

The Application of 3D Image Acquisition Systems to Palatal Rugae: A Technical Improvement for Personal Identification?

Daniele Maria GIBELLI^{1,2}, Danilo DE ANGELIS², Riccardo LUPI³, Paolo DANESINO³,
Mike MARIC³, Valentina PUCCIARELLI¹, Chiarella SFORZA^{1*}

¹ Dipartimento di Scienze Biomediche per la Salute, Università degli Studi di Milano, Milano, Italy;

² LABANOF, Laboratorio di Antropologia e Odontologia Forense, Dipartimento
di Scienze Biomediche per la Salute, Università degli Studi di Milano, Milano, Italy;

³ Università degli Studi di Pavia, Pavia, Italy

DOI: 10.15221/16.105 <http://dx.doi.org/10.15221/16.105>

Abstract

The modern 3D image acquisition systems have acquired in the last decades a growing importance in clinical anatomy and in different fields of application of physical anthropology, including also forensic issues. An example can be found in the development of novel procedures concerning the comparison of palatal anatomical structures, such as palatal rugae.

This study aims at exposing possible protocols of superimposition for the comparison of palatal rugae, useful for clinical and forensic purposes: the palate is acquired by a laser scanner (Dental Wing®). Superimposition is then performed according to the surface of the three main palatal rugae through VAM® software which is able to give back an estimation of RMS (root mean square) point-to-point distance between the two models. Models can be also assessed separating the right and the left side in order to test possible modifications of palatal structures in cases of maxillary expansion.

The 3D superimposition provides a chromatic visualization of corresponding areas (areas with full superimposition are represented in green, whereas possible discordances are in blue or red) that offer a visual depiction of the quantified differences, useful in clinical contexts.

The proposed protocol may therefore provide a relevant help in the assessment of palatal modifications in clinical anatomy and forensic anthropology.

Keywords: Palatal rugae, laser scanner, 3D scan

1. Introduction

Palatal rugae are irregular ridges made of connective tissue across the anterior portion of the palate and have long been considered a stable and unique marker on each individual [1]. The anatomical importance of such structures may provide relevant application to clinical and forensic fields of research: for example, they can be used in order to identify unknown decedents, i.e. cadavers without a specific identity which needs to be verified through biological means. The need for personal identification of unknown decedents is an urging need in forensic anthropology: for example, in Milan, one of the most populated cities in Italy, every year 32 new cases of unknown decedents occur (3% of all postmortem examinations) [2]. Personal identification can be obtained through the comparison of individualizing features from the body (postmortem data) and from the suspect of identity (antemortem data). The comparison of palatal rugae may provide a crucial help in order to reach a personal identification [3].

In addition, palatal rugae are analysed also from a clinical point of view, as they can be used as reference structures to measure teeth migration during orthodontic therapy; they are also useful markers to detect submucosal clefts in the palate [4].

Most of the above mentioned fields of applications rely on the supposed stability of palatal rugae with time: however, surprisingly there are conflicting opinions in literature, and several dark points still need to be enlightened. A relevant issue concerns the possible modifications suffered by palatal rugae with growth: common opinion is that palatal rugae are not affected by growth and remain unchanged until death with decomposition of soft tissues [5,6]. On the other hand, other authors suggest that palatal rugae may be modified in length because of the growth of the palatal plate [7], together with the movements of teeth [8].

* chiarella.sforza@unimi.it; +39 02 503 15387; www.scibis.unimi.it

Another field where the positions expressed by authors are even more diverging concerns the relation between palatal rugae and orthodontic treatment. Literature suggests that dental extractions may reduce the length of the second and third ruga [8], whereas the medial landmarks are more stable, probably because closer to the sagittal plane [9]. An overall analysis of possible modifications observed in patients treated for orthodontic purposes was recently given by Mustafa et al. [10]: in 22% of cases an increase in number was observed for a segmentation of pre-existing structures, whereas in 20% they merged in fewer elements. In 28% of cases palatal rugae suffered increase or decrease in length and in 6% of cases they changed shape [10]. The third ruga seems to be more stable as it is located most posteriorly on the palate, but again some orthodontic therapy such as maxillary expansion devices proved to be able to modify also this element [8].

As one can observe the traditional studies based on linear modifications of palatal rugae recorded in casts have not been able to provide a unique version of relations existing between palatal rugae, age and orthodontic treatment. The scenario concerning stability of palatal rugae is conflicting, and represents a novel field of study of such important structures. The need for more advanced and detailed means of analysis of palatal rugae is therefore clear. A hand may be given from modern 3D image acquisition systems which have enabled researchers to improve the morphological and metrical assessment [11]: some examples are the measurements of surfaces and volumes of the palate in growing subjects [12]. In the field of congenital pathological abnormalities, the 3D approach was used to explore the metrical modifications of cleft palate [13-15]. Other applications in orthodontics concern the assessment of palatal linear modifications after maxillary expansion therapy [16-18].

The main use of the novel technologies relies on the metrical assessment of different parameters, be they linear distances, surfaces or volumes: however, another important tool concerns the chance of superimposing 3D models [11]. In this way the two scans can be compared, highlighting possible discordant areas with a colour-coded map, and measuring point-to-point distances between the two models. This type of approach may give additional information concerning modifications of palatal rugae and provide a novel method of comparison of dental profiles, useful in the clinical field.

This study aims at exposing some examples of protocols for the analysis of palatal anatomy through the assessment of palatal rugae, useful both in the clinical and forensic fields of applications.

2. Materials and methods

This study was performed on a population of children treated for orthodontic purposes in the Hospital of Pavia. For each individual two casts were available (before and after the treatment). Data were anonymized according to the Italian and international ethical rules. The casts underwent to 3D scan by a laser scanner (Dental Wing®), in order to obtain a 3D model of each palate as an .stl file (Fig. 1). The 3D models were analysed through VAM® software, a 3D image elaboration program, useful for metrical analyses and superimposition.

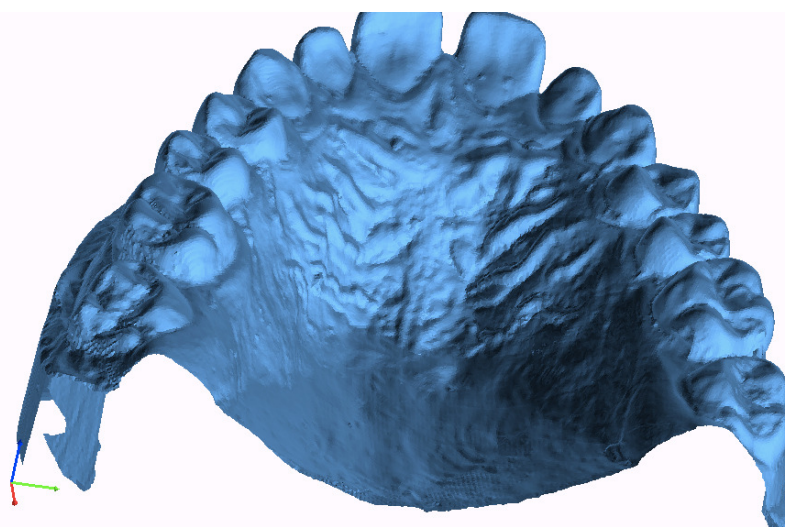


Fig. 1. Laser scan of palatal rugae

A first elaboration consists in the metrical assessment of palatal rugae: length of each ruga can be automatically measured as distance between the most mesial and distal points of the structure. The use of 3D models enables the operators to perform superimpositions between different palatal scans. In this case the morphology of the two sets of rugae are superimposed one on the other, and, on the scan used as reference, palatal structures are colored in different chromatic variations according to the sense of modification (in blue areas with an increase in comparison with the other scan, in red those with a decrease, in green those remained unchanged). The software is requested to provide first a registration of a model on the other one, according to specific landmarks or surfaces defined on each model. A possible protocol may consist in the selection of landmarks corresponding to the mesial and distal part of each palatal ruga (Fig. 2).

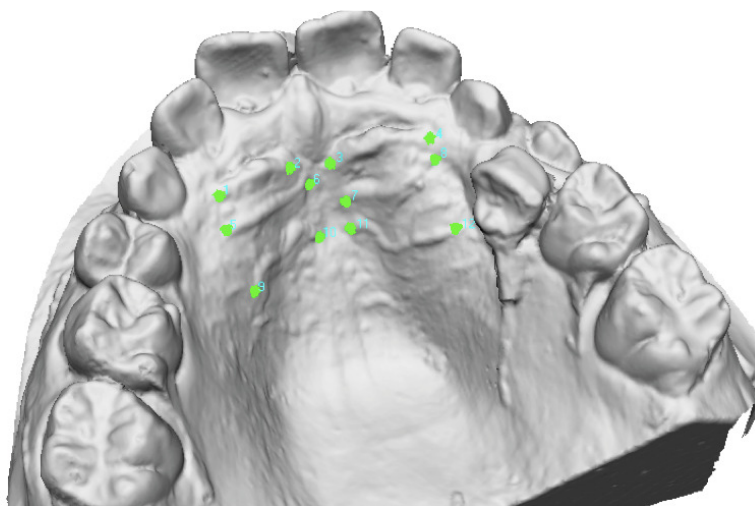


Fig. 2: selection of 6 landmarks corresponding to the most mesial and distal portion of each ruga

After the automatic registration, the 3D image elaboration software can calculate the point-to-point distance between the two registered scans, with a chromatic map of modifications on the model used as reference (Fig. 3).

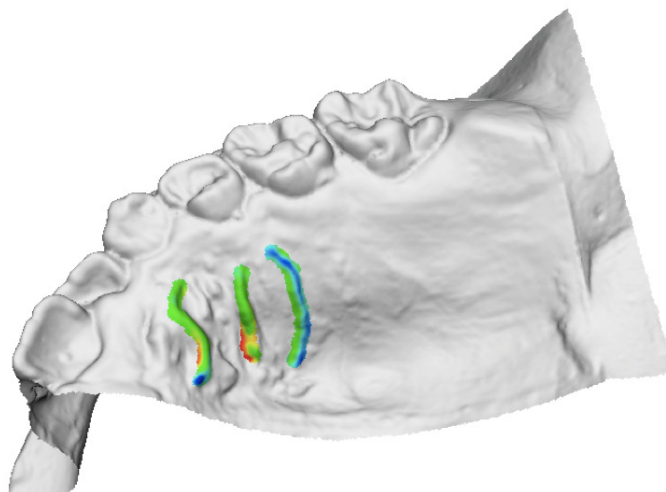


Fig. 3: chromatic map of modifications of palatal rugae between two scans: (in blue areas with an increase in comparison with the first scan, in red those with a decrease, in green those remained unchanged)

The chromatic observation of changes passing from a scan to the other one is very useful as it allows the operators to easily detect where modifications are more intense. In addition metrical parameters of point-to-point distance (minimum distance, maximum distance, mean, standard deviation, RMS – root mean square) can be automatically assessed.

The same method can be applied to context where, on the contrary, we are requested to verify the modifications of the palate compared with palatal rugae: in this case, palatal rugae are chosen as reference structures in order to perform the registration of two models and assess possible changes of the dental arch. Figure 4 exposes an example on superimposition performed between two models

belonging to the same individual, before and after orthodontic treatment. On the post-treatment model, the superimposition highlights the presence of blue areas on the cusps of canines, premolars and molars, concordant with the physiological dental growth. In this case the stability of palatal rugae was used in order to assess modifications in the rest of the palate.

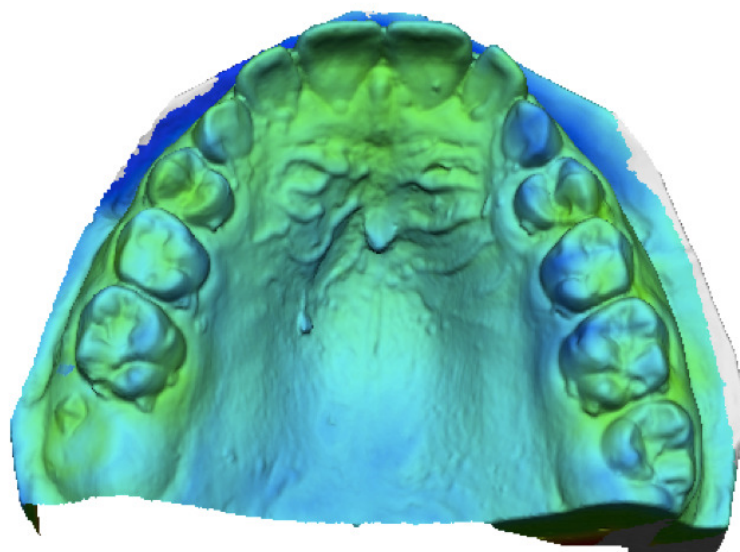


Fig. 4: chromatic map of modifications of a palate between two scans: blue areas on the cusps of canines, premolars and molars are concordant with the dental growth occurred between the two scans

Another possible application is the assessment of palatal modifications after maxillofacial surgery or the application of devices for the modification of palate (such as in rapid maxillary expansion). Figure 5 shows an example of 3D-3D superimposition between two scans obtained from the same individual before and after maxillary expansion. As one can observe, the palatal rugae in the post-treatment model are colored in green, and this means that no modification was observed in this area between the two models. In contrast, the lingual part of each alveolar process is colored in yellow, whereas a slight blue coloration is observed on the vestibular surface. This chromatic sheet is concordant with an expansion of the palate, and therefore may provide also a quantification of the obtained results.

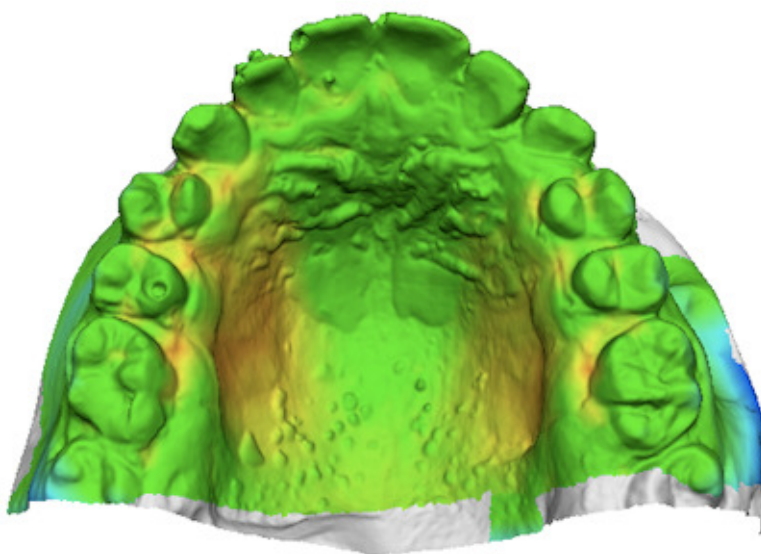


Fig. 5: chromatic map of modifications of a palate after rapid maxillary expansion: the yellow color on the lingual surface of the dental arch is concordant with the widening of the palate

3. Results and discussion

Techniques of 3D-3D superimpositions may provide a relevant help to the assessment of anatomical structures, adding a novel and more complete method of assessment.

A first advantage concerns the chance of performing traditional metrical assessment of palatal structures, usually limited to linear measurements taken through calipers. However, some limits have to be taken into consideration: first of all, both the techniques request the manual positioning of landmarks and perimeter lines on the 3D model, with a clear need to verify inter- and intra-observer error.

The 3D-3D superimposition enables the researchers to obtain a complete analysis of three-dimensional structure of palatal rugae. Results from superimposition provide a more detailed scenario of modifications including the more affected areas and the type of modification according to the reference scan (decrease or increase). This is an additional information than the mere modifications in shape and size evaluated on casts, as it allows the researchers to follow changes of palatal rugae with time. The application of this experimental protocol on orthodontic patients with different casts obtained at specific time points may provide more information concerning the possible modifications of palatal rugae with time.

The same is valid also for the assessment of modifications of palatal rugae due to orthodontic treatments: existing studies are mainly based on the comparison of casts and linear measurements [8-10]. Techniques of superimposition may represent a novel method for assessing changes with different therapies.

Another field of application concerns the study of palatal modifications due to maxillary expansion therapy: also in this case the contribution provided by 3D-3D superimposition techniques may provide a novel point of view in order to evaluate the possible outcome of the treatment.

In the last years the introduction of novel 3D image acquisition systems has allowed researchers to perform a more detailed analysis of anatomical structures in different fields of application. One of the most important concerns forensic analysis and in detail personal identification which passes through the comparison of individualizing anatomical structures. Procedures of identification have been performed so far through the 2D visualization of three-dimensional structures: some examples are the profile of frontal sinuses [19] and the silhouette of bones and teeth in radiological examinations [20]. The introduction of stereophotogrammetry and laser scanners have provided the chance of a more detailed analysis of the three-dimensional characteristics of each structure, with possible advantage for what concerns the judgment of identification. The use of 3D-3D superimposition technique has been already known in other forensic fields, such as facial identification [21]. In this case the most important advantages come also from the chance of quantifying the point-to-point distance between the two models, and therefore the differences between two faces. In this way the analysis of superimpositions performed between models belonging to the same individuals or different persons may enable the researchers to reach a quantitative threshold, useful for confirming or excluding identification.

However this procedure necessarily requests the development of protocols in order to improve the repeatability of analyses and observations. The main technical issue concerns the choice of reference landmarks or surfaces in order to reach the superimposition which will be performed in the configuration with the lowest distance. This requires to identify the most stable structures in order to highlight the modifications in the area of interest. In addition, as the choice of reference structures for superimposition is manual whereas the rest of the procedure is automatic, it may be affected by inter- and intra-observer variability, which needs to be verified in every experimental protocol concerning 3D-3D superimposition.

This study aimed at proposing different methods for assessing palatal rugae on 3D models of casts: our preliminary results show that the advanced 3D methods of superimposition may provide a relevant help also in the clinical field of research, for example in order to assess changes of the dental arch after treatment. Clearly the reliability of novel methods has to be ascertained through further experimental studies

References

- [1] E. Lloyd du Brul, "Anatomia orale di Sicher", Edi Ermes, Milan, 1988
- [2] C. Cattaneo, D. Porta, D. De Angelis, P. Poppa, D. Gibelli, M. Grandi, "Unidentified bodies and human remains: an Italian glimpse through a European problem", *Forensic Sci Int*, Vol. 195, 2010, pp. 167.e1-e6
- [3] D. De Angelis, F. Riboli, D. Gibelli, A. Cappella, C. Cattaneo, "Palatal rugae as an individualising marker: reliability for forensic odontology and personal identification", *Sci Jus*, Vol.52, no.3, 2012, pp.181-184
- [4] G.M. Ayman, M.Z. Allouh, R.M. Alshehab, "Morphological changes in palatal rugae patterns following orthodontic treatment", *J Forensic Leg Med*, Vol.31, 2015, pp. 19-22
- [5] D.C. Peavy Jr, G.S. Kendrick, "The effects of tooth movement on the palatine rugae", *J Prosthet Dent*, Vol. 18, 1967, pp. 536-42
- [6] W.R. English, S.F. Robison, J.B. Summitt, L.J. Oesterle, R.B. Brannon, W.M. Morlang, "Individuality of human palatal rugae", *J Forensic Sci*, Vol. 33, 1988, pp. 718-26
- [7] G. Hauser, A. Daponte, M.J. Roberts, "Palatal rugae", *J Anat*, Vol. 165, 1989, pp. 237-49
- [8] A. Batool, A. Shaikh, M. Fida, "Stability of palatal rugae as a forensic marker in orthodontically treated cases", *J Forensic Sci*, 2016 [Epub ahead of print]
- [9] L.T. Bailey, A. Esmailnejad, M.A. Almedia, "Stability of the palatal rugae as landmarks for analysis of dental cases in extraction and non-extraction cases", *Angle Orthod*, Vol. 66, no.1, pp. 73-8
- [10] A.C. Mustafa, M.Z. Allouh, R.M. Alshehab, "Morphological changes in palatal rugae patterns following orthodontic treatment", *J Forensic Leg Med*, Vol. 31, 2015, pp.19-22
- [11] L. Huanca Ghislanzoni, I. Perondi, C. Tagliatesta, C. Sforza, "New perspectives on the use of three-dimensional dental models in orthodontics", *Dental Cadmos*, Vol. 81, no. 2, 2014, pp. 1-9
- [12] J. Primožic, G. Perinetti, S. Richmond, M. Ovsenik, "Three-dimensional longitudinal evaluation of palatal vault changes in growing subjects", *Angle Orthod*, Vol. 82, no. 4, 2012, pp. 632-6
- [13] C. Sforza, M. De Menezes, E. Bresciani, A.M. Ceròn-Zapata, A.M. Lòpez-Palacio, M.J. Rodriguez-Ardila, L.M. Berrio-Gutiérrez, "Evaluation of a 3D stereophotogrammetric technique to measure the stone casts of patients with unilateral cleft lip and palate", *Cleft Palate Craniofac J*, Vol. 49, 2011, pp. 477-83
- [14] V. Pucciarelli, L. Pisoni, M. De Menezes, A.M. Ceron-Zapata, A.M. Lopez-Palacio, M. Codari, C. Sforza, "Palatal volume changes in unilateral cleft lip and palate paediatric patients", 6th International Conference on 3D Body Scanning Technologies, Lugano, Switzerland, 27-28 October 2015
- [15] M. De Menezes, A.M. Ceròn-Zapata, A.M. Lòpez-Palacio, A. Mapelli, L. Pisoni, C. Sforza, "Evaluation of a three-dimensional stereophotogrammetric method to identify and measure the palatal surface area in children with unilateral cleft lip and palate", *Cleft Palate Craniofac J*, Vol. 53, 2016, pp. 16-21
- [16] A.P. Muchitsch, H. Winsauer, B. Wendl, M. Pichelmayer, E. Kuljuh, A. Szalay, M. Muchitsch, "Remodelling of the palatal dome following rapid maxillary expansion (RME): laser scan-quantifications during a low growth period", *Orthod Craniofac Res* Vo. 15, 2012, pp. 30-8
- [17] A. Ugolini, C. Cerruto, L. Di Vece, L. Huanca Ghislanzoni, C. Sforza, T. Doldo, A. Silvestrini-Biavati, A. Caprioglio, "Dental arch response to Haas-type rapid maxillary expansion anchored to deciduous vs permanent molars", *Angle Orthod*, Vol. 85, no.4, 2015, pp. 570-6
- [18] P. Trefny, V. Krajček, J. Veleminská, "Three-dimensional analysis of palatal shape in patients treated with SARME using traditional and geometric morphometrics", *Orthod Craniofac*, 2015 [Epub ahead of print]
- [19] M. Yoshino, S. Miyasaka, H. Sato, S. Seta, "Classification system of frontal sinus patterns by radiography. Its application to identification of unknown skeletal remains", *Forensic Sci Int* Vol. 34, 1987, pp. 289-99
- [20] R. Ciaffi, D. Gibelli, C. Cattaneo, "Forensic radiology and personal identification of unidentified bodies: a review", *Radiol Med*, Vol. 116, 2011, pp. 960-8
- [21] D. Gibelli, D. De Angelis, P. Poppa, C. Sforza, C. Cattaneo, "A view to the future: a novel approach for 3D-3D superimposition and quantification of differences for identification from next generation video surveillance systems", *J Forensic Sci*, 2016, in press