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O3DC: The Curiosity in Orthopaedics

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Abstract

To explore Mars, NASA sent a robot ''Curiosity'' which has many goals including Martian climate, geology, and the preparation for future human exploration. NASA has successfully overcome many challenges in terms of the complexity of the technology, Mars conditions and space problems. The mission of Curiosity has a powerful take-home message for the orthopaedic community: the design of a realistic training simulator is possible, which requires time, resources, and great effort. In this article, we detail orthopaedic 3D collection (O3DC). This paradigm was the result of discussion of the challenge in orthopaedic simulations discussed by many scientists.

Keywords: Orthopaedic simulation; Training; Fracture; Medical imaging

O3DC: Strategies

The great challenge of the orthopaedic innovation is to develop a transition strategy in a large scale, in order to transport the advanced achievements in the technology framework and the pilot projects for the benefit in research. Mediouni et al. [1] mentioned the trends and challenges in orthopaedic simulation. For that purpose, we need a universal common language that facilitates international exchanges. Orthopaedic 3D Collection (O3DC) is a platform that facilitates the design of the training simulator. The architecture of the platform, which has three principal aims is illustrated in figure 1:

- A 3D database of all surgical instruments (section 2).
- A good comprehension of biology can help to simulate the different levels of bone (section3).
- Using a 3D simulation, we can redefine a new classification of fractures (section 4).

Based on these three aims, the surgeons can evaluate the performance of the simulation, in which we are able to make a difference between expert and novice, otherwise between the experimented and inexperienced orthopaedist. O3DC is a multidisciplinary project that needs many researchers in different fields (orthopaedic, biology, mathematics, physics and computer science). Today, to ensure achievement of O3DC, we need a translational researcher [2] to identify new research discoveries in the biological field and clinical problems. He must ensure coordination between researchers in a transparent, organized and structured way.

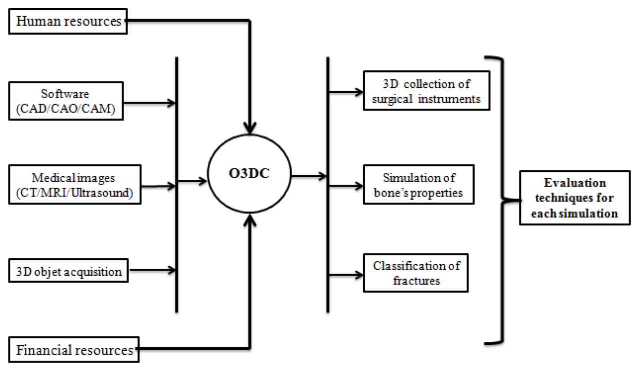

Figure 1: Architecture of O3DC.

3D Collection of Surgical Tools

Among the challenges to perform a simulator is the unavailability of 3D surgical instruments. In the literature, there are several 3D databases for industry such as Aim @ Shape [3], The Stanford 3D Scanning Repository [4], and 3D Warehouse [5]. Today, to achieve an efficient orthopaedic simulator, we need a specific database for surgical instruments which can be accessible online. 3D objects can be performed by a technology of acquisition such as a Kinect camera [6] and a 3D scanner or 3D modelling software [7]. The visual quality plays an important role in the efficiency of the simulation. The different stages of pre-processing are described by Mediouni [8] (Figure 2).

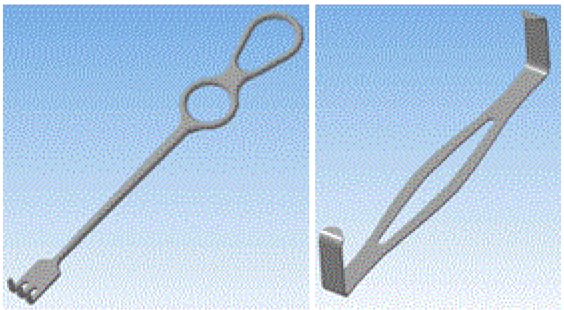

Figure 2: 3D Orthopaedic instruments have been designed in Russian Ilizarov Scientific Center for Restorative Traumatology and Orthopaedics.

Simulation of Bone's Proprieties

The bone has a homogeneous and complex material structure at many length scales. In order to understand mechanical properties, we must distinguish the different levels of hierarchical structure of the bone. Figure 3 shows four levels which are: (1) macrostructure, (2) microstructure, (3) sub-microstructure, (4) nanostructure. The simulation of mechanical properties needs a model that explains the mechanism of interaction between different layers to improve surgeons' knowledge in materials and structural level. At macrostructure, the properties depend on the nature of the bone (cortical and cancellous). For example, the structural properties are important to determine the global stress analyses. At microstructure, osteoporosis is the subject of active research. The osteons properties were determined for various stress modes: tension [9], compression [10], shear [11] and flexion [12]. To complete the microstructural analysis of bone tissue, the evaluation of mechanical properties of cortical bone seems necessary, particularly as the number of studies on the human cortical bone is relatively low. At sub-microstructure, the mechanical property is a major element in understanding bone anisotropy. On the scale of the nanostructure, the bone tissue can be considered as a composite material constituted of an organic matrix in which are inserted minerals. According to Fratzl et al. [13], hydroxyapatite crystals grow essentially in the intermolecular spaces of the collagen fibrils. The largest dimension of the crystals is aligned along the axis of the collagen fibrils. The shape, location and quantity of mineral extrafibrillaire remain unknown and subject to controversy despite the presence of crystals on the surface of the fibrils.

Using medical imaging becomes an important tool to simulate the bone architecture. Odgaard [15] discusses the usefulness of three-dimensional imaging to quantify trabecular architecture (Figure 4), which helps surgeons for studying the mechanical proprieties of cancellous bone, we need a compressive test. We can distinguish two major problems which are: (1) the absence of the standard model that can describe completely the mechanical proprieties, (2) the results provided are not of good quality for different reasons: temperature effects [16], storage [17], and viscoelasticity [18]. Parkinson et al. [19] have mentioned many features that we can distinguish from a 3D representation of cancellous bone: bone volume, density, trabecular thickness, and trabecular separation.

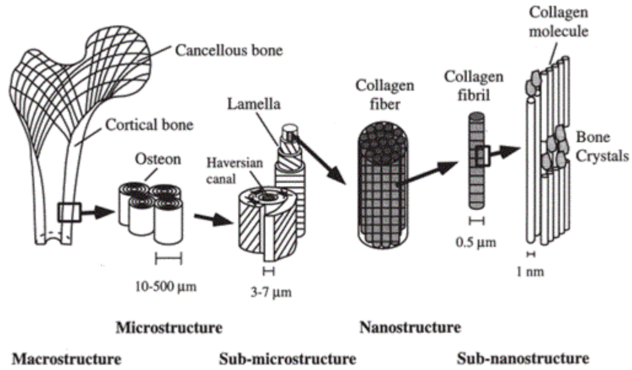

Figure 3: Hierarchical structural organization of bone [14].

In addition, other features, such as degree of anisotropy, structural model index and connectivity density, can be calculated. With all the layers and the complexity of the characteristics, which include different details, the simulation of a bone remains a major challenge in orthopaedics.

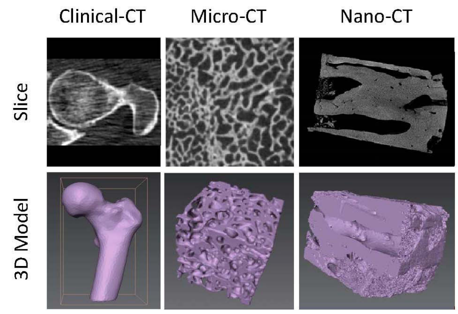

Figure 4: Micro-and nano-CT [20]

Classification of Fractures

There are over 6.2 million bone fractures in the U.S. each year [21]. The recognition and classification of fractures become a necessity for an effective treatment. The Judet and Letournel system [22], which is a traditional system based on the X-ray, does not answer to complex fractures. Today, with the 3D simulations, radiologists must reclassify fractures. Matsushigue [23] explains 3D reconstruction images (CT) to improve the classification of the proximal extremity of the humerus. Using the alphanumeric system, the Arbeitsgemeinschaft für Osteosynthesefragen Association grouped the humerus fractures into 27 groups (Figure 5). 3D (CT) provides many advantages to identify the fracture and help surgeons make a decision for the treatment. Many studies of 3D imaging of acetabular fractures have been cited in the literature [24-29]. This fracture is tricky because of the complex spatial anatomy.

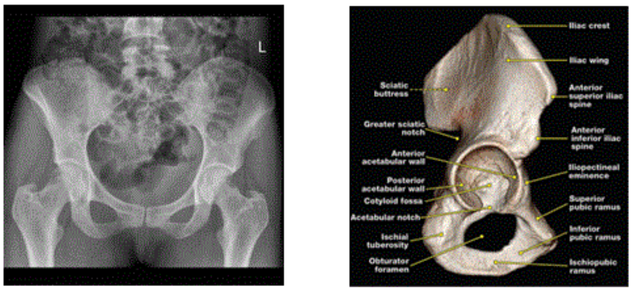

Figure 5: Normal annotated x-ray [30], Lateral surface-rendered 3D CT image shows the acetabulum [31]

Evaluation of Simulation

In literature, there are some evaluation models of surgical simulations [32-36]. Unfortunately, there is no standard model to validate the assessment followed by orthopeadic community. Among the O3DC missions, is to provide an evaluation model for the gestures performed by surgeons to reduce each fracture (simple and complex). Generally, the validation is performed in the presence of a surgeon who discusses the effect of the simulation with his students [37]. Today, we can speak about the development of metric methods that can allow simulators to be autonomous. Sewell et al. [38] discuss the method of automated feedback in the context of a mastoidectomy simulator. The question arises: Is it possible to apply this model in orthopaedics?

Conclusion

This project is a call for orthopeadists to provide more research in 3D medical images to align with the complexity of fractures and diseases in the bone. The sentence mentioned by Dr. Pedowitz [39] can summarize our article:

"I think the changes we are going to see in resident education will be quite profound over the next decade or so."

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