QUANTIFICATION OF DENTAL MOVEMENTS IN ORTHODONTIC FOLLOW-UP: A NOVEL APPROACH BASED ON REGISTRATION OF 3D MODELS OF DENTAL CASTS

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ABSTRACT

Introduction: The assessment of dental displacement achieved by orthodontic procedures is important as it allows operators to verify their clinical treatment and provide adequate adjustments. Modern 3D image acquisition and elaboration systems may represent a valid method for the three-dimensional assessment of dental movement.
A novel protocol for the 3D assessment of success of orthodontic therapy is proposed, based on registration of surfaces.
Methdology: Pairs of casts of the upper dental arch, taken at two different time periods during the therapy, were chosen for three patients who underwent an orthodontic treatment. Dental casts were scanned by a 3D laser scanner: for each patient, the two 3D models were then registered according to the least distance at the area including palatal rugae. The chromatic map of changes within the dental arch and the RMS (Root Mean Square) point-to-point distance between the dental profiles from the two models were obtained, and compared with the same data from a control group including five adult individuals who did not undergo orthodontic therapy. Inter- and intra-observer errors were evaluated as well.
Results: The novel procedure proved to be repeatable and gave a detailed description of those dental areas most affected by orthodontic therapy: RMS values seem to be related with the weight of dental modifications and are far higher than the same parameters computed in the control group.
Conclusion: Further studies are needed in order to explore the possible correlation of RMS value with clinical parameters linked to the improvement of dental function and aesthetics due to orthodontic therapy.
Keywords: orthodontics, dental anatomy, laser scanner, RMS (root mean square)

1. Introduction

Orthodontics represents one of the most sensitive fields of research in dentistry, where the technological developments and treatment modalities are constantly applied in order to ameliorate anatomical and functional characteristics of the dental and facial profile[1]. During the past century orthodontic techniques have been developed in order to obtain more controlled and faster movement of dental elements: the main tasks are the improvement of dental occlusion and function, anatomical stability and facial aesthetics[1]. However, an important issue concerns the assessment of

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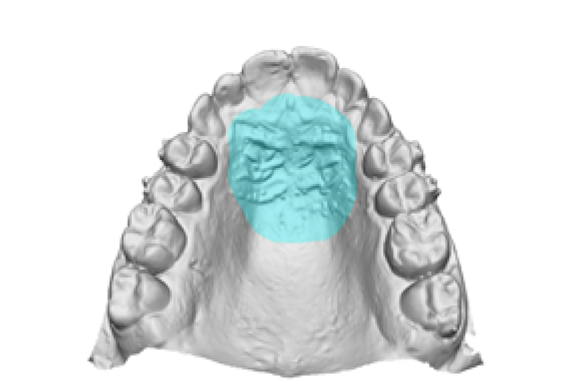

Figure 1 3D model of a dental cast and selection of area including palatal rugae

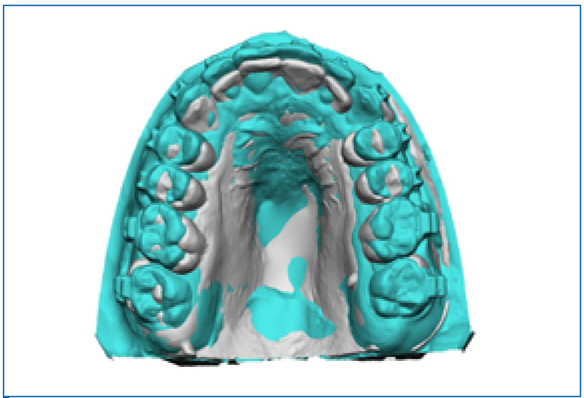

Figure 2 Example of registration according to area of palatal rugae: in white the earlier cast, in light blue the more recent one

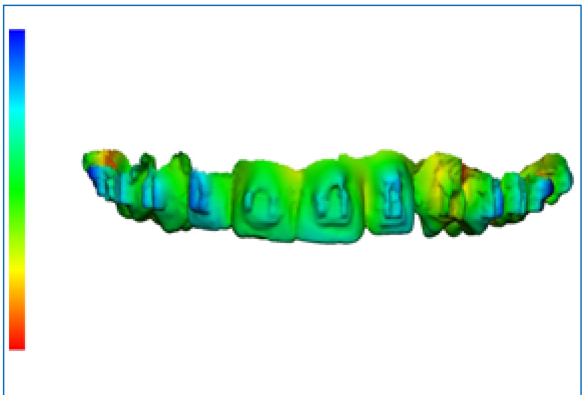

Figure 3 Example of chromatic map according to point-to-point distance between the two 3D models: blue areas are more vestibularized, whereas red and yellow areas are less vestibularized in the last cast than in the first one

dental displacement due to orthodontic devices for verifying the success of therapy and provide adequate corrections. Most of these procedures are based on X-ray examinations (OPG or cephalometric radiographs[1-3]. In the last years modern 3D image acquisition systems, already applied to the study of facial modifications caused by dental displacement[4], have been used also to detect the characteristics of dental movements. The main advantage concerns the chance of performing a three-dimensional assessment of dental morphology, more informative than the traditional radiological methods which are mainly based on the analysis of displacement of single landmarks or dental two-dimensional profile. In addition metrical measurements taken on digital models have been widely tested and proved to be reliable, with a high concordance with measurements taken directly on the plaster models[5-7]. However, surprisingly very few studies have tested 3D image acquisition systems so far for assessment of orthodontic therapies: an example was provided by Thiruvenkatachari et al. who first developed a protocol for 3D-3D superimposition of three-dimensional models of dental casts acquired through a laser scanner[8]. This procedure is based on the registration of 3D models of casts performed at different times and registration of surfaces according to the least point-to-point distance between the respective surfaces including palatal rugae. Displacement of molars was then assessed according to possible movements of their center of mass as calculated by the software[8]. The authors state that the use of laser scanner provides accurate and reliable measurements of dental displacement and might be a valid alternative to cephalometric radiographs[8]. However, the potential advantages which may derive from 3D-3D superimposition techniques have still to be explored: for example, the previously cited study took only the center of mass of the tooth into consideration, whereas techniques of registration may give information on the displacement of the entire surface of the dental crown, with a more anatomically adherent evaluation of dental arch modifications. In addition, the assessment of the translation of dental center of mass does not take into consideration the entire range of movements which may affect the 3D dental surface, such as rotation. A possible alternative is given by modern 3D image elaboration software, which are able to provide the registration of 3D surfaces and metrical parameters useful to assess the discordance between two models, expressed in terms of point-to-point mean and RMS (Root Mean Square) distance. In addition, the same procedure can generate a chromatic sheet able to immediately highlight areas affected by possible modifications[9,10]. These procedures may represent a novel point of view for the assessment of dental movements in orthodontic procedures.
The present article aims at exposing a protocol for 3D-3D registration of three-dimensional models of dental casts for the quantification of dental displacements, based on the calculation of point-to-point distance between two surfaces. This may provide additional information for evaluating the success of therapy and orthodontic procedures.

2. Materials and methods

Casts of the upper dental were chosen from three patients aged from 10 to 15 years who underwent

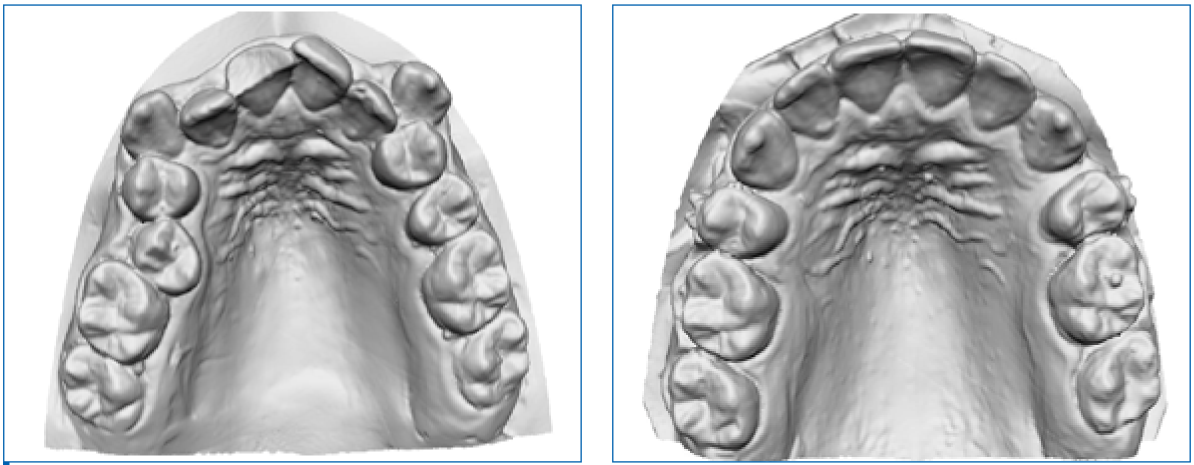

Figure 4 first patient: on the left, the 3D model from the first cast, showing a malposition of both canines; on the right, the 3D model from the second cast, after one year and the removal of the second premolar on the right side and the first on the left side, and consequent realignment of canines

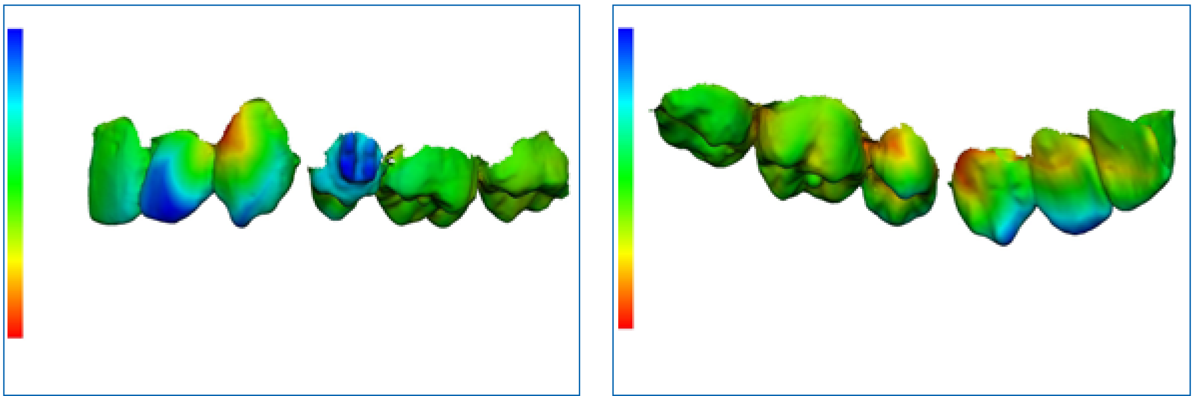

Figure 5 first patient, chromatic map of modifications of dental surfaces from the left side between the two casts (on the left vestibular surface, on the right lingual surface): blue areas are more vestibularized in the last cast, vice versa for the red and yellow areas. Green areas (including the first and second molar) remained unchanged

an orthodontic treatment in a private dental office: all the patients were IOTN (index of orthodontics treatment needs) ≤3 (11). At least two dental casts were available for each patient, taken at different time periods during the therapy. The casts were scanned by a 3D laser scanner (iSeries, Dental Wings©, Montreal, Canada). According to the manufacter, the precision of the instrument is 15 µm. The 3D models were then elaborated through VAM© software (Canfield Scientific, Inc., Fairfield, NJ): first the palatal area including palatal rugae was manually selected in both surfaces (Fig. 1); then the software was requested to automatically register the two models in order to reach the minimum point-to-point distance between the selected areas (Fig. 2). Once the registration between the two surfaces was reached, the dental arch (dental crown surfaces) was manually defined on the 3D model obtained from the more recent cast, and a Region of Interest (RoI) was obtained. The software was then requested to select the RoI and to calculate the point-to point mean distance and RMS value (Root Mean Square) of the two models within the selected RoI. Mean values consider together positive and negative movements, whereas RMS values are all positive, and can provide a complete evaluation of the variations between two dental scans. Together with these quantitative parameters, a chromatic map of surface modifications of dental element extracted from the more recent dental cast is provided, with areas coloured in blue, green and red: the blue areas are more vestibularized in the last cast than in the earlier one, whereas the red areas are less vestibularized. Green areas do not show modifications between the two casts (Fig. 3).To test the method on a control group, the same procedure was applied on the dental arch models of five adult patients aged over 18 years who had longitudinal records taken but where no dental movements or modifications were expected. Time elapsed between the two casts was 1.5 years on average. The same procedures of registration, RoI selection, and calculation of RMS values on the control group was repeated by the same operator and by another observer: intra- and inter-observer differences were statistically assessed by Student's

Table 1 Details of dental modifications between the two casts in the three analysed patients, and comparison of correspondent RMS values with the control group

	First cast	Second cast	RMS value	Average point-to-point distance
Patient 1	Malposition of 3 teeth distal rotation of central incisors	removal of two teeth adjustment of malposition realignment of central incisors	1.61 mm	1.07 mm
Patient 2	Malposition of a tooth	adjustment of malposition	1.13 mm	0.24 mm
Patient 3	distal rotation of central incisors right canine in eruption	correction of central incisors right canine erupted	0.98 mm	0.26 mm
Control group	-	-	0.26 mm (SD: 0.06 mm)	0.02 mm

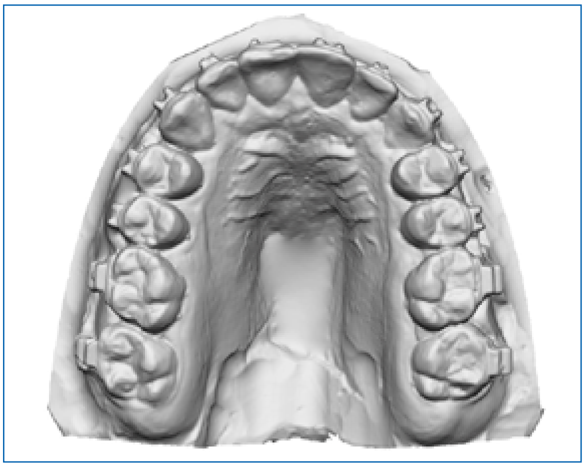

Figure 6 Second patient: on the left, the 3D model from the first cast, showing a malposition of the left canine; on the right, the 3D model from the second cast, after orthodontic therapy

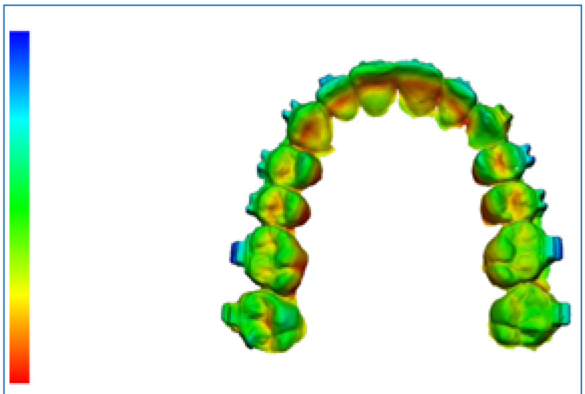

Figure 7 Second patient. Chromatic map of modifications of dental surfaces between the two casts: blue areas are more vestibularized in the second cast, vice versa for the red and yellow areas. Green areas remained unchanged

t test ($p<0.01$). In addition the technical error of measurement (TEM) was evaluated.

3. Results

In the group of control subjects, on average the RMS value was 0.26 mm (SD: 0.06). No statistically significant differences were observed between measurements taken by the same operator or different observers ($p>0.01$). The technical error of measurement (TEM) was respectively 6.1% for intra-observer error and 9.6% for inter-observer error.

The first analysed patient was a female aged 12 years. She had a malposition involving both the canines and the second premolar on the right side. The orthodontic treatment was based on the removal of the second premolar on the right side and the first on the left side and the application of an orthodontic device, as shown by the second cast performed after one year (Fig. 4).

The registration and calculation of point-to-point distances between the two models highlights the mesial rotation of the lateral incisors and realignment of the canine, whereas the molars did not show any appreciable modification (Fig. 5). In addition the method was able to verify the novel orientation of the second premolar; mean RMS value between the dental profiles from the two 3D scans amounted up to 1.61 mm.

The second patient, a female aged 11 years, showed a malposition of the left canine: the application of an orthodontic device was able to produce an adjustment of the canine position, as shown by the second cast taken after four years (Fig. 6).

The procedures of registration were able to verify the vestibular translation of all dental elements,

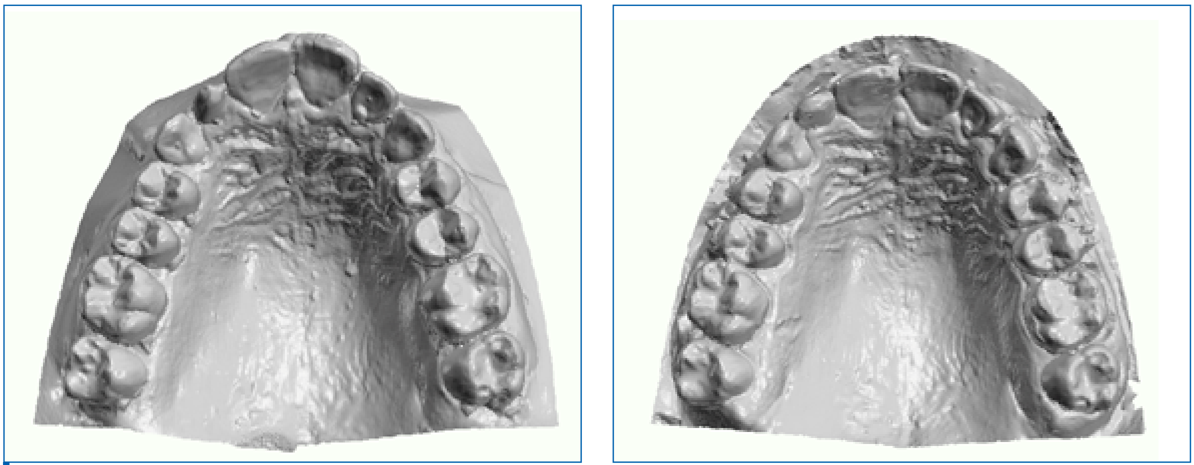

Figure 8 Third patient: on the left, the 3D model from the first cast, showing a malposition of the left canine; on the right, the 3D model from the second cast, after orthodontic therapy.

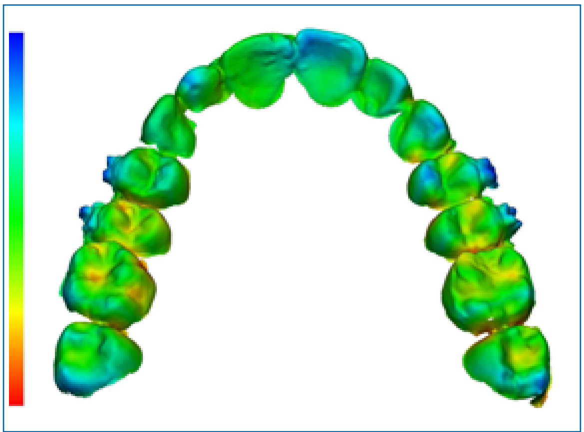

Figure9 Third patient, chromatic map of modifications of dental surfaces between the two casts: blue areas are more prominent in the last cast, vice versa for the red and yellow areas. Most of modifications can be observed on the left central incisor and the left canine

but for the left canine which remained in the same position and was realigned within the dental arch (Fig. 7). In addition, the method was able to accurate describe the novel presence of brackets and wire in the second cast, correctly assessed in blue areas (more vestibularized in the second cast than in the first one). The average RMS value was 1.13 mm.

The third patient was an 11 year old girl, who was chosen in order to test the detectability of lesser dental displacements like pathological overjet value. In detail, the central incisors were distally rotated, whereas the right canine was still erupting with the exposition of the tip. In the second cast, after orthodontic therapy, the central incisors were medially oriented, whereas the canine crown was erupted and in correct occlusion. The second cast was taken after four years.

The registration procedure correctly assessed the change in orientation of the left central incisor: in addition, the eruption of the canine was detected as well (Fig. 9); RMS value was 0.98 mm.

Interestingly, RMS value increased with the entity of dental displacement and number of involved teeth, and was in every case significantly higher than the same parameter shown by the control group (Table 1).

4. Discussion

In the last century orthodontics has seen a progressive update of technologies and clinical procedures, with an amelioration of dental position, functionality and aesthetics[1]. On the other side, a parallel issue concerns the assessment of dental displacement powered by orthodontic therapy, in order to verify the clinical success and provide corrections. Surprisingly, although the constant development of 3D image acquisition systems has represented a crucial revolution in dentistry, their application to the field of orthodontics is still at the beginning and most of their potentiality remains to be explored[8]. An example is provided by Thirvenkatachari et al. who proposed a protocol for the registration of 3D surfaces and calculation of displacement of the center of mass of dental elements[8]. This type of approach provides a metrical information but is not able to predict the modifications of the entire dental surfaces, especially where the movements do not consider dental translation. Another important aspect concerns the morphological assessment of dental movements, which may give an additional information for the evaluation of orthodontic therapies.

The present protocol may represent a proposal for an innovative analysis of dental movements: registration is based on the morphology of palatal rugae which are stable with time[12,13] and have been already used as reference point in 3D-3D superimposition of dental arches[14]. The procedure is repeatable and provides both morphological and metrical analyses of dental movements. The chromatic map of dental arches can give information concerning the specific movement of each dental element (rotation, translation or inclination), immediately readable by the operator.

On the other side, RMS value provides a reliable indication concerning the differences between the two casts, which seems to be adherent to the importance of modifications suffered by the patients. In addition, patients who were not treated from an orthodontic point of view, show lower RMS parameters, and this suggests that the metrical parameter is strictly linked to the general modification of the 3D position of dental crowns.

Some limits should be acknowledged: first, modifications highlighted by the registration procedures consider also dental eruption, and therefore are partly explained by orthodontic therapy. A possible improvement may consider the elaboration of each dental element, in order to separately consider already erupted elements.

Another important limit concerns the possible correlation of RMS with clinical parameters linked to the gain in dental function and aesthetics due to orthodontic therapy. This point is crucial, as it may verify if RMS value in registration of 3D models of dental cases do represent a potentially useful clinical parameter for assessing the success of therapy.

5. Conclusions

In conclusion, a novel protocol for the assessment of dental displacement in orthodontic therapy is proposed: further studies on a large sample of patients may provide additional information about the clinical advantages which may derive from its application.

Acknowledgments

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Questions

Which instruments can be used to obtain a 3D virtual model of dental arches?

❑a. Laser scans;
❑b. Ultrasounds;
❑c. Conventional orthopantomographs;
❑d. Bite wing radiographs.

Which kind of modifications can be assessed on 3D virtual model of dental arches?

❑a. Dental root reabsorption ;
❑b. Parodontal alterations ;
❑c. Dental crown movements ;
❑d. Tempomandibular disorders.

In the current study we assessed

❑a. Three edentulous patients ;
❑b. Seven patients with deciduous dentition ;
❑c. Two patients submitted to orthognathic surgery ;
❑d. Three adolescent patients.

In the current study, we superimposed 3D virtual models of dental arches using

❑a. The vestibular surface of anterior teeth ;
❑b. The palatal area including palatal rugae ;
❑c. The lingual surface of mandibular incisors ;
❑d. The occlusal surface of maxillary first molars.