Design of an Innovative Simulation Device Dedicated to the Learning of Biomechanics Applied to Orthodontics

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***Abstract*—Health simulation devices offer the possibility of improving practitioners' knowledge, skills, and behaviors. The current biomechanics simulation tools in the orthodontics field are technically and pedagogically limited. The need to develop an innovative simulation device in this area is commonly shared by orthodontics students. This article aims at identifying (i) the learning objectives, (ii) the technical specifications, and (iii) the constraints to design a innovative device.**

Keywords*—*Simulation; device; orthodontics; biomechanics.

I. INTRODUCTION

Previous studies on the training expectations of orthodontics practitioners revealed (i) the limitations of the current biomechanics simulation tools, (ii) their need to develop an innovative simulation device in this field [7]. After a presentation of the context (Section I), section II describes the data gathered to identify the priority fields of application for developing a biomechanics simulation tool. Section III and IV outlines the educational goals and elements of further studies to be conducted on the subject.

A. Biomechanics applied to orthodontics

Whatever the appliance used, orthodontic movements respond to biomechanical notions. To understand the dental displacements, it is necessary to represent the equivalence of the forces system at the center of resistance (CR) of the tooth [4]. The CR is a theoretical point on the tooth. When a force is applied to it, the tooth is displaced in translation (i.e., without causing rotation). The CR is on the long axis of tooth. Location of the CR depends on the alveolar bone height, the root length and the number of roots (Figure 1). In orthodontics, forces cannot pass through the CR (i.e., forces are applied on the orthodontic bracket, bonded on the crown). Thus, the distance between the CR and the point of application of force varies.

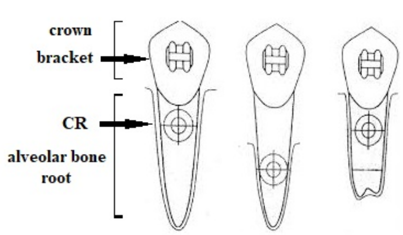

Figure 1. Different locations of a canine CR,depending on the root length and the alveolar bone height.

So, there is a moment (rotational movement) in addition to translation (linear movement). The force system will depend on (i) the clinical situation, (ii) the chosen appliance, and technique (e.g., segmented, continued). Learning biomechanics can be challenging as the concepts are difficult to grasp in a static context [6].

B. Interest of an innovative biomechanics' simulation device for orthodontists

Simulations devices in the health field aim at securing patients care. They are based on the concepts of (i) "never the first time on a patient", and also (ii) "mastering gestures before treating patients". Simulation allows training in semi-real conditions which makes the learner more involved than during lectures (i.e., with a top-down teacher-learner scheme). A meta-analysis conducted in 2011 highlighted the possibility of improving practitioners' knowledge, skills, and behaviors through health simulation [3]. Moreover, animations could help practitioners to understand complex dynamic processes in a simple and realistic way [6].

C. Current and future simulation device

In the orthodontics field, clinical skills are currently taught through demonstrations on patients (by trial and error). The use of technology is currently limited and poorly designed [5]. Orthodontics novices learn biomechanics (i.e., theoretical knowledge and practical skills) using an occlusor, made of metal teeth embedded in a sticky wax (Figure 2). Sticky wax is a mixture that dissolves in water at the temperature of 60–65°C (i.e., by heating, it allows the dental movements). However, this system (i) does not reproduce faithfully the bone remodeling, and anchorage (e.g., mini screw), (ii) does not make it possible to visualize the root displacements, nor the successive stages from the initial to the final clinical situation.

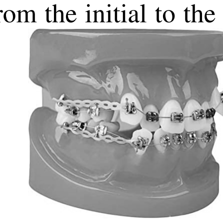

Figure 2. Orthodontic occlusor

Technological advances (e.g., imagery/ 3D radiography and computer image processing) enable to obtain specific anatomical models of a patient, meshable and usable by finite element software [1]. Thanks to the monitoring, it's possible to correlate the finite element analysis with the clinically

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observed movements. However, the finite element approach still has some limitations:

1-Long-term tooth movement could not be predicted from the initial force system.

2-Tooth movement depends on (i) the characteristics of the patient (e.g., drugs, dental morphology, alveolar bone, masticatory forces, tongue), (ii) the force system (e.g., continuous or segmented archwire, alloy, friction)

In addition, computational modelling remains complex and time-consuming [8]. In the literature, studies conducted on finite elements applied to orthodontics aimed to improve :

1- the treatment planning optimization and individualization (i.e., choice of the archwire) [8].

2- the anticipation of iatrogenic damages (i.e., caused by orthodontic treatments)

3- the accuracy of the forecasts of the treatment results

Thus, the implementation of an optimal orthodontic force system modelling that meets all these requirements is challenging. New studies are underway to improve digital modelling precision [8]. Some studies have already combined experimentation (i.e., to quantify forces and moments, using test beds), and digital modelling [8]. Furthermore,the scan of different stages of orthodontic treatments could improve the management of similar clinical situations (i.e. machine learning is already used for treatment planning by aligners). Along with these, we believe that from a learning and training perspective, the current technologies are sufficient to design new simulation-based learning activities in biomechanics. These should allow orthodontics students to (i) improve their manual skills, (ii) anticipate the effects of the appliances, (iii) be able to choose the most suitable device(s) according to the initial clinical situation.

II. PRIORITY FIELDS FOR A FUTURE SIMULATION DEVICE

From the literature, we have carried out the following classification. It summarizes sub dimensions of bio mechanics applied to orthodontics:

1-Physiology of tooth movement (Physiological periodontal and bone response related to orthodontic strength...)

2-Tooth movement (the three orders, theory, indications)

3-Force systems (Moment/force, equilibrium...)

4-Anchorage (Anchorage and its control, mini-implants...)

5-Fixed devices (treatment mechanics, vectors, forces, moments applied, arches deformations and constraints)

6-Biomaterials related to tooth movement (biomaterials and production of orthodontic forces...)

7-Removable Device (interception and prevention...)

8-Factors affecting tooth movement (patient factor, growth)

9-Iatrogenic effect of tooth movement

We therefore interviewed the Reims Hospital students (N=6) to identify the priority fields for developing simulation tools, among this classification. They have considered the following sections as priorities : force system (9 points), anchorage (7 points), and fixed appliance (6 points). Points were assigned to each response based on their rank of importance. This survey should be extended to a wider pool of students in orthodontics, in order to ensure that this order suits them.

III. EDUCATIONAL GOALS

According to the identified priority fields and the current occlusor objectives, an effective simulation device should allow students to:

- scan a patient's malocclusion and virtually position the brackets on the teeth crown.

- improve manual skills: (i) scan archwires bent by students, and integrate them in the simulator to evaluate the dental movements they generate (i.e., but that could be technically challenging), or (2) to compare the ideal archwire with the scan of the archwire prepared by the student.

- visualize the dental movements according to the clinical initial situation and the chosen fixed appliance. The dental displacements should be split into successive steps (i.e., from the initial to final situation) by showing and quantify the forces and the moments on each tooth (i.e., including roots).

IV. FURTHER THOUGHTS

The superiority of a dynamic over a static presentation for learners' understanding and learning is debated in the literature. However, the animations and/or interactive medium could improve the understanding of the relationships between force application and tooth movement. Animations are not sufficient, simulations' aims are to foster learning through immersion, reflection, feedback, and practice minus the risks inherent in a real-life experience (i.e., to safer patient care) [2], [3], [5].

To assess the effectiveness of an innovative simulation device (in terms of understanding, gesture mastering and memorization), further studies on this subject should combine (i) an ergonomic approach, through a user-centered design to identify the practitioners' needs and characteristics, (ii) an instructional engineering/educational psychology approach to design efficient learning activities.

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