Influence of 3D models choice on cervical outline measurements of teeth

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Abstract

Among different study techniques, which are used in dental research, measurements of teeth play one of the most important roles. However classical measurement techniques usually show consistent results on morphologically complete objects, while teeth can be found in different conditions, depending, for instance, on the natural wear degree. In order to increase the sample, which is especially important when findings are not abundant, and to improve the analytical part, alternative techniques have been proposed, among which cervical measurements are considered to be informative, especially taking into consideration morphological and methodological importance of the cervical area. Algorithms of automated digital measurement techniques also use the cervical area for providing stability of results. Visualisation of the tooth cervical margin and reconstruction of its projections can be achieved by two conventional imaging techniques, which are tomography (preferably high-resolution) and intra-oral confocal optical scanning. They both were used for obtaining 3D reconstruction of upper premolar taken from palaeoanthropological materials. In line with applying the same automated coordinate system setting algorithm to both types of reconstructions, contours of their enamel cervical margins were defined and their projections to horizontal plane were obtained and measured. Despite the fact that 3D reconstructions from different imaging sources technically can serve for running automated odontometry, measurement results, especially in comparative studies, should be handled with attention.

1. Introduction

Teeth are one of the most important, informative, interesting and usually well-preserved objects of study in dental clinical, anthropological, paleontological and other areas of research. Numerous methods are used separately or combined in studies of dental morphology. Taking into consideration wide variance of teeth, quite often visual methods take a leading role in description of morphological traits and their scoring (e.g. ASUDAS system (Scott and Irish, 2017) or odontoglyphic method (Zubov and Nikityuk, 1978)). In line with the mentioned above techniques measurements are carried out on teeth for additional quantitative analysis of their dimensions. Actually different techniques can be used for measurements. Some researchers are interested in measuring the whole tooth dimensions (Yu et al., 2019), (Shinde et al., 2019), (Rathmann et al., 2019), however, probably the most widely used and regulated are measurements of crowns in buccal-lingual and mesial-distal dimensions, which can be used independently (Priyambadha and Artaria, 2016), (More et al., 2017) or in combination with other techniques (Xiao et al., 2014), (Glantz et al., 2008).

The typical problem for applying classical measurement methods is the condition of teeth, as the majority of techniques work adequately on well-preserved teeth, which allow setting measurers on morphologically complete surfaces and measurement results on different teeth can be compared correctly. Nevertheless it is impossible to discard changes caused by natural functional wear. This is a gradual process, and as a result, teeth can be found in morphologically different conditions. In order to increase the sample (this is especially important in palaeontology or palaeoanthropology, when findings are not abundant) and to improve the analytical part, alternative techniques have been proposed. Thus measurements in cervical parts of teeth are considered to be informative when morphological changes hinder use of traditional techniques on other parts of teeth. Cervical measurements continue ideas of classical methods (Hillson et al., 2005); (Stojanowski, 2007), also include diagonal measurements (Manchanda et al., 2015) or combined techniques (Zorba et al., 2011). They are now successfully applied in different studies of dental morphology of permanent and deciduous teeth (Pilloud and Hillson, 2012); (Pilloud and Hillson, 2012). (Luna, 2015), sex estimation (Garcia-Campos et al., 2018). etc.

Morphologically enamel cervical edge is a specific area. It unites outer and inner layers of enamel cap (the latter is congruent to the layer of dentine and depicts its morphology). This is also the zone of terminal maturation in ontogenical development of tooth coronal part (Butler, 1956). Many researchers find this structure of teeth very important in their measurement techniques referring to the cervical area for positioning landmarks and orientating geometric constructions in 2D modes (Olejniczak et al., 2007) as well as construction of flat and curved planes on 3D reconstructions of teeth (Benazzi et al., 2014). Use of 3D models of teeth expands the range of application of different methods and their combinations (Woods et al., 2017). Thus cervical area contour outlines can be depicted on plane for further application of odontometric and morphometric techniques (Benazzi et al., 2011). Here we see that the cervical area and especially the margin is very important from morphological and methodological point of view.

In our previous works on developing automated measuring techniques, cervical margin become one of the important structures for orientating teeth along the vertical axis (Gaboutchian et al., 2021), (Gaboutchian et al., 2023). However the cervical structures themselves attract more interest as study ob-

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jects, and therefore further extension of the odontometric technique for the analysis of cervical outlines is in the process of development. Actually, projections of the enamel cervical margin outlines on planes are of interest. It should be said that this structure is rather thin, and its correct imaging and reconstruction meets certain technical challenges, requiring correct choice of imaging technique and reconstruction resolution (Maret et al., 2014). Moreover the enamel sometimes chips and requires re-contouring for studies of contour outlines (Benazzi et al., 2012). High-resolution imaging techniques (Smith et al., 2018), (Zanolli et al., 2020) usually have certain advantages if compared to optical methods or medical imaging techniques.

However in some cases intra-oral cameras can function successfully in obtaining 3D reconstructions of tooth surfaces as optical features of dental enamel often distort results when more "aggressive" scanners are being used without scan-sprays. The intra-oral devices provide decent accuracy usually depending on the scanned objects size (tooth-size are preferred; more discrepancies can be observed on reconstructions of dental arches or their closure registrations). Reconstruction details of intra-oral scans, such as mesh density, are also important as they influence the model features, especially in the enamel cervical margin zone (Solaberrieta et al., 2016), (Richert et al., 2017). We therefore present an overview of projecting cervical enamel edge contour outlines on the example of regularly obtained 3D models after optical and tomographic imaging. The general focus is on the development of automated dental measurements system for outline analysis.

2. Material

For testing enamel cervical margin outline projection we chose samples from the Upper Palaeolithic archaeological site of Sunghir. This choice was made largely due to finely preserved morphological detail, including cervical area of the teeth. The skull with teeth of the adolescent individual Sunghir–2 was scanned on Phoenix v—tome—x m (Waygate Technologies) tomographic scanner. Scanning parameters are the following: voltage - 275 kV, current at tube - 400 µA, exposition - 250 ms. Processing of images was performed on Avizo 9.01 software. The images of each tooth were separated from the entire stack. Subsequent segmentation was based on differences in absorption level of dental tissues (dentine and enamel) and bone, and then irrelevant areas with similar to enamel radiopacity level were cleaned out. After that 3D model of enamel cap was generated.

Optical imaging of dental arch was performed by confocal Trios (3Shape) intraoral scanner. Models of separate teeth were obtained by "manual" trimming of the dental arch scan under visual control. Both optical and x-ray tomographic 3D reconstructions were saved in .stl and .x formats for use both in generally available and custom software products.

The most appropriate tooth for comparison of the enamel cervical margin was found to be the upper left first premolar. This choice was mainly defined by absence of contacts with adjacent teeth, and therefore, preservation of complete morphology of the side surfaces on the reconstruction cut out from the optical scan.

3. Methods

Both reconstructions served as input data in custom software, which has been used in our previous studies for automated measurements on posterior teeth (molars and premolars).

Orientation of Teeth. Orientation is a significant part of the presented method that influences the results obtained through measurements; it is performed automatically in the suggested odontometric technique. The initial part of tooth orientation is based morphologically on the contour of anatomical occlusal surface and serves for vertical axis alignment. This contour actually is the border between centrally located depression on tooth crown and its outer surfaces. It is defined through surface analysis methods and represents a set of points surrounding the occlusal surface. They set orientation for coordinate system and serve for setting vertical axis inclination, which is marked in green (Figure **??**). This process is staged and requires iteration for more accurate settings. We should mention that the use of tomographic imaging allows accurate reconstruction and clear access to morphological structures, which is due to different circumstances can be completely hidden or non-obvious for correct detection. Thus, the edge of cervical enamel has been tested for orientation algorithms in automated digital odontometry in line with occlusal surface contour (Gaboutchian et al., 2021), which we consider a reliable morphological structure as a reference landmark.

The result of the scanning data processing is a 3D model of a tooth $\mathbf{T}$. It is represented in a form of triangulated irregular network (TIN) – a set of coordinates of surface points (nodes) $t_i, 1 = 1, \dots N$ and a set of corresponding edges $l_j, j = 1, \dots L$ that connect the nodes into elementary surface element (facet). To perform correct and interpretable morphometric analysis, it is necessary to define a tooth coordinate system that allows for comparing measuring results for teeth of different shape and dimension. As the occlusal surface seems to be the most relevant reference for teeth morphology comparison, it is taken as a basis for the XY plane of the tooth coordinate system.

The occlusal surface is an area lying inside the occlusal border O_b that can be defined as a set of tooth surface points having maximal values of Gaussian curvature $K = \kappa_1 \cdot \kappa_2$. Here, κ_1 and κ_2 are principal curvatures of a surface. The XY plane is defined by its normal $\mathbf{n}_T$ that is calculated as an average value of the normals at points of the occlusal border O_b.

The procedure of the tooth system of coordinates determination is presented as Algorithm 1.

The next stage for orientation is the mesio-distal, or anteroposterior, axis orientation (this axis is marked in two colours: yellow and blue, in order to distinguish its direction easier). It is set perpendicular to the vertical axis and according to the shape of occlusal surface contour.

Additional calibration of mesio-distal axis is performed according to maximal dimensions of tooth crown. The third – vestibulo-oral (bucco-lingual, transverse) axis direction – is set as perpendicular to both mentioned above axes; it is marked in red in Figure 1.

Orientation was performed in the current study for the enamel cap reconstruction, which was studied both in terms of its outer and inner morphological features. Algorithms were set to orientate the system of coordinates according to enamel occlusal surface contour. The same orientation was used for measurements on dentin.

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Algorithm 1: Tooth system of coordinates determination

Input:
TIN 3D model of a tooth $\mathbf{T} = \{t_i, l_j\}$,
Output:
tooth occlusion surface border array O_b,
tooth occlusion surface normal $\mathbf{n}_T$,

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Tooth 3D model T orientation into the standard position ;
Procedure Orienting(T):
    for each point t_i of tooth 3D model T do
        Find Gaussian curvature K_i = κ_1 · κ_2 at point t_i
        if K_i > K_treshold then
            find normal to the tooth surface n_i at point t_i
            save t_i in occlusion border array O_b;
            save n_i in occlusion border normals array O_b^n;
        else
            skip;
    Find the occlusion border O_b as a set of points with maximal curvature K_i ;
    Find tooth occlusal normal n_T as an average of occlusion surface normals n_i ;
    Define the z-axis in the direction of occlusal normal n_T ;
    Find maximal mesio-distal dimension of tooth crown D_m d ;
    Define x-axis in the direction of maximal mesio-distal dimension D_m d ;
    Define y-axis as perpendicular to the xz-plane;
    return O_b, n_T;
```

The algorithms function on the basis of surface analysis, sectioning, locating specific landmarks and setting coordinate system direction. In the current case preliminary orientation was performed on the basis of defining occlusal surface contour (Figure 1) with following correction of the tooth coordinate system direction according to the cervical margin contour (Figure 2).

The number of sections was set as 30. The main focus was on vertical axis orientation defined according to the positions of the centroids of the both mentioned above contours. The vertical axis defines positioning of the perpendicular plane for subsequent projecting of the enamel cervical margin contour on it.

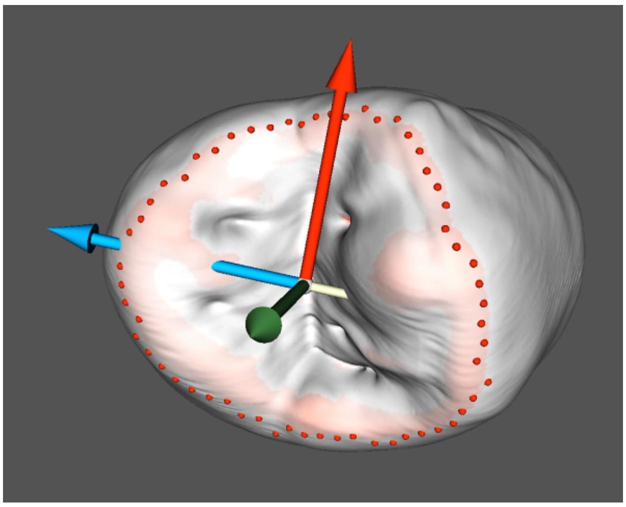

Figure 1. Initial stage of orientation; occlusal view of enamel cap reconstruction obtained on tomographic scanner.

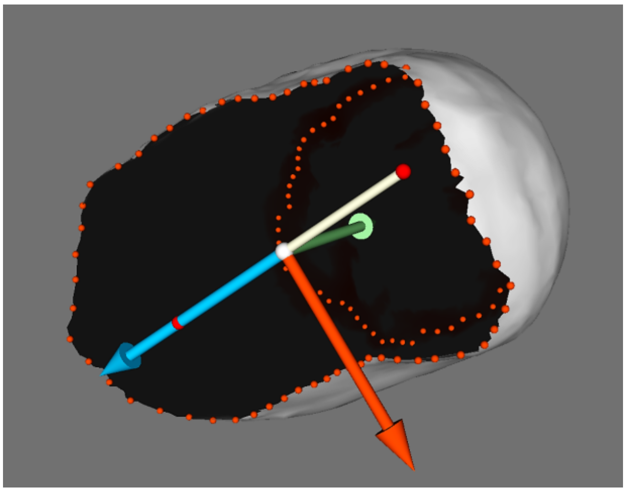

Figure 2. Tooth coordinate system set according to two, occlusal and cervical, contours; bottom view of enamel reconstruction obtained on intra-oral scanner.

These operations were performed on custom software developed for automated measurements of teeth. After orientation the system obtained enamel cervical contour projection on horizontal plane.

4. Results and discussion

The odontometric algorithm improvement automatically saves enamel cervical margin projections. Both images for the upper left first premolar 3D reconstructions obtained through microtomographic and confocal optical scanning are shown in Figure 3.

Visual comparison of the contours reveals more smooth outlines in case of tomographic scanning, which corresponds to imperfection caused by manual trimming of the optically scanned reconstruction. In addition mesh generation protocol serves as the factor providing for leaving serrated edges on the trimmed cervical edge. At the same time the contours possess high degree of resemblance, which could probably correspond to typical acceptable level of errors in many odontometric techniques (this parameter is not estimated in the current paper). Superimposing of the two contours clearly demonstrates the difference of the two contour projections (Figure 4)

We could believe that trimming, as one of many manually conducted processes in dental measurements, is the source of discrepancies. However the automated measurer set previously in the custom software, which we have been using in recent studies, showed difference in the contour length for the two reconstructions. Tomographically obtained contour is 27,19 mm long, when optically – 23,52 mm. Such a difference of 3,67 mm, which actually doesn’t correspond to the visually observed difference in contours, suggests to accept 3D reconstructions for measurements from different sources with care until after more detailed studies are conducted.

5. Conclusions

Different 3D reconstructions of teeth technically can serve for running automated measurement algorithms. As an extension

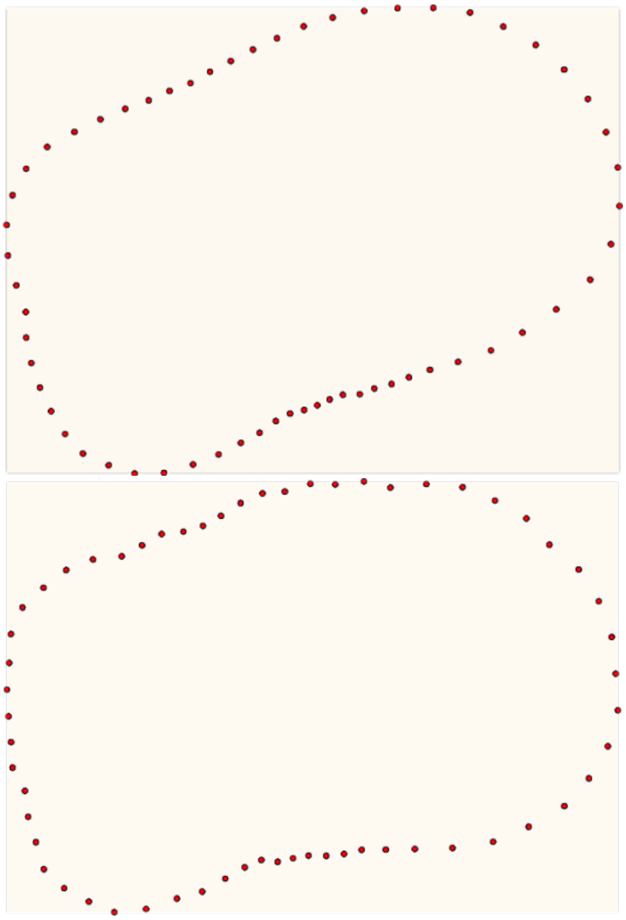

Figure 3. a – projection of the enamel cervical edge obtained from the micro-tomographic scan, b - projection of the enamel cervical edge obtained from the optical scan.

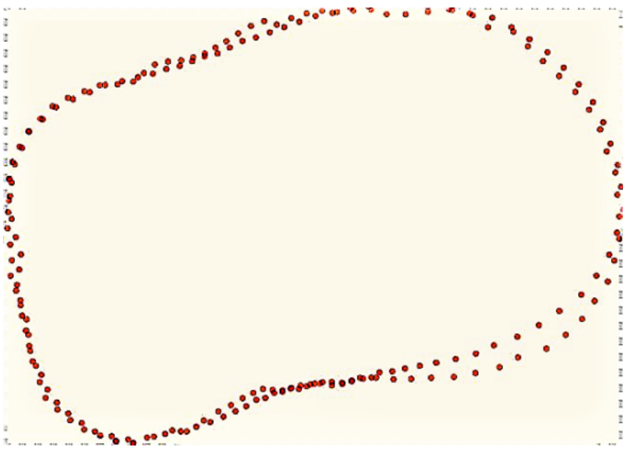

Figure 4. Superimposed enamel cervical edge contour projections

of the odontometric technique we here propose an effective projecting technique for studies of contours of dental morphological structures. However measurement results, especially in comparative studies, should be handled with attention, especially when the studied 3D reconstructions come from different sources.

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