Learning Biomechanics Applied to Orthodontics: Interest and Characteristics of an Innovative Simulation Device

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Abstract—**Healthcare simulation devices offer the opportunity to improve practitioners' knowledge, skills and behaviors. The biomechanical simulation tools currently used in orthodontics are technically and pedagogically limited. The simulation tool (through dynamic visualization) could enable students to better understand the biomechanical principles of tooth movement, both in theoretical courses and clinical practice. The need to develop an innovative simulation device in this field is indeed shared by orthodontics students. The aim of this article is to identify (i) the interest in developing a innovative digital simulation device in this field, (ii) the learning objectives, (iii) the technical aspects, (iv) the constraints for designing an innovative device.**

Keywords—Training; Simulation device; Orthodontics; Biomechanics

I. INTRODUCTION

Previous studies on orthodontic students' training expectations revealed (i) the limitations of current biomechanical simulation tools, (ii) the need to develop an innovative simulation device in this field [1][2]. Section I provides background on (i) biomechanical concepts applied to orthodontics (ii) current simulation devices in the field of orthodontics and (iii) their pedagogical results. Section II describes the data collected to identify priority application areas for the development of a biomechanical simulation tool. Sections III to V describe the pedagogical objectives, as well as elements of further studies that should be discussed and carried out on the subject.

A. Context

1) Biomechanics applied to orthodontics: Whatever the appliance used, orthodontic movements are based on biomechanical concepts. To understand tooth movement, it is necessary to represent the equivalence of the system of forces at the tooth's center of resistance (CR) [3]. 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 a version of the tooth crown). The CR is located on the long axis of the tooth. The location of the CR depends on the height of the alveolar bone, the length of the root and the number of roots (Figure 1). In orthodontics, forces cannot pass directly through the CR (i.e., forces are applied to the orthodontic bracket, bonded to the crown). The distance between the CR and the orthodontic bracket is therefore variable.

Tooth translation involves moving the tooth along the occlusal plane without altering the orientation of the major axis. As shown in Figure 1, this movement is impossible to achieve using a simple linear force on the bracket. As shown in Figure 2, the application of a simple linear force on the orthodontic bracket creates an uncontrolled rotational movement of the crown and tooth root around the tooth's center of rotation (close to the CR).

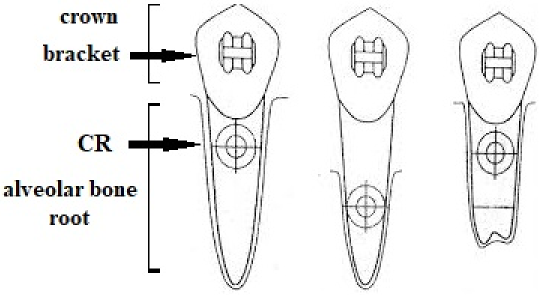

Figure 1. The different locations of a canine CR depend on the length of the root and the height of the alveolar bone. The distance between the orthodontic bracket and the CR modifies the forces system and tooth movement

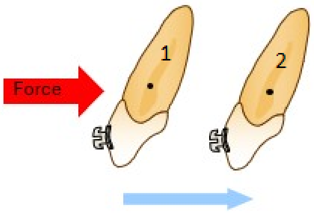

Figure 2. A simple force applied on the center of resistance implied a movement of translation (parallel to the long axis of the tooth, from position 1 to position 2)

So, as Figure 3 shows, there is a rotational and/or version movement (i.e., moment) in addition to the linear movement (i.e., called the translation movement). The force system depends on (i) the initial clinical situation, (ii) the chosen chosen appliance and (iii) the orthodontic technique (e.g., segmented or continuous). Learning biomechanics can be challenging, as the concepts are hard to grasp in a static context [4].

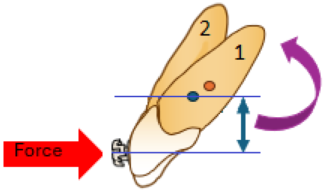

Figure 3. A simple force applied on the tooth orthodontic bracket (far from the center of resistance) implied a non-controlled tooth movement, from position 1 to position 2

Figure 4. Orthodontic occlusor

2) Current simulation devices for orthodontists: Several simulation devices dedicated to orthodontic practitioners have recently been developed in the following formats: 3D, immersive learning, haptics, augmented reality, serious games. The simulation devices identified have been implemented in various fields such as education, covering diagnosis and treatment planning, orthodontic bracket positioning, orthodontic procedures, facial marking, orthodontic aligners and cephalometric tracing. Most studies dealing with biomechanical simulation focus on the development process without evaluating the results [5]. Most simulation devices were designed specifically to facilitate orthodontic treatment planning and procedures. They incorporate biomechanical concepts to anticipate tooth movements according to the chosen archwires (size, section and materials). However, these systems seem to be limited. For example, it is not possible to simulate anchorage, such as miniscrews or extra-oral forces, or elastomeric chain (even though these devices are part of current daily practice). Orthodontic anchorage is defined as a means of resisting the movement of one or more teeth, using different techniques or tools. Anchorage is indeed an important consideration in treatment planning, as unplanned or unwanted tooth movement can have disastrous consequences. Furthermore, the purpose of these simulation devices is not pedagogical: they have been developed for private orthodontic practitioners (i.e., not for orthodontic students).

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 [6]. Orthodontics novices currently learn biomechanics (i.e., theoretical knowledge and practical skills) with static schemes or using an occlusor, made of metal teeth embedded in a sticky wax, as Figure 4 illustrates. Sticky wax is a mixture that dissolves in water at the temperature of 60–65°C (i.e., by heating, it allows dental movements). However, this system (i) does not faithfully reproduce bone remodeling and anchorage (e.g., mini screw), (ii) does not make it possible to visualize root displacements, nor the successive stages from the initial to the final clinical situation.

The aim of this paper is to list the characteristics of an “ideal” simulation device for learning orthodontic biomechanics and therefore choosing the mechanics best suited to their patients’ malocclusion.

II. DIGITAL DEVICES DEDICATED TO LEARNING ORTHODONTICS

A. *Pedagogical outcomes*

Orthodontics is a discipline that requires the acquisition of theoretical knowledge in various fields (such as head and neck anatomy, maxillary growth and development, physiology and biomechanics of tooth movement) and a number of manual skills (e.g., archwire bending, bracket positioning, dental stripping). The practice of orthodontics requires knowledge and skills in a variety of areas. Several experiments have demonstrated the effectiveness of digital simulations in terms of knowledge acquisition and improved reaction levels. These results are consistent with the impact of digital simulations, including virtual and augmented reality, in other areas of dental education [7]. For example, 92 percent of students understand dental anatomy better using virtual learning than using a traditional written document [8]. Virtual learning improves X-ray detection of bone lesions compared with traditional courses [9]. More generally, virtual learning could enhance theoretical knowledge.

Concerning the improvement of medical gestures, gesture recognition based on wearable sensors has developed in the health and dental sector in recent years [10]. Dexterity improvement is difficult to assess, and there is a lack of data in this area [11]. No orthodontic digital tool dedicated to learning biomechanics and/or mastering movements has been found in the literature.

The collected data confirmed that digital and simulation tools could be efficient in terms of learning. This simulation device could therefore help orthodontic students gain expertise (i.e., to enhance theoretical knowledge, and practical skills).

B. *Interest of an innovative biomechanics’ simulation device*

Simulation devices in the health field aim at securing patient 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 [12]. Appropriate substitutes for clinical practice should be considered to ensure that students treat patients without making errors damaging to their orthodontic treatment. Moreover, animations could help practitioners understand complex dynamic processes in a simple and realistic way [4]. According to a collective of orthodontic experts, simulation tool and video could be very helpful to enhance students' understanding of bio mechanical principles of tooth movement (such as forces control and the moment/force ratio). The visualization of tooth movement (depending on the chosen appliance) could achieve a clear understanding of how tooth's crown and roots move inside the bone. This could also allow students to predict the treatment outcomes (based on the treatment plan and the chosen system of force).

The future learning device should enhance both biomechanical theoretical knowledge and manual skills. Thus enabling orthodontic students to acquire clinical expertise.

C. Technological aspects

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 [13]. Thanks to the monitoring, it is possible to correlate finite element analyses with clinically observed movements. However, the finite element approach still has some limitations:

1- Long-term tooth movement cannot 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 [14]. In the literature, studies conducted on finite elements applied to orthodontics aimed at improving:

1- The treatment planning optimization and individualization (e.g., choice of the archwire in accordance with the clinical situation)

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 model that meets all these requirements is challenging. New studies are underway to improve digital modelling precision. Some studies have already combined experimentation (i.e., to quantify forces and moments, using test beds) and digital modelling [14]. 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). This approach is similar to what has been assumed in medical practice: records of the best clinical decisions made by thousands of professionals should be leveraged to improve patient care and practitioners training [15]. 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 orthodontic students to (i) improve their manual skills, (ii) anticipate the side effects of the appliances, (iii) be able to choose the most suitable device(s) according to the initial patient clinical situation.

III. PRIORITY FIELDS FOR A FUTURE SIMULATION DEVICE

The mastery of biomechanics applied to orthodontics requires both theoretical knowledge and manual skills in various areas, such as archwire bending or bracket positioning. From the literature, we have carried out the following classification concerning the theoretical knowledge necessary to understand biomechanics. It summarizes the sub-dimensions of biomechanics 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.

IV. EDUCATIONAL GOALS

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

- scan a patient's malocclusion and virtually position the brackets on the tooth crown.
- improve their manual skills: (i) scan archwires bent by students on a real-life occlusor, and integrate them in the simulator to evaluate and visualize the dental movements they generate, (ii) compare the ideal archwire with the one bended 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 the final situation) by showing and quantify the forces and the moments on each tooth (i.e., including the visualization of dental root movement)
- evaluate the probability with which the movement will occur, according to the therapeutic choice and the treatment objectives (such as control of the mandibular incisor axis, finishing with a dental Angle's class I, preparation for maxillofacial surgery)

- send alert messages according to the chosen therapeutic and treatment objectives (e.g., insufficient anchoring to obtain the attempted dental movement)

- integrate a wide choice of devices and anchorages (e.g., fixed, segmented techniques, miniscrew, headgear)

- compare different therapeutic options (e.g., with and without dental extractions, maxillofacial surgery)

- compare the treatment outcomes by superimposing the initial and final clinical situations (i.e., initial and final 3D digital patients dental arches).

V. 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 enhance the understanding of the effects that an orthodontic appliance has on the tooth movement. Animations are not sufficient, simulations' aims at fostering learning through immersion, reflection, feedback and practice minus the risks inherent to a real-life experience (i.e., to safer patient care) [16][6][12].

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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