Journal of Education and Praxis Research. Volume 1, Issue 1, (2015) 1-7
http://www.cayley-nielson.com/jepr

3D Patient Education System Designed for Communication in Orthodontic Treatment

Honda Uchida
School of Creative Science and Engineering, Waseda University, Tokorozawa, Saitama 359-1192, Japan
E-mail: *hondauchida@hotmail.com*

Abstract

The complete treatment of orthodontics often takes several years. In order to increase the satisfaction degree and reduce the gap problem, orthodontists and patients should have a sufficient communication between each other and reach the consensus prior the treatment. The paper simulates the treatment processes through tuning the 3D virtual model of oral and maxillofacial, including face, oral and teeth, to educate the patients the processes of the clinical paradigms. In addition, this research is the first one, as we know until now, to provide the functions that the orthodontist can arbitrarily operate the 3D virtual model to demonstrate the process of orthodontic treatment. The orthodontist can represent the corresponding 3D virtual model for a patient in a short time according to his/her status, showing the moving of the teeth and answer the possible questions from the patient about the treatment processes with the 3D model. Clearly, the system is an effective education and communication vehicle between the patient and orthodontist.

Keywords: 3D model, patient education, communication vehicle, CAI.

1. Introduction

Since the quality of life improves a lot, people have been aware of the aesthetic in daily life and even their appearance. Orthodontic is one of the medical treatments that can improve dental esthetics [1], beautify the facial appearance to build confidence and develop good relationship,

treatment, which takes a long-term duration to cure and often costs a lot of money. In addition, the results of treatment sometimes cannot fulfill the expectation of the patient. Ackerman and Proffit mentioned that a good communication between the orthodontist and the patient is the key to effective treatment plans [2]. Sinha, Nanda and McNeil designed an empirical study and confirmed that a good orthodontist-patient relationship has significant effects on the success of orthodontic treatment [3]. In other divisions, patient eduation has been proved as critical factors in the treatment of many diseases that are related to patients' quality of life, satisfaction, self-confidence and self-management in medical behavior [3]. Therefore, to increase the quality of treatment and reduce the gap between the expectation of patient and the limitation of orthodontic treatment, a comprehensive education to patient is very important.

Since the complicated materials in education emerges, the oral expression by the teacher is not enough any more [4] [5]. In tradition, orthodontics prepare many real devices like tooth model and casts to show the process of the orthodontic treatment [6]. Since of the advancement of computer technology, many researches incorporate the computer simulation as a education and communication vehicle in orthodontics [7], [8]. The computer-based education has introduced to leverage the loading of the teachers [9] [10].

Nowadays, three dimensional (3D) graphic with advanced computer technology can generate 3D virtual dental model as real devices and objects, reducing the cost and manual error and even save the space of store. Thus, the simulation with 3D technology is prevailing in orthodontics simulation system. For example, Alca˜niz and Montserrat proposed a 3D system that can model orthodontic treatment plan, including movement and rotation of teeth [11]. This system has an acquisition system that derives a 3D model of a patient by 3D scaning upon the cast of the patient. Through complex mathematic formula, orthodontists can perform the operations like tooth movement and rotation upon the 3D model through changing the parameters provided by the system. In addition, the system adopted viscoplastic behavior law for the alveolar bone to simulate teeth displacements during orthodontic treatments. However, the 3D acquisition of the system was lack of a high resolution image in that time; in addition, the system did not equip with the professional knowledge such as diagnosis and symptoms in orthodontics.

Recently, with the finer 3D scanning upon the cast, Li introduced a 3D simulation system, called OSD (Orthodontic Simulation and Diagnosis) [12], which generates high resolution 3D model in multiple views since the resolution of scanner increases a lot. Rodrigues and Silva designed and implemented an interactive simulation system for training and treatment planning in orthodontics [13]. Their system can simulates the tuning of maxilla and mandible, and teeth movement of patient from pre-treatment to post-treatment under different treatment options. Orthodontist needs to scans the dental cast of a patient and then generates a 3D virtual model with skull, dental and brace. Then orthodontist and patient can evaluate treatment results in advance about whether the treatment achieved the anticipation or not. Through 3D simulation, the above systems provide a better communication tunnel between orthodontist and patient and improve the satisfaction of patients. However, these systems are too complicated and costly in preparing the simulation model that patients may wait for days to get the simulation results. In addition, their systems do not record the treatment process from the diagnosis, pre-treatment, in-treatment, and post-treatment, and the treatment experiences cannot be accumulated as a knowledge base or a paradigm for later education or reference. To provide the education functions, an orthodontics computer-assisted instruction system developed by Yeh [10] was proposed. This CAI system collects many past orthodontic cases and constructs a 3D animation video for each case. The system can immediately find the most similar past paradigm cases through the technique of case-based reasoning. When an orthodontist needs to explain the treatment to patients, the system can provide the most similar case shown in a 3D animation, performing a good communication vehicle between patients and orthodontist prior to the treatment. However, the treatment is based on past orthodontic cases; it did not consider the status of current patients; in addition, the system did not provide teeth arrangement simulation for patients. As we knew until now, there's no orthodontics simulation system with the capability of just-in-time 3D simulation of processes from pre-treatment to post-treatment and all potential operations like movement, rotation, extraction on each tooth under the consideration of current patient's status.

In this paper, we developed a just-in-time 3D simulation system for orthodontics. It provides just-in-time simulation functions like tooth movement, rotation, extraction, arrangement and face morpher from pre-treatment to post-treatment, all of which are operated in an intuitive 3D way like picking, dragging and rotating the 3D model by mouse. Via the intuitive 3D operations, the orthodontist can real-time arrange the 3D model according to the status of the patient. Then the system can automatically attach the arch-wire and brackets into the teeth in the mandible and maxilla. The system automatically or the orthodontist manually arrange or set this 3D model that should become at each treatment stage. Then the system can automatically move teeth and morph face of the initial 3D model of the patient to the resultant 3D model, through one 3D model in one stage moving to another one 3D model in the next stage. The arch-wire attached to the teeth will be also moved accordingly. The 3D simulation and the related photos of the treatment of the current patient can be selected as a new paradigm for teaching materials for later patients or interns. Orthodontist or dentist can use this system to present dynamical process of orthodontic treatment to patients. As a result, patients can more understand the treatment procedure and then increase the satisfaction.

2. Model establishment

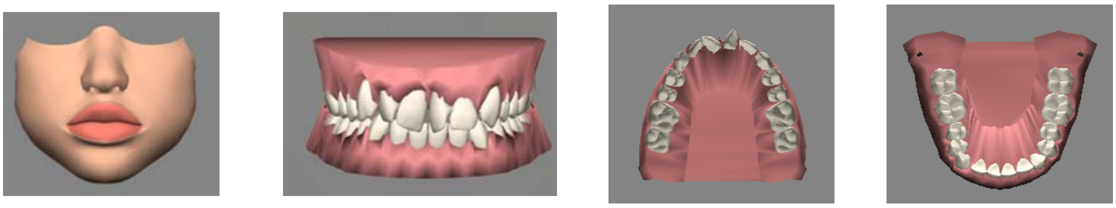
In order to present the simulation results, we use the basic 3D models consisted of skull, mandible, maxilla, teeth, masseters, soft tissues, etc. These 3D models can be edited and synthesized to generate new 3D models for simulation by 3ds max tool, which is one of the most popular 3D modeling, animation, and rendering software. To generate the new model, we first removed the unnecessary basic 3D models, such as skull and masseters, which the system does not use in the simulation of orthodontic treatment. In the next step, we separate the 3D teeth models, which are connected with each other initially, into a set of 32 disconnected tooth models such that these 32 models can be operated individually in the system. For simulating the process of orthodontics of a patient, we also create 3D arch-wire and brackets models that can be attached to the basic 3D models. The original soft tissues are also separated into lower half-face, and gums of teeth. Through the edit poly modifier operating upon the lower half-face of 3D model, we create 10 different morph results in advance for the appearance of the face, i.e. mouth open, lips open, plumping/sinking of cheek, plumping/sinking of cheek in left side, plumping/sinking of cheek in right side, rising/descending of mouth, protruding/recessing of mouth, protruding/recessing of upper lip, protruding/recessing of lower lip, and protruding/recessing of jaw.

To provide finer rendered results, under the consideration about the light reflection, antialiasing and so on, we can attach complex shaders to the materials and textures of these basic 3D models. However, the more complex shaders need more powerful graphic hardware for rendering. For increasing the rendering speed and performance, we can simplify the properties of materials, such as diffuse color, which is the color reflected from an 3D model while it is illuminated by daylight or artificial light, and bump map, which builds visual effect in a way that the lighter (whiter) areas of the map appear to be raised, while the darker (blacker) areas appear to be sank. In the final step, we attach the smooth modifier to these 3D models to sleek the edges of polygon in the models. Fig. 1 shows two 3D models of the rendered results after the above editing upon basic 3D models.

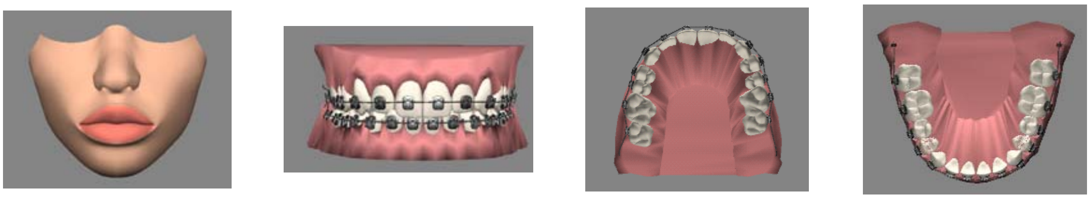
With the proposed system, dentists can communicate with patients in two ways. The first way is to demonstrate the process of treatment for the current patient. Fig. 2 show the 3D models after simulation in face and teeth arrangement for the pre-treatment and post-treatment. The dentist can arrange the face and teeth arrangement according to the patient status in the pre- treatment. The system can then copy these 3D models in the pre-treatment as the prototype that the dentist can arrange this prototype into the models in the post-treatment under the consideration of the malocclusal status for each teeth and the limitation (i.e., constrains from gum or periodontal disease, tooth decay, and extractions number) of orthodontics. After the dentist choses the anchor pair of teeth for hanging the arch-wire to pull the frontal teeth, the system can then automatically and step-by-step arrange the teeth positions from the start point to the end point. Some more in-treatments can be inserted into the simulation evolution to fit the progress of treatment in each phase of the treatment. Dentists and orthodontists can display the full process from the pre-treatment, through several in-treatment statuses, to the status of post-treatment. During the display, the dentist can educate and explain related procedures to the patients. The second way is to display the past paradigm cases. Dentists and orthodontists first diagnose the symptoms of the current patient and select the most similar past paradigm cases. Since the simulation of the paradigm cases are prepared beforehand, no time to wait for the patients and dentists to watch the canonical treatments for the paradigm case. Clearly, the more paradigm cases the system has, the higher similarity the simulation has.

(a) (b)

Fig. 1. The rendered results after the editing steps upon basic 3D models (a) lower half-face; (b) oral containing teeth, gums, arch-wire and brackets.



(a)



(b)

Fig. 2. Simulated 3D model. (a) the case in the pre-treatment; (b) the case in post-treatment.

3. Validation and verification

To show the effectiveness of the system, we performed two empirical studies which are qualitative interview with experienced orthodontists and the questionnaire to patients groups. The first one is to exam whether the system meets user requirements and achieves the desired goals. The second one is to evaluate and compare the education and communication capability of the system with the traditional communication way used by the dentists.

We first interviewed five orthodontists, all of whom have more than two years of practices. These five orthodontists consisted of 3 male and 2 female, denoted as A, B, C, D, and E. In order to access whether the simulation functions and displays of system meet the need in clinical practices, the main goal of the interview focuses on the satisfaction with the simulation functions provided by the proposed system against the traditional physician–patient communication way. The overall results of the interview are positive, as is summarized as follows.

All orthodontists agreed that through the system the communication with patients is clearer than the traditional communication way; all orthodontists believed that they can explain the orthodontics treatment vividly with the help of the system, especially the system can step-by-step express the evolution of treatment from pre-treatment, in-treatment(s), to post-treatment. All orthodontists also agreed that these simulation functions can increase the intention of patients to receive orthodontics treatment and can improve the quality of communication between orthodontists and patients. From the above results of the interviews, we can see that the system does provide vivid simulation functions to help and educate patients to understand the procedure of orthodontics treatment and can point out the potential limitation in advance before treatment. Clearly, the system is an effective communication tool between the dentists and patients, providing the more expressing capability to dentists and giving more confidence and satisfaction to patients.

In addition to validating the effectiveness of the system, this paper also evaluates the communication capability of the proposed system through questionnaire. The population group of subject is consisted of 36 patients, including 15 males and 21 females, whose individual age is from 12 to 27. The questionnaire consisted of eight statements focuses on four aspects, namely, convincing ability, communication quality, understood degree, and intention change rate. The first two aspects are evaluated from the view point of the instructor (i.e., the system) in the communication. The last two aspects are evaluated from the view point of the receiver (i.e., the patient) in the communication.

To show the effectiveness of the system in the above four aspects, we designed a set of empirical experiments consisted of two phases. In phase one, the dentists educatd and communicated with patients with the traditional way through the photos and casts of the past cases as well as the explanation to patients. That is, the dentist explained the notices (including the cost and duration for the treatment) in orthodontics treatment, the procedures of treatment, the result of similar past cases in the post-treatment, and the estimated result of the current patient.

After the communication in phase one, these patients are asked to fill the questionnaire to evaluate the effectiveness of the traditional communication way. The questionnaire adopted Likert's 5-scale scoring; that is, the patient replied each question by ticking the score from 1 to 5, meaning "strongly disagree" to "strongly agree". After that, the dentist immediately starts the phase two, that is, the dentist educate and communicate with these same 36 patients with the proposed system. The way is either through displaying with past paradigm cases or through just-in-time simulation of the current patient. If the symptoms of the current patient is similar to some past paradigm case in the system, the dentist immediately displays and communicates with the patient by the past paradigm case. But if the symptoms of current patient is dissimilar to the past paradigm cases or the system does not have enough past paradigm cases for the current case, the dentists or dental hygienist can take the photos for the current patient and then, according to these photos, arrange 3D models in the system to emulate the status of the current patient in the pre-treatment within about 10 minutes. They then arrange these 3D models into the estimated status of the post-treatment as well as the in-treatment status(es) according to their experience. Finally, they activate the system to automatically evolve the treatment step by step from pre-treatment, in-treatment to post-treatment. In the same time, dentists can display and communicate with the patient along with the evolution of treatment.

Through analyzing the two questionnaires in the above two phases, we get the scores of patients who evaluate the system with respect to the aspects of convincing ability, communication quality, understood degree, and intention change rate. Fig. 3 shows the average scores in the above four aspects. We can see that the communication capability with the additional help of the proposed system is greater than only the traditional communication capability in all the four aspects. In the aspects of convincing ability, the communication way through the proposed system obviously outperforms the traditional one. The reason is that some patients, especially the adolescent, are asked to receive the orthodontics treatment by their parents and elders, rather than by their own will. For such a kind of patients, they have some hesitation or even refuse to receive the treatment. After the 3D display of the proposed system, that emulates the appearance of the patients from the pre-treatment to the post-treatment, they know the treatment can really improve their appearance. From the vivid display, they are convinced or have higher incentive to receive the treatment. In the aspects of communication quality, although the communication time needs three more minutes in average for the additional communication way through the proposed system in phase two, the whole communication (i.e., phase one and phase two) let the patients conceive more details of the evolution in orthodontics treatment, which can compensate the extra communication time taken in phase two. We can see that the patients consider that the extra time to explain the treatment with the proposed system is acceptable and that the patients can more understand the process of the treatment through the communication way provided by the system. Thus, we concluded that these patients can receive high quality communication through the system.

In the aspects of understood degree, the traditional communication way inherently cannot

dynamically display the details of process in orthodontics treatment, such as the displacement of the teeth with/without the extraction of a tooth (or teeth), and the morphing of face. The dentist can only give an abstract explanation, lack of concrete images of the evolution of the treatment.

In the aspects of intention change rate, which the moist concerned about by the practical dentists, we can see that the intention rate of receiving orthodontics treatment if explained through the traditional way is lower than that if explained through the proposed system. The reason is guessed that same patients do not have the full confidence or hesitate to receive the treatment while facing the unclear and uncertain change of their teeth appearance. The proposed system can display the 3D models of the post-treatment of them resulting in the fact that intensive rate of receiving the treatment increases if explained with the proposed system.

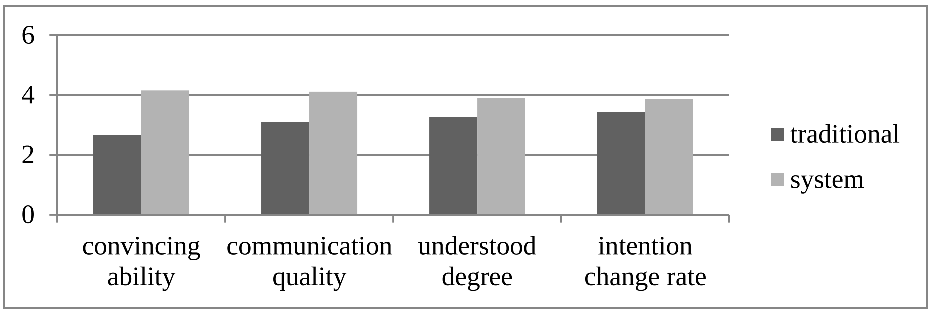


Fig. 3. Result of the four aspects in two phases.

4. Conclusion

This paper proposed a new framework of 3D simulation system for orthodontics. The system can simulate profile of face, arrangement of teeth, gums, arch-wire, and brackets to emulate the current status of a clinical patient, and simulate and display the procedure from malocclusal to normal occlusal or from pre-treatment, in-treatment(s) to post-treatment. Through these simulation functions, dentists can educate and communicate with patients vividly, and patients can more understand the process and results of treatment. In addition, through intuitive operation provided by the system, the system provides just-in-time simulation results. The result of system evaluation showed that this system receives positive recognition by dentists. Clearly, the system builds an effective tool in education and communication between dentists and patients and reduces the gap between the expectation of the patient and orthodontics limitation, and then increases the satisfaction of patients.

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