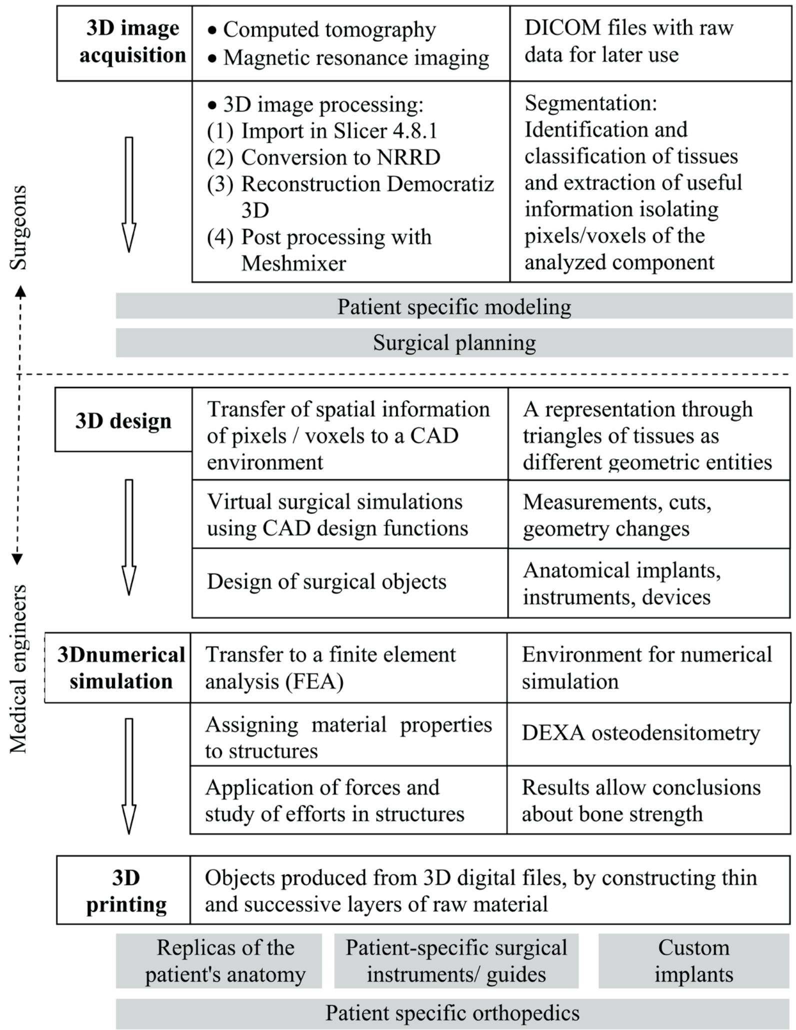

Figure 1. Clinical workflow integrating 3D technologies for patient-specific applications in orthopedics.

2. AIM

The purpose of this study is twofold: the first is to develop a clinical workflow integrating 3D technologies for patient-specific applications in orthopedics and the second is to validate it for preoperative planning of a tibial plateau fracture by employment of a free 3D software solution with the aim of minimizing the extent of the intervention.

3. METHOD

By exploring the applications of 3D technologies in orthopedic surgery, we have created a clinical workflow for the patient-specific applications in orthopedics which integrates 3D technologies (Figure 1), in the following sequence:

· 3D imaging involves the use of various available techniques, including the computed tomography and the magnetic resonance imaging which can provide raw data for the later use in 3D processing. The software solution we have employed is Democratiz3D, from Embodi3d platform (26) which allows patient-specific modeling and subsequent surgical planning. The data is converted to the Nearly Raw Raster Data (NRRD) format which allows the correction of surfaces and the removal of unnecessary components, after which the data is transferred to Computer Aided Design (CAD) format.

· 3D design allows virtual surgical simulations with the help of CAD design functions through the measurements or cutting paths, adjusting geometries or even for the processing of implants, surgical instruments, and medical devices adapted to the patient's anatomy.

· 3D numerical simulation using the Finite Element Analysis environment (FEA), assigns material properties to different structures, allows the application of desired forces and tracking the variation of stresses.

· 3D printing consists of building replicas of the patient's anatomy, the manufacture of the surgical instruments or custom implants. Typically, high complexity models can be fabricated in a few hours. 3D printing systems can use several types of materials, textures or colors and several well-known manufacturing techniques, such as: stereolithography, lamination, condensation deposition and selective laser sintering. Along

Figure 2. Schatzker fracture type VI, right leg, male, 49 years : a) DICOM image; b) RadiAnt image.

with these, there are new technologies in the development phase, such as the electron beam melting. Each of the shown techniques can be employed for segmental bone defects (27), production of anatomical models, implants, surgical guides, or other various clinical applications. Even if 3D printing appears to be the "second industrial revolution" especially for orthopedic trauma surgery (28), the technology is not still utilized at its full potential in the field of orthopedics and traumatology (29, 30).

Our research includes a particular study on a 49-year-old male patient who had a tibial plateau fracture in his right leg. The patient was sent to the orthopedics department, based on the initial clinical examination, diagnosis and imaging examination performed in the emergency department. Tibia scans were performed with an OPTIMA 580W CT. The fracture was classified according to the Schatzker classification as a type VI fracture. Figure 2 shows: a) extracts from DICOM files and b) analysis of DICOM files with RadiAnt DICOM Viewer software, of the patient's fracture included in the study.

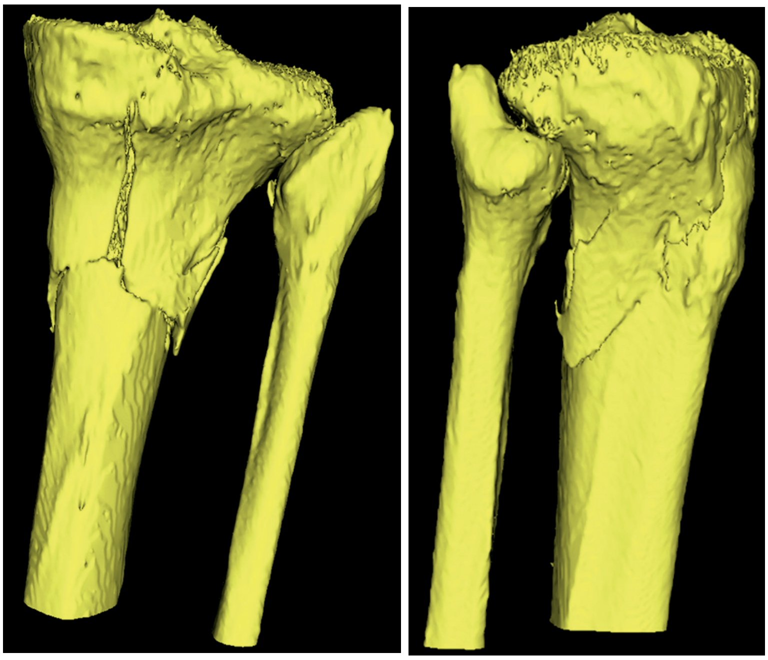

Figure 3. 3D segmentation and reconstruction of the tibial plateau fracture Schatzker type VI: a) posterior view; b) lateral view.a

4. RESULTS

The first and most important step of the study was to obtain accurate data from collected images in the standard format DICOM (Digital Imaging and Communications in Medicine), which is currently provided by conventional medical scanners. 3D image processing with the support of Democratiz 3D platform allowed obtaining a model of the tibial plateau fracture Schatzker type VI, that is a "solid" representation in stl type files (Figure 3). This means that the surface geometry of the analyzed bones fragments from fracture is known. It allows further mathematical processing, such as the best matching

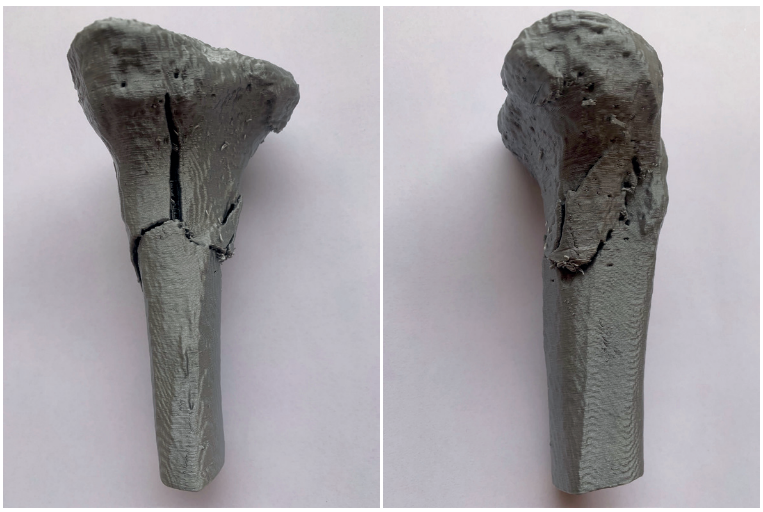

Figure 4. 3D printed model of the tibial plateau fracture Schatzker type VI: a) posterior view; b) lateral view.

of fragments with the support bone by using various mathematical algorithms.

Also, the 3D capabilities of the program allow the user to manipulate and see the location of the fracture from any plane, without subjecting the patient to awkward manipulation while taking radiographic images. The model can then be printed and 3D replicas of the fracture can be obtained (Figure 4), which allow an even more detailed analysis.

The use of the acquired 3D images and printed replica of the tibial plateau fractures helps the surgeon in planning the surgical approach as follows: a) it allows a better identification of the independent fracture fragments (by segmenting the fracture fragments into color-coded groups); b) to better understand the nature of the fracture and to identify the difficult reductions of the fragments; c) the careful reconstruction of the articular line; d) reducing the risk of post-traumatic osteoarthritis; e) to perform numerical simulations and study the bone strength; f) to print replicas of the patient's anatomy / surgical instruments / guides / custom implants; g) to compare with the postoperative results.

The time required to perform the entire check in the case of the aforementioned clinical trial was 193 minutes, which means that in the case of complex surfaces/fractures, the processing is difficult and time consuming.

5. DISCUSSION

The clinical workflow integrating 3D technologies for patient-specific applications in orthopedics developed in this research is a synthetic document supporting strategies for the customized surgical treatments, such as: preoperative planning, surgical simulation, patient-specific instrumentation, implants, prosthetics, orthoses. This study is focused on the identification of software solutions and testing them in virtual segmentation and 3D reconstruction modeling for the preoperative planning of the tibial plateau fractures.

The Democratiz3D-based like approach (26) employed in the study has the following characteristics: it allows easy use and a hassle-free learning curve for the preprocessing part; uses cloud processing resources; an intuitive modification of the parameters for the reconstruction; free scheme access for standard models; it requires a larger number of applications to obtain a final 3D reconstruction model and therefore it implicitly requires knowledge of operating multiple tools; testing the comparative reconstruction with several parameters requires the resumption from the beginning of the whole process from loading of raw data.

The analysis of the results shows that the time required for preoperative analysis requires more than 3 hours of planning. The time required for the reconstruction and analysis of 3D segmentation may be a discouraging factor for its current use, as this time period may not be available in most clinical settings.

The investigated case of the tibial plateau fracture modeling allowed the validation of the software solution for segmentation and 3D reconstruction. There are some reservations about the length of the trial and the following randomized studies. It should be determined whether the clinical outcome is worth the time.

Running the software used in the current study required relatively long time frames, and a suggestion for the future is to identify newer versions of this software which should reduce the time required for planning, while increasing segmentation and cleaning processing facilities of the images.

The results are consistent with other studies in the literature reported by Suero et al (23), which used the VoXim1 planning software and indicated an average time of 227 minutes required for the planning of type C fractures, which is higher by approximately 15% in comparison with our result.

However, the amount of new information obtained in less complicated fractures may not be worth the time invested in planning preoperative 3D reconstruction.

From a financial perspective, customizing surgical treatment in 3D reconstruction of tibial plateau fractures can be costly. For these reasons, the results of the treatments should be compared when using 3D technology in conjunction with the preoperative planning through conventional procedures. The obvious advantages of this new technology can compensate for the possible high costs of the intervention (31).

Another requirement for surgeons is to acquire new technologies in order to support the improvement of surgical procedures implementation.

Limitations of the current study may occur mainly because the integration of 3D technologies for orthopedic modeling was tested for the phase of patient-specific modeling and the particular situation of a tibial plateau fracture. There are many other situations in clinical practice that can be explored.

6. CONCLUSION

The systematization of the 3D technology integration approach opens new research perspectives towards the construction of guides which allow the elimination of any sources of error towards an easy reduction in the most complicated tibial plateau fractures, which in this way will enhance the optimization of patient results and minimize surgery complications.

The planning potential of the software solution used in this study is a valuable instrument for surgeons in exploring the nature of tibial plateau fractures and formulation of a suitable surgical plan for:

- Surface alignment–the coordinates of the points on the fracture surfaces are described mathematically and allows preoperative simulation of the desired alignment;
- Design and 3D printing of screw fixation guides for tibial fracture fragments;
- Strength calculations of bone fragments fixed by screws;
- Establishing the optimal direction of the percussive screws for fixing the bone fragments by preoperative simulation.

Applying such patient-specific guidance tools can make surgery more accurate, cost-effective, and possibly easier in complex cases.

It can be concluded that virtual modeling with the help of computer by creating 3D visualizations of the anatomy and the physical production of the anatomical replicas identical to the real organs is the revolution of the preoperative planning for many orthopedic procedures, offering many advantages for the personalized therapy.

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