*Future Technologies Conference (FTC) 2017*
*29-30 November 2017| Vancouver, Canada*

# Evaluation of Soft Tissue Variations using a 3D Scanning System for Orthodontic Applications

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***Abstract*—There are different three-dimensional (3D) imaging systems which allow obtaining measurements from surface geometries. However, for medical applications, such methods need to be safe, with no harm or radiation. Therefore this paper proposes a methodology for obtaining facial surfaces in order to be compared over time for orthodontic applications. Specifically, it was employed a 3D laser scanner for facial geometry acquisition and a dedicated software for performing a rigid surface registration among three different times: (T1) before the treatment, (T2) 15 days after wearing the orthodontic appliance and (T3) three months after ending the treatment. It was observed a change in the face, especially in the region of the nostrils (1.47 mm) and maxilla (1.78 mm). The use of a 3D scanner for facial scanning is able to measure small slightly volumetric changes caused by wearing a palatal expander over time, producing significant facial changes, which will provide social and health impacts.**

***Keywords—Three-dimensional measurements; laser scanning system; facial geometry; orthodontic applications***

## I. Introduction

There are several clinical specialists that are using measurements from the body's patients, especially in order to improve health, to guide clinical procedures and to evaluate the respective volumetric changes. In terms of medical imaging, there are a variety of technological improvements, covering not only the inner images of the body (such as computer tomography, magnetic resonance, ultrasound), which cover detection of physiological and anatomical changes into the body [1]. On the other hand, there are the imaging systems responsible for obtaining changes at the external surface geometry, i.e. at the soft tissues. For example, the medical applications that have most impact of such technology are the plastic surgeries and orthodontic procedures [1], [2].

The systems being used for allowing such inspections are the three-dimensional scanning or digitizing systems, which includes from photogrammetric systems (based on photographs only) up to laser scanning systems. The 3D scanning systems are considered "gold standard" systems for obtaining 3D models, due to its increasing spatial resolution, being achieved recently. There are a vast number of commercial systems being employed for different applications. Some of them are achieving about even 0.1 mm for surface spatial resolution.

In order to illustrate some of these applications involving orthodontic purposes, the work by Ramieri et al. [3] presented changes in the soft tissue of adults, based on a palate distraction and surgical procedures. Therefore, the area of orthodontics represents a good site for applying and testing new technologies, enabling for the confirmation of results and also the expansion of new findings.

The applications in orthodontics are very broad, covering several treatments and deformities that could be enhanced based on 3D measurements. The approach that is being presented here is the narrow maxilla, which is a dentofacial deformity. The incidence of maxillary deficiency is estimated to be from 8 to 18% of patients referring to orthodontic treatments. In this scenario, the upper jaw is forward towards the lower jaw (mandible), at the transverse plane [4]. As consequences, the narrow maxilla causes the narrowing of the upper arch, usually accompanied by dental crowding, ogival shaped palate and cross bite. In addition, some effects are sucking habits, respiratory and phonetic problems [5]. The usual procedure for such jaw discrepancy is to perform an orthodontic treatment based on palatal disjunction, which will produce the separation of the palatine suture. Such treatment, using a proper orthodontic appliance, i.e. a palatal expander, is usually recommended at the children's early age, ranging from 8 up to 13 years-old [6], [7].

Research supported by CAPES and CNPq Foundations.

This research employs laser scanning technology, in which a laser beam is transmitted towards the object/volunteer and sensors record the surface based on the acquisition of the 3D coordinates of the several points which belong to the surface and are acquired. So, this process generates a point cloud which is then converted to a surface (usually and STL format). Based on this process is possible to record the Cartesian coordinates and it enable a representation of the 3D geometry under study, in this case the facial surface.

This paper evaluates the use of a 3D laser scanning system in order to obtain and analyze three-dimensional faces submitted to orthodontic treatments. So, this research provides means for guiding, evaluating and monitoring changes in soft tissues over time. This approach represents a significant methodology because it helps planning, to make measurements, comparisons and for inspecting volumetric changes that might occur due to a specific orthodontic appliance, in this case a palatal expander over time.

## II. Methodology

This paper presents evaluation and analysis within an eight-years-old patient, whom has good oral health and absence of previous orthodontic treatment. During the clinical examination, held by an orthodontist, it was verified the presence of narrow maxilla and lack of space in the upper jaw. Then the volunteer was conducted to orthodontic examinations, which include: extrabuccal facial photos (front, smiling and profile), plaster models, panoramic and lateral radiography. After this previous analysis, it was confirmed the presence of narrow maxilla, and it was appointed treatment with a palatal expander appliance, for opening of the maxillary suture.

### *A. Orthodontic Appliance*

Based on the clinical exams conducted within this volunteer, it was recommended the orthodontic appliance using a hyrax-type expander, in which there is a screw in the middle, as shown in Fig. 1. The purpose of the screw is to allow expansion of the central area towards both sides. This is called activation and it is performed during 15 days (by daily increments). These procedures were performed by the orthodontist responsible for the patient.

### *B. 3D Scanning System*

Depending of the technology employed, the three-dimensional scanning systems are classified in *Structured Light* and *Laser Scanning*. Specifically for this research, we had employed the Laser Scanning system, which is considered portable, versatile and with a reasonable resolution for this application. Additionally, this system is non-invasive and safe (based on a *Laser Class* II).

Fig. 1. Orthodontic appliance, hyrax-type expander, being worn by the patient.

In this study, for acquiring the facial geometry, we had employed a handyheld scanner, model REVscan (from Creaform Ametek [8] – Fig. 2). For the data collection, we have used the software VXelements, which is responsible for the three-dimensional acquisition combined with the system.

Mentioning some technical specifications, this scanner has a surface resolution ranging from 0.2 mm to 2 mm, its accuracy of 50 µm, and field of view about 30 cm. The acquisition is quick, providing about 18 millions of measurements/second. However, it provides a surface mesh (in STL format) without texture, i.e. no colors, since this system is not like the photogrammetric systems, which are based on photographs only.

For the scanning acquisition, it is used circular retro-reflexive targets, which are attached to the face (Fig. 2), allowing that the VXelements software [9] can recognize both points and face during the scanning process. With such targets the scanner can keep constant reference of the face.

Since the surface resolution acquisition can vary from 0.2 mm to 2 mm, this represents the distance among the acquired points forming the surface, which is responsible for changing the points cloud density (being denser or sparser, respectively). This parameter also impacts at the speed of the acquisition, for example with 0.2 mm it is slower than with 2 mm. Therefore, for this application, scanning children's face, we had tested and found out that a resolution of 1 mm would be fine for our purposes. So, for a complete face acquisition, within a skilled operator the average time acquisition is about 5 min.

So, the face scanning were performed in three different moments, according to the progression of the treatment: (T1) at the beginning of the treatment (before the activations); (T2) 15 days after ending the activations within the palatal expander; (T3) three months after ending the activations (but during all this period the patient was kept with the device in order to keeping the expansion). Within this acquisition approach, we manage to observe the changes along all this period, which represents a long term evaluation. The 3D scanning device was calibrated before each acquisition.

For the acquisition of the face, the following protocol was applied: 1) The patient remains lying on a dentist chair in dorsal view, with closed eyes, keeping neutral facial expression; 2) The retro-reflective targets were added on the face (especially placed maintaining triangulation for allowing better positioning of the scanner during acquisition). 3) Next the scanning process started, keeping the distance about 30 cm from the face to the scanner (which is the recommended range distance). 4) The obtained surfaces are aligned and registered based on a rigid registration. 5) Having all the surfaces (from the three proposed timings, T1, T2 and T3), the comparisons are performed in order to identify areas that are corresponding to more changes.

During the scanning, it was required from the volunteers to remain still, having as little changes in their facial expression as possible. Usually, we would wait for about 5 min for relaxing period before starting the scanning. At the end of the process, most of the kids would fall asleep and make this task easier. That is one of the reasons why we employed 1 mm resolution, since it would provide quicker scanning and helping to minimize possible movements.

Fig. 2. Handy held scanner, model REVScan (from Creaform).

## III. Results and Discussion

One of the reasons for orthodontic treatments is to reach facial harmony and to provide an ideal dental occlusion. Therefore, this represents a potential research area, which consists in analyzing and evaluating the effects of the facial soft tissue differences triggered by such orthodontic appliances. This paper investigates the facial differences (based on a 3D laser scanning technique) caused by wearing a palatal expander in a patient diagnosed with narrow maxilla.

The 3D models obtained were analyzed based on a three-dimensional rigid registration in order to evaluate the effects of such orthodontic treatment in the face of the patients. This analysis was performed at Geomagic software, from Creaform Ametek [10]. Since it was obtained the 3D facial geometries in three different moments, we compared by overlapping the results from T1 versus T2, and T1 versus T3. This registration provides measurements of the volumetric differences, which are displayed through a color scale to enable inspections. At the 3D surface models obtained, we have removed the superfluous surface data from the hair, ears, and the below-neck region, focusing in analyzing changes only at the face itself.

Fig. 3 shows the registration procedure, based on the selection of at least 3 common points at both meshes. This registration implies in the alignment of both surfaces at the same coordinate system. Initially, for the manual alignment, it were selected at least three common points. In this experiment the points were located at both corners of the eyes, and under the nose (middle line). The next phase corresponds to the global alignment to adjust any inconsistency. Fig. 3(a) and (b) show two facial meshes (corresponding to before and after 15 days of treatment, respectively). Fig. 3(c) shows both surfaces already overlapped (after the global alignment).

Fig. 4 represents volumetric differences between T1 (before wearing the appliance) and T2 (15 days after the treatment, i.e. after ending the activations).Through this analysis, it is observed a volumetric variation at the upper and lower jaw, which is also propagated towards the whole face.

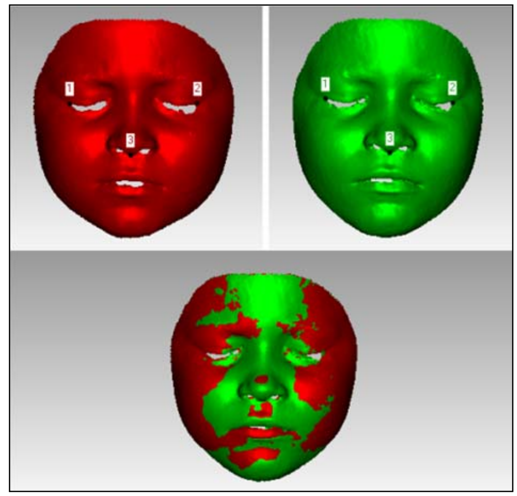

Fig. 3. Facial Surface meshes: (a) At T1 – Before the treatment; (b) At T2 – 15 days after the treatment; (c) Both surface already registered.

The comparison is performed between different 3D surface models obtained at these different time phases. The surfaces were aligned having as initial reference the model obtained at T1. Positives values represent that the images are in front of T1, while negative values consist in the images behind T1. We chose to represent the deviations obtained based on the color system. Green tone represents small deviations (around ± 0.25 mm deviation) from T1. Reddish tones represent positive values deviation, while the shades of blue denote the negative values deviation. The total range displacement was selected ranging from ± 3 mm.

For instance, mentioning specific regions, it is identified and quantified the following key points at the face:

- At the upper lips and nose region it was observed up to 1.47 mm.
- On the other hand, at the lower jaw (mandible), especially at the chin area, there was a retraction of 1.47 mm.
- At the tip of the nose there was a minor change, about 0.25 mm.
- The nose width (nostrils) was incremented from 0.86 reaching up to 1.17 mm.
- At the forehead, there are little changes (0.25 mm).

It is worth to mention that common effects of the palatal disjunction are represented by the forward and backward displacement of the maxilla/mandible, which also produces a down and backward rotation towards the maxilla [13]. With our results, we manage to quantify a backward offset of about 1.17 mm for this patient around the chin area (comparing T1 and T2). This is according to the literature as well [11].

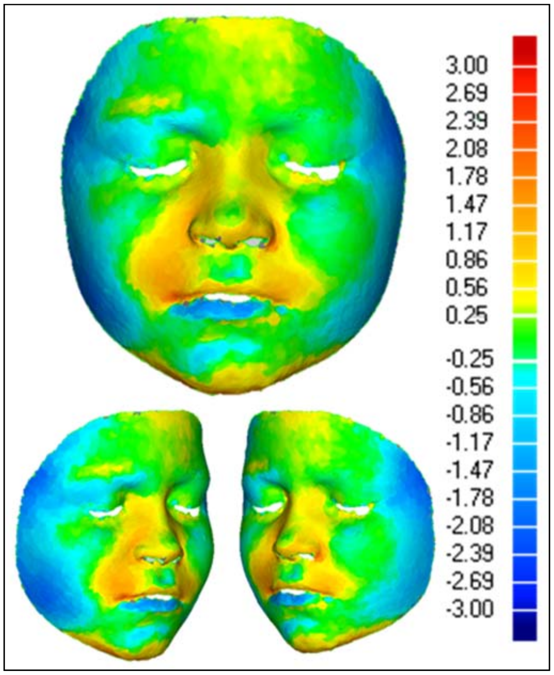


Fig. 4. Registration comparison between the 3D facial geometries from T1 versus T2 (15 days).

Another analysis representing the differences at long term is shown at Fig. 5, which is between T1 and T3 (after three months). The reason for choosing the timing of three months is due to the fact that after this period, the palatal expander is removed. Therefore, quantifying this registration, it is highlighted that in general terms it was not changed much. Although, there are slight changes which could be related to the normal child growing patterns during this period, it is identified similar patterns and quantified alike values as well, which would reach at the most ± 1.78 mm, being both increments and retractions at the overall volumetric changes.

The widening of the nasal cavity is also another skeletal characteristic observed in the literature [11], [15] and within our results. In this case, it was observed about 1.17 mm, but the pattern of such variations is much more representative than the quantitative variations. We also found out an effect on the tip of the nose, similar to the literature [11], which corresponds to a retraction and flattening of the tip of the nose. In our case, it is minimally observed about 0.25 mm (corresponding to the green area). The benefits reported from this lateral separation of the nasal cavity, include improving asthma, allergic rhinitis and sleep disordered breathing [16].

In terms of checking the effects of palatal disjunction, the literature mainly brings some studies presenting evaluation by three-dimensional jaw's reconstruction based on X-ray Computer Tomography imaging [5]. However, this approach requires the use of invasive radiation. Through this procedure it is possible to obtain up to 12 mm jaw enlargement, which returns aspects of normal craniofacial development [6]. Some side effects observed after the palatal disjunction are: the lower jaw offset, rotation down and toward the back of the jaw, inclination of the occlusal plan, and increasing the angle of the mandible axis [7].

Additionally, the literature also brings description about the upper lips extension [14] as one of the consequences after this orthodontic treatment. This characteristic was also observed in our research, especially seen at the corner of the mouth/lips (about 1.78 mm).

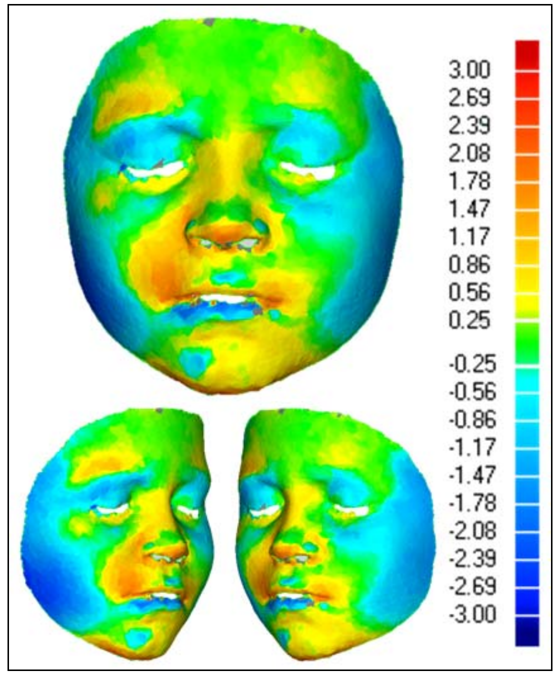


Fig. 5. Registration comparison between the 3D facial geometries from T1 versus T3 (three months later).

## IV. Conclusion and Future Directions

The 3D imaging systems allow obtaining 3D surface models, which provides the soft tissue inspections for a variety of medical specialties. Usually the orthodontics' interventions produce changes in the facial soft tissues.

Therefore, in this research we evaluated the variations caused by the use of an orthodontic appliance (which causes a palate expansion), using a 3D laser scanning system. Through the use of a palatal expander (hyrax-type), it was produced and observed slightly changes at the nose, upper lips and lower jaw regions.

During this research we acquired data from ten patients, although this paper presents results obtained within one volunteer, which are guiding us for initial analysis and discussion, proving the concept if the methodology is adequate, apart from the social impact, for evaluating and planning the orthodontic procedures in the future as well.

In general terms, based on the overall analyses of the volumetric differences, we observed about ± 1.78 mm of forwarding of the sub-nasal region. The results are also corresponding to similar studies being conducted in the literature [11], from which were also observed significant changes, but they employed a different scanner, i.e. a three-dimensional stereo-photogrammetric system. Another difference is related to the timing, we managed to obtain data after three months wearing the appliance [12].

Further studies are in progress in order to evaluate more volunteers involving even long-term deviations in facial soft tissues.

## ACKNOWLEDGMENT

We would like to be grateful for UTFPR for allowing us to use the 3D scanner and to PUC–PR for selecting the patients.

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