Development of a Computer Based System for Simulation of Orthodontic Treatments

Maria Andréia Formico Rodrigues  
Universidade de Fortaleza - UNIFOR  
Centro de Ciências Tecnológicas  
mafr@unifor.br

Milton Escóssia Barbosa Neto  
Universidade de Fortaleza - UNIFOR  
Centro de Ciências Tecnológicas  
milton@unifor.br

Isabel Maria Magalhães Pinto Ribeiro  
Universidade de Fortaleza - UNIFOR  
Centro de Ciências da Saúde  
izabelribeiro@secrel.com.br

Abstract

Volumetric visualization and functional simulation of human body have been frequently utilized for medical consultation and treatment. In this paper, we aim to simulate the changes in shape that the dental arcades and teeth perform during orthodontic treatment. In particular, we have a special interest in the behaviour of the main anatomical factors leading to complex teeth movement. A central issue in building such a computer-based simulation is to find a way to represent this behaviour so that the relationship between different mouth measurements, orthodontic appliances, and small translations and rotations the tooth executes over time can be simulated and analysed. This includes developing an understanding of how the 3D dental arcade behaves in response to the appliance used, when it is subjected to a variety of loading conditions.

Key-words: Computer System, Simulation, Teeth Movement, Orthodontics.

1. Introduction

An interactive computer-based training tool for using in Orthodontics is aimed at students and experienced professionals who need to perform orthodontic medical treatment. The orthodontic treatment is commonly used to obtain the proper position of the teeth in dental arch, thus giving the correct occlusion with the best functional and aesthetic features [1]. The ideal teeth position in dental arch is geometrically defined by the Angle’s line of occlusion and by the 6 keys to normal occlusion by Andrews [2]. The treatment consists in applying forces to the tooth crown by means of elastic deformation of metallic wires. The mechanical
actions generate a stress state into the periodontal ligament and hence in the alveolar bone determining the tooth movement, and consequently, the bone remodelling. Usually, treatment planning and the choice of a proper appliance model are based exclusively on clinician expertise. To circumvent unexpectedly situations that eventually occur during the treatment, most orthodontists work on a trial and error basis, estimating an “ideal” loading condition that can lead to a precise and aimed tooth movement. According to experts in Orthodontics, it is very common to initially predict a specific tooth movement (caused by applying a continuous force during a certain period of time) that in practice does not occur. The tooth does not move at all or does not move enough as a response to the applied loading. The main disadvantage of the present method is that, besides taking time, the orthodontist does not have an interactive and dynamic simulation tool that allows to visualize the temporal evolution of the treatment and a series of simulation trials to determine the most suitable strategies and appliance models to overcome possible dental arcade clinical problems. Consequently, many unpleasant side-effects of applying inappropriate orthodontic treatments have been reported, including damage and extraction of tooth without need. This can cause serious problems to the functional and aesthetic features of the teeth in dental arch of the patient.

We aim to simulate the changes in position that the dental arch and teeth undergo during the mechanical actions performed. In particular, we have a special interest in finding a way to represent this behaviour so that the relationship between different mouth measurements, teeth movements, and appliances can be analysed. This includes investigating to which present computer aided orthodontic systems can contribute to the characterization of the behaviour of the teeth movement and what are their main limitations, as well as developing an understanding of how the 3D dental arch and teeth behave when they are subjected to a variety of loading conditions. We expect our prototype to be a useful environment for training orthodontists, residents and students giving experience in both simulation and actual dental images. It is also one of the generic purposes of this research to assist in the Orthodontics field by constructing an image morphing tool that allows the clinician to simulate and visualize the temporal evolution of the treatment on dental arcade models of patient over time. As the warping process proceeds, the original image (before the planned treatment) will be gradually distorted and will fade out, while the final image (after the planned treatment) will start out toward the original and will fade in.

2. Previous Computer Aided Orthodontic Systems

Although no attempt was made to be comprehensive, we have carried out a considerable number of studies of the current commercial systems available in the market that permit a certain planning of orthodontic treatments (42 systems were investigated). The great majority of these systems do not act as valid clinical tools for treatment simulation, nor integrate several functionalities in one single tool. We have classified the commercial systems into 3 main groups: clinical management systems, 2D tools for image analysis, and 2D and 3D systems for simulation of orthodontic treatments.

The most common systems available are the clinical management softwares [12,13,14,15,16]. In particular, there are just a few examples of systems developed in Brazil [15,16]. Basically these systems aim at financial management and following up of orthodontic treatments. In some cases, they include a cephalometric analysis module as one of its software components. None of these commercial systems allows to get a 3D model of the arcade of the patient and effects a real simulation of tooth movement over time as an interactive computer-based tool. By contrast, we aim to have these basic functionalities available in our system. Moreover, we plan to integrate these main functionalities into one single computer-based tool. Motivated by the aim of reducing the human error (except for errors of landmark identification) on doing cephalometric analysis, as well as performing the
analysis in less time than in normal registration (in situations where it is only necessary to identify the radiological points with the click of a mouse on a computer monitor, for example) many researchers have been modelling a great number of interesting and useful cephalometric analysis software [17,18,19,20,21,22]. These systems have traditionally been accomplished by using a superimposition of the X-Ray and photograph into one manipulable image which shows both hard and soft tissue. Cephalometric landmarks are then identified and anatomical measurements are compared to established norms and displayed for easy reference. Using clinically accurate hard tissue movement, the patient's profile can be morphed to show the results of the proposed treatment. The relevance and advantage of these systems are demonstrated by the significantly increase of patient acceptance of proposed treatment plans after performing the cephalometric analysis using the software. On the evidence of their own literature, the use of this group of systems has proved to be an invaluable approach to support dental treatment planning, and thus, has to be included in our computer prototype due its significant role in orthodontics. Some investigators concentrated on the development of 2D and 3D computer-based orthodontic treatment tools [23,24,25,26,27]. In these systems, data can be obtained by cephalometric measurements of the patient. In particular, the 2D models use elementary parameters in which full validation is necessary, and consequently, may be an excessive oversimplification of the orthodontic problem being considered because they do not include volumetric dental arch and appliance shapes. Just a few of these works are most closely related to ours in that they represent the teeth movement by a functional model composed by geometric restrictions of displacements in three-dimensions. However, they have some disadvantages because they are expensive commercial tools and usually do not offer free code access to permit extensions. On the evidence of their own literature, there is a considerable number of commercial systems proposed for orthodontic practices. In no case, they advise on better type of treatment to apply to the patient as a tool that integrates different functionalities into one single public domain software with free code access. Further, the great majority of these commercial systems are developed abroad. Few examples developed in Brazil are essentially focused on clinical managements [15,16] and 2D cephalometric analysis [16,17]. The goal of this work is to build a computer-based system that provides an integrated and public domain software for simulation of orthodontic treatments. The prototype can be a valuable training tool for examining and interpreting large amount of clinical data.

3. The Computer Based Orthodontic System

The proposed system consists of 3 basic modules: cephalometric analysis, volumetric mesh generator of dental arch and appliance models, and the orthodontic treatment simulator (as shown in Fig. 1). In particular, we propose an architecture model of the behaviour of the teeth as it is mechanically displaced by the appliances and loading conditions applied to them. A simple low resolution model of a face and skull was used to allow a better understanding of the movements and provides more realism to the simulator and particularly do not influence the simulation results. The cephalometric analysis module is responsible for the X-Ray segmentations and the calculation of the ideal teeth position in dental arch based on the mouth measurements of a patient. Together with the actual dental cast, these measurements are used to build the 3D dental arch. The orthodontic treatment simulator provides an interface for planning and simulation using different appliance models, as well as for helping to identify the best possible orthodontic techniques for the treatment of a patient based on its anatomy. The teeth movements are basically represented by translations and rotations. Dynamics are also used to give a more realistic behaviour based on the loading applied. We will investigate two subjects performing an analysis using our prototype. To represent the 3D dental model of an individual subject, the anatomy was generated by using the 3D dental cast, X-Ray images, and cranometric points (see Fig. 1). As part of the therapy planned, the
Figure 1: The main architecture components of the orthodontic system, including the lateral radiography of the first subject investigated. A set of anatomical structures and points (cranio- and eometric points) are identified and used as a template for the application of cephalometric analysis methods.
initial measurements of dental displacements will be realized during 12 clinical check-ups of
the patient over 1 year. The moved and the reference teeth on the cast model were marked for
identification, and particularly, we have used the molar and premolar teeth as reference teeth.
The magnitude of translation and rotation will be calculated relative to the basis of these
reference points before starting treatment. In particular, it was designed for this subject the
fixed appliance model with brackets that already embeds established torsion values in its
designed structure. The advantage is that the resultant torsion can be applied on an individual
tooth or in a group of teeth at once. An extraction of the first premolars on both sides of the
mandible and maxilla was planned for both subjects. A dental extraction results in bone
remodelling, a process that takes time (21 days approximately). After the extraction process,
the teeth will be aligned and levelled using rounded dental archs. The simulator module will
perform all the dynamics, including the distalization of the canines and incisors into the
extraction space in direction of the molars, according to the model of dental arch appliance
chosen (teeth displacement generally takes 8 months). As a fine stage, the teeth will be
aligned again and a few of quite small torsions may be still applied to them. The morphing
tool will illustrate the whole process.

4. Discussion

Our aim is to provide a computer model to help orthodontists to predict and deal with
orthodontic problems, as well as suggesting possible treatments. We have approached this by
defining a simple prototype. It is aimed to combine and improve the main ideas of some
existing commercial models which are difficult to test and validate because they are not open
source and free available tools. We believe that computer orthodontic models may be used as
training tools for those seeking a better understanding of the geometric and dynamic factors
involved in the control strategies of orthodontic treatments as well as to investigate the
accuracy of the results and whether a specific planned treatment can be detrimental to the
patient in any circumstance. Finally, as far as the software components of the interactive
computer model proposed are concerned, there is a great potential for modelling current
treatment plans and possible new solutions to dental problems that can lead to expanded
knowledge in orthodontics.

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