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Determination of efficiency of orthodontic treatment by using engineering tools

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Abstract
Dental malocclusion and crossbite can result in aesthetic and functional problems. Up until recently, the characterisation of crossbite was performed on photographs and radiographs that are generally limited to 2D representations and an inaccurate determination of the distances between teeth. The advent of 3D scanners provides the possibility to enhance the accuracy and relevance of measurements performed on dental casts, enabling the study of the effectiveness of orthodontic interventions. A systematic description of the procedure used to scan maxillary casts is thus described in this work. The dental impressions are scanned by using a 3D scanner. The obtained STL files are hence imported into a suitable CAD software where the processing of the rendered casts and the determination of the required characteristics (palatal volumes and gingival planes' surfaces) are performed. The variation of these values can thus be monitored on pre- and post-treatment casts, achieving the goal of the work.

Malocclusion, orthodontic treatment, 3D scanning, elaboration of data, CAD software, gingival surface and palatal volume

1. Introduction

Dental malocclusions and mandibular shift or crossbite in particular, which can occur due to genetic and environmental influences, including nasal area inadequacy with the prevalence of mouth- with respect to nose-breathing, can result in aesthetical malformations such as facial and mandibular asymmetry causing potential psychological burdens, as well as in functional problems related to the asymmetry of the mastication pattern that affects the muscular functions of the jaws and the bite forces [1-4]. Up until recently, the characterisation of malocclusions was performed based on measurements on photographs and radiographs, which are not only invasive, but also generally limited to 2D representations and, when the needed irradiations are performed on children for mere research purposes, can give rise to ethical questions. What is more, these procedures are limited to the often cumbersome and inaccurate determination of the relative distances between teeth (in particular intermolar, intercanine and alveolar widths), failing to provide a complete information about the 3D morphology of the palatal vault [1, 3]. The advent of sophisticated contactless 3D scanners, nowadays often used in automotive industry or documentation of cultural heritage objects [5-6] but increasingly also for medical prosthetics [7], provides now the possibility to enhance the accuracy and relevance of measurements performed on dental casts. This enables thus a horizontal study of the effectiveness of orthodontic interventions minimising malocclusions, both by studying the short-, mid- and long-term effects of the interventions depending on the age of the patients, as well as comparing the data of patients with malocclusions with respect to control groups with normal occlusal and facial development. In the current state-of-the-art where this approach is used [1-4], the procedure to determine the characteristic orthodontic parameters is, however, in engineering terms, poorly explained.

A systematic description of the engineering procedure used to assess maxillary casts is described in this work. Dental casts are hence scanned by using a 3D scanner on a number of views sufficient to assure the overlap of the scans. The obtained STL files are hence imported into a suitable CAD software, where the processing of the rendered digital casts and the determination of the required characteristics are performed. The variation of the obtained values of palatal volumes and surfaces of the gingival planes allow, therefore, to analyse the changes of maxillary morphology on pre- and post-treatment casts, achieving the goal of the work.

2. Determination of the 3D morphology of the palatal vault

The dental cast are non-invasively scanned in this work by using the high-accuracy non-contact DAVID SLS-2 structured-light 3D scanner [8] illuminating the samples from a working distance of 30 cm and detecting the distortions of the reflected light stripes, while adjusting the focus of the projector and the scanner, as well as the brightness and the aperture of the camera, so as to maximise the sharpness and the intensity of the resulting image. The nominal resolution and accuracy of the used scanner is on the level of 1 ‰ of the size of the object [8], i.e., in the considered case, it is roughly 60 μm. Six views, rotated by 15° with respect to each other, are performed on each cast placed on a horizontal rotational platform, assuring sufficient overlap of the scans, i.e., that the scans can be fused via the scanner's DAVID3 software in a single high-quality 3D image of the upper jaws' casts. The overall scanning time per dental cast is roughly 3 minutes. In order to reduce the size of the output STL file, the used mesh density of the fusion is set to 2000, corresponding to a vertex spacing (average spacing of the points between the cells) of the pre-processed 3D cell grid of 1.5 μm.

The STL file is hence imported into the SolidWorks 2016® CAD software package where the processing of the obtained rendered digital casts and the determination of the required anatomical characteristics of maxillary arch morphology are performed [9]. In a first instance, three guide points, defining the gingival plane, are placed on the dento-gingival junction of the raw image; two of these points are placed on the distal of the primary molars, while the third is placed on one of the central incisors (Fig. 1). The editing of the raw cell mesh is then performed to create the palatal surface. In a first step the unwanted data (topological errors and other imperfections in the mesh) are thus removed, while the excess details are smoothed using the SolidWorks' Mesh Prep Wizard tool. The superfluous points of the mesh, related to the parts of the image not needed for the determination of the required parameters, are then removed, while the remaining surfaces are simplified and smoothed allowing to reduce the size of the used file and the time needed for its processing. The holes present in the resulting mesh are filled thus enabling, finally, the definition of the 3D morphology of the palatal vault via the Surface Wizard and the Automatic Surface Creation tools (Fig. 2). The surface of the palate, obtained from the mesh, is needed to create the solid body whose volume will be equal to the palatal volume.

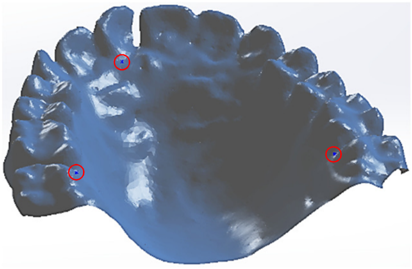

Figure 1. Definition of guide points.

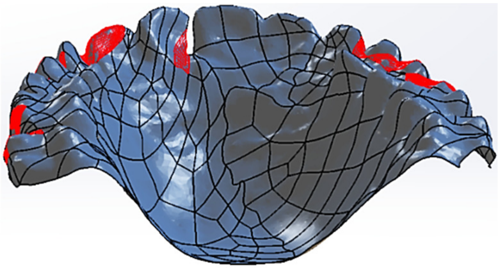

Figure 2. Palatal vault's surface.

The respective body is created by bounding the palatal surface in space by the gingival plane passing through the three previously defined guide points (horizontal plane in Fig. 3), while the distal plane is that passing through the points at the distal of the left and the right first molar, perpendicular to the gingival plane (vertical plane in Fig. 3).

With the Trim Surface tool, the excess surfaces are removed, leaving a closed volume defined by the palatal surface and the residual parts of the two planes. The volume enclosed by these surfaces, obtained via the Knit Surface tool, is the negative of the required palatal volume, while the residual surface of the gingival plane itself is the second parameter of interest. Both parameters are finally quantified by using, respectively, SolidWorks' Mass Properties (Fig. 4) and Measure tools (Fig. 5).

To analyse the changes of the anatomical characteristics of maxillary arch morphology, the variation of gingival surface area and palatal volume can hence be monitored on pre- and post-treatment casts, achieving successfully the goal of this work.

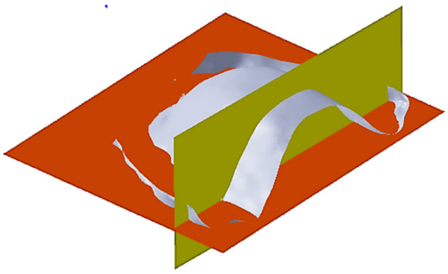

Figure 3. Definition of the boundaries of the vault.

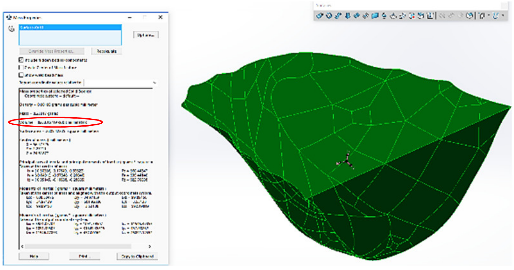

Figure 4. Calculation of the palatal volume.

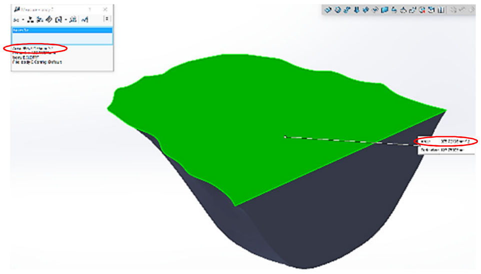

Figure 5. Calculation of the surface area of the gingival plane.

3. Conclusions and outlook

Engineering tools (3D scanner, CAD software) are used in this work to assess the values of palatal volumes and gingival planes' surfaces, since the variation of these values on pre- and post-treatment dental casts can be proficiently used to evaluate the efficiency of orthodontic treatments aimed at achieving normal occlusal and skeletal development.

In addition to the described procedure based on using Solid Works, the possibility to use open access and/or student versions of other CAD software packages (Freecad, Blender, MeshLab, Creo PTC, Catia) for the same purpose was also assessed. It is hence established that a combined use of MeshLab (used to create the palatal surface's mesh) and Creo can be a viable solution to obtain the value of the palatal volume only, and it is accompanied by additional digital data elaboration steps. The use of the Catia V5R20 CAD package is proven to be feasible to asses all the needed data but it is cumbersome.

In any case, it was established that the obtained values of the palatal volumes and gingival planes' surfaces are highly dependent on the accuracy and repeatability of setting the guide points defining the dento-gingival junction, although their impact on the relative change of the monitored values on pre- and post-treatment casts is limited. The orthodontic community might thus consider improving the definition of these parameters.

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