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Evaluation of Dental Arch Form Using 3D Dental Cast Scanning Technology

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Introduction

The dental cast is the traditional three-dimensional (3D) patient record for measuring linear changes in the dental arch. However, plaster model analysis for this purpose does not provide important information such as structural and volumetric changes in the palate or 3D measurements of orthodontic tooth movement.

The use of 3D scanners to determine the surface contour of objects by optical methods has become important in scanning of dental structures to create a 3D model and to assess the dental arch form and jaw morphology parameters. Orthodontic treatments of most patients in permanent dentition stage use fixed appliances, with an arch wire as one of the most essential elements and the set of braces exerts continual force on the teeth and gradually urges them toward their intended positions. The lower jaw arch form is an important factor in the planning of orthodontic treatment and treatment outcome stability. Because the lower arch is more constrained, the limits of expansion for stability seem to be tighter for it than the maxillary arch. The basic principle of arch form in orthodontic treatment is that within reason, the patient's original arch form should be preserved.

Replacement of plaster orthodontic models with 3D computerized images can benefit in accuracy, efficiency, and ease of measurement of tooth and arch sizes [1].

Aim of study is to consider a possibility of using 3D models for evaluation of dental arch form and approximation of dental arch curvature by mathematical functions for treatment outcome planning.

Description of the method

The two-dimensional (2D) image processing techniques are widely used for dental arch form approximation [2-5]. In these cases the 2D digital camera is placed directly above the model for direct imaging. Prior to imaging, a black pencil can be used to mark points of interest on the dental casts. Using 2D capturing it is not possible to convert the image captured from pixels to real distances directly because of the zooming effect and because the size of the object imaged is not necessarily preserved. To associate the pixel count of each imaged model with the true length measurements (mm), each model can be placed within a box of known size or the millimeter acetate paper can be placed between the camera and the occlusal plane of the dental cast [2]. By using picture analysis software, the (x, y) location coordinates of each pixel representing the landmarks of interest can be converted into a matrix of numerical data representing the location coordinates of each landmark.

The curve fitting can be carried out for each case data set by utilizing a number of mathematical functions. This method is not accurate, because the occlusal plane of the dental cast can be assessed only using the spatial coordinates of the incisors and tips of the occluding surfaces of the posterior teeth.

Therefore, the geometric parameters of dental arches can be assessed using high-precision 3D dental scanner [1]. System operation is based on the laser triangulation method. The rotating platform, driven by a step motor, had a flat surface over which a dental cast was placed. The dental cast surface intersects with the known position of the laser plane, so using standard vector mathematical techniques it is possible to discover 3D locations of individual surface points. In this case, the point cloud of geometric samples of the surface of the dental cast is created. For meshing of surface point clouds captured from different views a special construction named the Power crust is used [6]. It takes a sample of points from the surface of a 3D object and creates surface mesh. Later the meshes captured from different views were registered using modified Iterative Closest Point (ICP) algorithm [7]. Remeshed 3D model of dental cast can be used for evaluation of dental arch form.

Twelve points were manually captured on each dental cast 3D model to represent the anatomical dental arch. The selected points were: the midincisal points of the incisors, the canine's cusp tips, the buccal cusp tips of the premolars, and the distobuccal cusp tips of the first molars (Fig. 1). For each 3D model of lower jaw, a numerical matrix was created and stored in a data file.

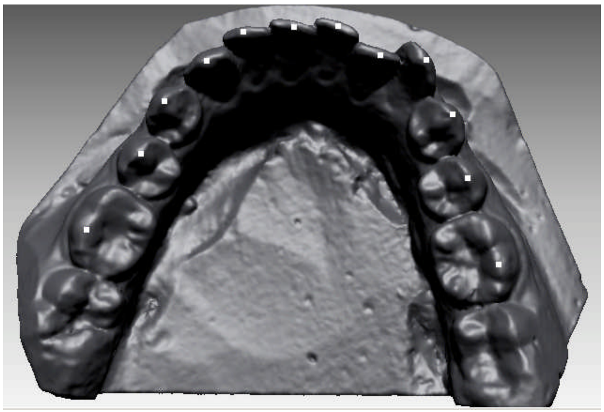

Fig. 1. Capturing of (x, y) location coordinates of pixels representing the anatomical dental arch

The orientation of the occlusal plane is an important clinical factor in treatment planning. 3D numerical data matrix of lower jaw was used for determinating the orientation of the occlusal plane. Principal Components Analysis (PCA) can be used to fit a linear regression that minimizes the perpendicular distances from the data matrix to the fitted model. This is the linear case of what is known as Orthogonal Regression [8, 9]. The coefficients for the first two principal components define vectors that form a basis for the plane. The third principal component is orthogonal to the first two, and its coefficients define the normal vector $\vec{n}$ of the plane. The equation of the fitted plane is:

$$[x\ y\ z] \cdot \vec{n} + M \cdot \vec{n} = 0, \quad (1)$$

here $M = [\bar{x} \quad \bar{y} \quad \bar{z}]$ – coordinates of centered point.

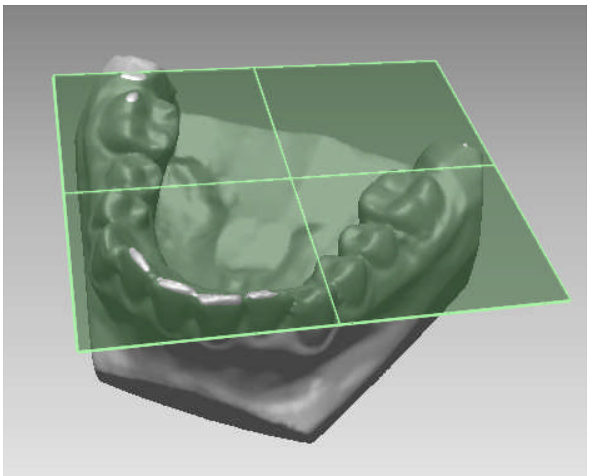

Fig. 2. 3D Dental cast data and oclusal plane

Occasionally the 3D data has offset from the world origin. In this case the reorientation of such data before working on it is needed. Using (1) equation a computer model of dental cast can be turned in space, so that oclusal plane coincides with the plane (*x, y*) and the plane can be ploted on the original 3D computer model (Fig.2). In this case, the projections to the plane of twelve points, representing the anatomical dental arch, can be easily presented using reverse modelling software package Rapidform™ 2006.

It was found that 50% of the dental arch forms in subjects having normal occlusion were best expressed by the fourth-order polynomial curves [4]:

$$y = p_1 \cdot x^4 + p_2 \cdot x^3 + p_3 \cdot x^2 + p_4 \cdot x + p_5, \quad (2)$$

here $p_1 \dots p_5$ – polynomial coefficients calculated with 95% confidence bounds using MATLAB Curve Fitting Toolbox. In Fig. 3, the fourth-order polynomial showed approximation of the data points representing the anatomical dental arch. This curve is a useful tool in treatment planning, because it represents the ideal arch form of subject after treatment (Fig. 4). But this method requires capturing of location of pixels representing the anatomical dental arch (manual determination of the spatial coordinates of each tooth is needed).

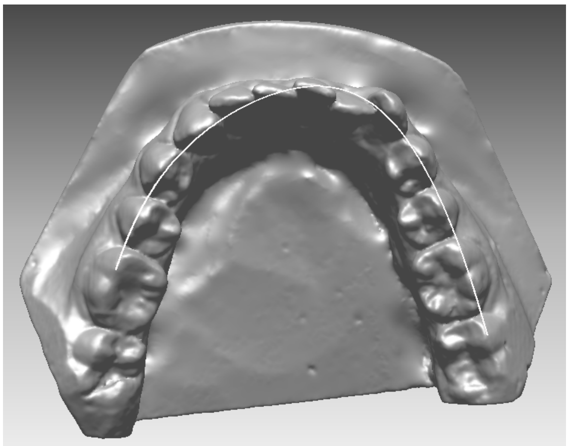

Fig. 3. Polynomial fitting for lower arch of subject before treatment

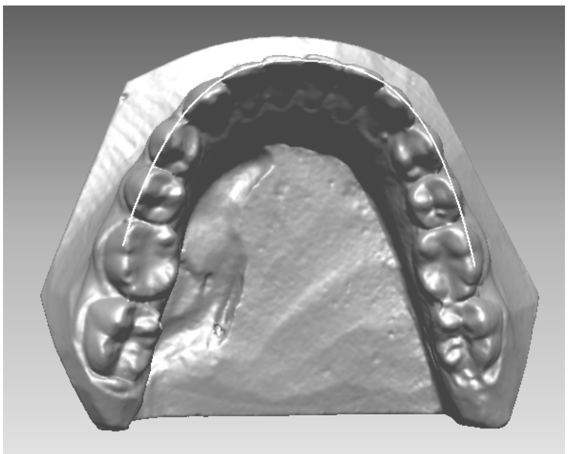

Fig. 4. Polynomial fitting for lower arch of subject after treatment

One of the possible ways to overcome this problem is to use the spatial positions only of the incisors and first molars. In this case, low order polynomial curve or β function can be used for approximation of dental arch form. The β function is an empirical formulation [5] expressed as:

$$y = 3.0314 \cdot D \cdot \left(\frac{x}{W} + \frac{1}{2}\right)^{0.8} \cdot \left(\frac{1}{2} - \frac{x}{W}\right)^{0.8}, \qquad (3)$$

here W – the molar width. It is the measured distance between the right and left first molars distobuccal cusp tips. D – the arch depth. It is the average perpendicular distance from the central incisors to the molar cross-arch dimension at the points at which W is measured. In Figure 5, the β function approximation of the data points representing the anatomical dental arch is shown (red curve).

Second of possible ways is to use modification of Pont index for prediction of the posterior arch width (the distance between the first molars), if perpendicular distance from the central incisors to the first molar cross-arch dimension is known. In this case, the mesio-distal width of the four upper incisors must be manually measured (Fig.6) and entered in the window SJ of Korkhaus Orthometer. The dental arch width in first molar area and anterior arch length may be read directly from the instrument. So, β function for posterior arch width of subject can be calculated using orthometer data and spatial positions of distobuccal cusp tips of the first molars (yellow curve in Fig. 5).

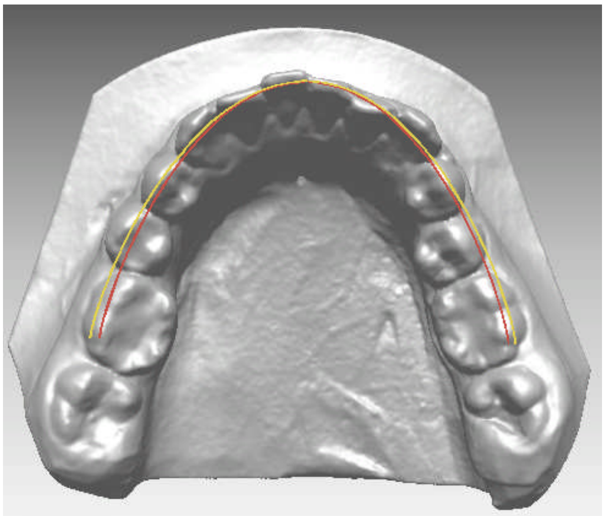

Fig. 5 Curve fiiting for posterior arch of subject: yellow – β function calculated using orthometer data, red - β function calculated using distobuccal cusp tips of the first molars and the central incisors

The β function is an empirical curve based only on two parameters (arch depth and molar width), it does not take the rest of the dental landmarks into consideration and it has no respect for asymmetry because it is a symmetrical function. So, there is no evidence that the β function fits to the entire dental arch and the possibility to use this method was experimentally tested.

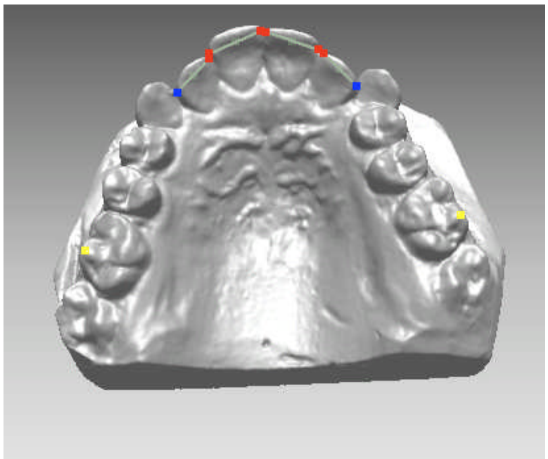

Fig. 6 Measurement of mesio-distal width of the four upper incisors

Results

To test the reliability of method the upper and lower dental casts of 15 persons before treatment and after treatment were scanned and the process of landmark capturing and numerical manipulation was applied. The spatial positions of the distobucal cusp tips of the first molars and measurement results were used for approximation of dental arch form. The approximation curves before treatment were compared with fourth-order polynomial fitting results for lower arch of subjects after treatment and cross-correlation coefficients were calculated.

In exclusive cases low correlation coefficient values were obtained when there were grubbed teeth in the dental cast. So, this data were removed from final statistical analysis of results.

Within a confidence interval of 90%, we could say that the average correlation coefficient between arch shape expressed by β function, calculated using orthometer data, and arch shape after treatment, expressed by fourth-order polynomial, is 0,9682 with a standard deviation of 0,0203.

The mean correlation coefficient between arch shape expressed by β function, calculated using real positions of the first molars and the central incisors, and arch shape after treatment, expressed by fourth-order polynomial, is 0,9455 with a standard deviation of 0,0308. So, the function calculated using distobuccal cusp tips of the first molars and the central incisors was the function that better described dental arch configuration.

Conclusions

1. The 4th order polynomial can be used to predict an individualized ideal arch for each particular patient when spatial coordinates of all teeth are known. But this method requires significant time capturing of location of pixels representing the anatomical dental arch.
2. β function has been shown to be an accurate representation of the human dental arches using only distobuccal cusp tips of the first molars and the central incisors.

3. β function, calculated using orthometer data, can be used in the case when patient has abnormal or missing molars.
4. Scans of each patient's models with mapping of arch form and anatomy was accomplished for individualized treatment planning. 3D database from digital models is useful tool for analysis of developmental changes, diagnosis and treatment planning.

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R. Adaškevičius, A. Vasiliauskas. Evaluation of Dental Arch Form Using 3D Dental Cast Scanning Technology // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 5(93). – P. 99–102.

Aim of our study is to consider a possibility of using 3D models for evaluation of dental arch form and approximation of dental arch curvature by mathematical functions for treatment outcome planning. The three-dimensional scanner based on the laser triangulation method was used for scanning dental casts. Occlusal plane was determined using Principal Component Analysis method. Curve fitting of projected on plane anatomical points was carried out by utilizing β function calculated using orthometer data or distobuccal cusp tips of the first molars and the central incisors. For the analysis of the results correlation coefficient between fourth-order polynomial after treatment and β functions before treatment was calculated. The dental casts of 15 subjects were scanned and measured to test the reliability of method. 3D database from digital models is useful tool for analysis of developmental changes, diagnosis and treatment planning. Ill. 6, bibl. 9 (in English; summaries in English, Russian and Lithuanian).

Р. Адашкявичюс, А. Василяускас. Использование технологии трёхмерного сканирования для определения формы зубного ряда // Электроника и электротехника. – Каунас: Технология, 2009. – № 5(93). – С. 99–102.

Цель исследования состоит в том, чтобы рассмотреть возможность использования трёхмерных моделей для оценки формы зубного ряда и апроксимации его кривизны математическими функциями при планировании лечения. Принцип действия трехмерного сканера основан на методе лазерной триангуляции и используется для сканирования стоматологических моделей. Окклюзионная плоскость была определена путем использования метода главных компонент. Апроксимация на плоскости спроектированных точек была проведена с использованием бета-функции, рассчитанной с использованием данных ортометра или координат центральных резцов и первых моляров. Для анализа результатов был рассчитан коэффициент корреляции между значениями полинома четвертого порядка и бета-функции. Для проверки надежности метода были отсканированы и измерены стоматологические модели 15-и субъектов. Использование цифровых трёхмерных моделей является полезным инструментом при анализе изменений в росте, диагностике и планировании лечения. Ил. 6, библ. 9 (на английском языке; рефераты на английском, русском и литовском яз.).

R. Adaškevičius, A. Vasiliauskas. Dantų lanko formos nustatymas taikant erdvinio diagnostinių modelių skenavimo technologiją // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 5(93). – P. 99–102.

Darbo tikslas – ištirti galimybę erdvinę diagnostinių modelių skenavimo sistemą pritaikyti dantų lanko formai nustatyti ir jai aproksimuoti matematinėmis funkcijomis. Gipsiniams diagnostiniams modeliams skenuoti buvo naudojamas erdvinis skeneris, kurio veikimas paremtas lazerio trianguliacijos metodu. Okliuzinei plokštumai įvertinti taikytas principinių komponenčių analizės metodas. Ant okliuzinės plokštumos esančių anatominių taškų aproksimuojančiosios kreivės aprašomos empirine β funkcija, naudojant ortometro rodmenis arba kandžių ir pirmųjų krūminių dantų gumburų erdvines koordinates. Rezultatų analizei buvo apskaičiuoti ketvirtos eilės polinomu dantų lanką po gydymo apibūdinančios kreivės ir β funkcija dantų lanką prieš gydymą apibūdinančių kreivių koreliacijos koeficientai. Metodo patikimumui įvertinti buvo nuskenuoti 15 pacientų diagnostiniai modeliai ir atlikta jų kompiuterinių modelių analizė. Diagnostiniai dantų kompiuteriniai modeliai yra svarbi priemonė augimo pokyčių analizei, diagnostikai, taip pat gydymui planuoti. Il. 6, bibl. 9 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

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