

Referent Geometric Entities in Orthodontics on 3D Models

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SUMMARY

3D modeling is often used in orthodontics. Most commonly used software today is problem-oriented CAD system (OrthoCAD and others), as well as general CAD software for engineering modeling. Both methods require definition and use of various geometric entities to describe and monitor orthodontic status, but still there have been more than one approach to definition of geometric entities that characterize orthodontic parameters. The aim of this study was to define the referent geometric entities (RGE) on 3D models, perform their classification and provide examples of their application. For defining and monitoring orthodontic parameters the following RGE groups are used: (a) basic geometric entities (point, line, straight line, plane, curve, curved surface); (b) derived geometric entities (coordinate origin, coordinate system, coordinate plane, axis, edge, perspective); and (c) anatomical geometric entities (surfaces, points). In this study, using 11 examples is shown how orthodontic parameters can be modeled over three classification groups RGE. Presented analysis and RGE examples indicate that RGE give interdisciplinary and systematic approach to computer modeling in orthodontics, and create a basis for development and implementation of methods of anatomical features in orthodontics which can be used to set up an integrated orthodontic parameter.

Keywords: 3D modeling; orthodontics; reference geometric entity; integrated orthodontic parameter

INTRODUCTION

The application of new technologies supported by computers can be found in different fields of dentistry. These technologies are commonly used for: CAD – design and 3D modeling (prosthodontics, orthodontics, endodontics), CAE – calculations and simulations in dentistry (strain, deformations), and use of finite element method (FEM). They are also used for CAM – manufacturing of fixed prosthetics and orthodontic brackets using computers, RP – rapid prototyping (fixed prosthetic elements and elements of orthodontic appliances), and CAQ – modeling and quality assurance of dental restorations and orthodontic appliances [1, 2, 3].

3D modeling is often used in orthodontics. The most common application is CAD – 3D modeling of teeth, jaws, and orthodontic appliances, CAE – modeling and calculations of stress and strain of teeth and jaws, CAM – design and brackets manufacturing, RP – advanced manufacturing technology of brackets and CAQ – modeling and quality assurance of orthodontic appliances. For this purpose most commonly used systems are problem-oriented CAD system (OrthoCAD and others), as well as general CAD software for engineered modeling. Both require definition and use of various geometric entities to describe and monitor orthodontic status. 3D modeling is increasingly used in orthodontic practice and for defining specific orthodontic parameters. On the other hand there is no unified approach to defining geometric entities which define orthodontic parameters.

The aim of this study is to, based on data from the literature, define and classify the referent geometric entities (RGE). 3D digital model was used as an example to show RGE. This concept represents unique approach which connects software modeling in orthodontics using oriented and general CAD systems.

REFERENT GEOMETRIC ENTITIES

For defining and monitoring orthodontic parameters the following groups RGE are used: (a) basic geometric entities (point, line, straight line, plane, curve, curved surface), (b) derived geometric entities (coordinate origin, coordinate system, coordinate plane, axis, edge, perspective), and (c) anatomical geometric entities (surfaces, points).

Basic geometric entities are directly or indirectly used for composing, measurement and analysis of orthodontic parameters using 3D model.

Quimby et al. [4] investigated the accuracy and reliability of measurements of orthodontic parameters on digital models. Measured parameters were divided in seven categories: (i) mesiodistal width (greatest distance from the mesial anatomical contact point to the distal anatomical contact points of each tooth); (ii) the length of the arc (measured by segments, where segment A is the distance from the mesial contact point of the right first permanent molar to the mesial contact point of the right canine, segment B is the distance from the mesial contact point of the right canine to the mesial contact point of the right central

incisor, segment C is the distance from the mesial contact point of the left central incisor to the mesial contact point of the left canine, segment D is the distance from the mesial contact point of the left canine to the mesial contact point of the left first permanent molar); (iii) the width of the arc (in molar region distance between mesiobuccal cusps of first permanent molars, in the region of canines the distance between cusps of permanent canines); (iv) incisal distance (distance from the labial surface of mandibular central incisors to the lingual surface of maxillary central incisors); (v) overbite of incisors (the largest distance between the vertical overbite of maxillary and mandibular incisors); (vi) available space (sum of lengths of segments in maxilla and mandible: A+B+C+D); and (vii) demanding area (sum of mesiodistal width from central incisors to second permanent molars).

Al-Khatib et al. [5] measured orthodontic parameters that related to the size of teeth and dimensions of dental arch. Parameters are defined as follows: (i) intercanine distance (distance between cusps of canines); (ii) interpremolar distance, as the jaw (distance between buccal cusps of left and right first and second premolars); (iii) intermolar distance (distance between mesiobuccal cusps of right and left first permanent molars in both jaws); (iv) arc length (diagonal line between the tip of mesiobuccal cusp of the first molar and mesial part of the contact between central incisors); (v) dental arch perimeter (the sum of two bilateral segments of dental arch, where the first segment is the distance between distal measuring points of first molars and mesial contact points of canines and the second segment is the distance between distal contact points of lateral incisors and mesial contact points of central incisors).

Holographic sensor in the new system for scanning and measurement of dental models was the main topic of the study done by Redlich et al. [6]. They measured mesiodistal tooth width of 30 pairs of orthodontic models with mixed and permanent dentition. Digital computerized measurements of mesiodistal width of teeth in permanent dentition were performed by linear measurements (drawing transversal lines from occlusal surfaces of posterior teeth and front surface of anterior teeth, on the greatest width in mesiodistal direction) and measuring the section plane (using two fixed parallel intersected planes with transverse intersection). For easier measurement, each jaw was divided in four segments: right and left anterior (from medial line to the middle of canines), and right and left posterior region (the middle of canine to the middle of first molar).

Akyaicin et al. [7] compared measurements of mesiodistal widths and vertical height, and buccolingual widths on 60 models.

Choi et al. [8] measured degree of tooth movement by overlapping 3D digital models, over three teeth (canine, first premolar and first molar). For each model coordinate systems was set, and for overlapping second and third pair of palatal rugae were used because they did not change position during therapy.

Tarazona et al. [9] compared measurements done on digital models and models obtained by CBCT. After scan-

ning and processing, the measurements were performed on 3D models and models obtained by CBCT in 27 patients where most of them were scheduled for surgical procedure or had CBCT for other reason. Analysis included the following measurements: mesiodistal tooth width (maximum width between mesial and distal anatomical contact points); intercanine distance (linear between canine cusps or centre of their facets); intermolar distance (maximum distance between buccal surfaces of first permanent molars); dental arch length (the length of ideal line, which passes through ideal contacts of each tooth, and actually connects the most mesial and the most distal point of each of selected teeth from the first molar on the right to the first molar on the left in both dental arches).

James et al. [10] have studied Bolton comparing parameters on digital and plaster model by measuring the difference between six anterior maxillary and six mandibular teeth, as well as the difference in the width of 12 teeth from the first left molar to the first right molar in both jaws.

Comparison of Bolton analysis and PAR index is the main topic of the study by Stevens et al. [11]. They measured the size of teeth from the first left molar to the first right molar in both jaws. That measurement was used for Bolton analysis, as well as for all other measurements needed to calculate the PAR index. Maximum mesiodistal width was recorded for each tooth from expected contact point, if the tooth was properly positioned in the jaw. Incisal distance was measured from the labial surface of the most protruded upper central incisor to the labial surface of the most protruded lower central incisor. Overbite was also measured as the greatest overlap vertically between upper and lower central incisors. Measurements were performed on plaster and digital model.

Smith et al. [12] measured parameters for Bolton analysis. Sample included 180 patients of both genders with Class I occlusion as per Angle. Three races were included (White, Black, Hispano).

For digital models, Horton et al. [13] performed measurements in five directions: occlusal (width of all teeth in the occlusal plane); increased occlusal (width of all teeth that are magnified several times); view from the right side (width of all teeth); view from front (width of all teeth in three positions: left buccal, anterior, right buccal); qualitative (the model is rotated in several characteristic positions and width of all teeth measured). All measurements were performed in upper and lower jaw.

El Zanaty et al. [14] examined the accuracy of three-dimensional orthodontic parameters of digital, plaster and CT model, by measuring the following parameters: mesiodistal width of teeth (from the first permanent molar on the left to the first permanent molar on the right side); arch width (width of maxilla in the region of lateral incisors, width of mandible in the region of lateral incisors, width of maxilla in the region of canines, width of mandible in the region of canines, width of maxilla in the region of first molars, width of mandible in the region of first molars); length of anterior maxillary arch, length of anterior mandibular arch, length of posterior maxillary arch, length of posterior mandible; maxillary

and mandibular arch circumference; and the thickness of the palate.

Evaluation of the accuracy of the space analysis in 30 digital and plaster models was done by Mullen et al. [15]. Measurements were divided in two parts. The first part included measurements on plaster models: arc length (the sum of mesiodistal widths of teeth from the first left molar to the first right molar), Bolton ratio of teeth size as well as the time needed to complete the analysis. Measurements on the plaster model were done using digital gaging with accuracy of 0.1 mm, while on digital models, all measurements were done in specifically designed software.

In the study of Sjogren et al. [16] 20 sets of plaster models were selected. Measured variables of interest were: rotation, distortion (mesial-distal inclination), and irregularity (moved contact points) of upper and lower incisors, distance between incisors, overbite, parameter and length of jaw. Because patients were with mixed dentition, position of numerous lateral incisors could not be measured because of incomplete eruption and crowding.

In their study Leifert et al. [17] analyzed space availability by measuring arch length in the shape of parabola, described as a line across teeth bases from the mesial aspect of the right first molar to the medial aspect of the left first molar and its comparison with measured width of teeth in dental arch. Tooth width was measured with a digital sliding gage, while the length of the arc was measured by using the piece of wire. The wire was placed on the contact points of last teeth, cusps of canines, incisal edges of lateral and central incisors, the first molar on the right to the first molar on the left side. The length of wire was the length of arc accessible via the basal bone.

Derived geometric entities, when defined, allow performance of various analysis and simulation of orthodontic parameters, both in global coordinate system (for the jaw) and in the local coordinate system (for each tooth).

Nine linear distances in the global coordinate system were measured by Jacquet et al. [18]. They measured: one intercanine distance (distance between the canines cusps), four intermolar distances (two between buccal cusps of upper and lower first and second premolars and between palatal cusps of upper and lower first and second premolars), and four intermolar distances (between mesio-palatal cusps of upper first molars, mesio-buccal cusps of upper first molars, distopalatal cusps of upper first molars, distobuccal cusps of upper first molars).

Unusual technique of lingual placements of braces was shown in the study of Grauer and Proffit [19]. After scanning the following parameters were observed in the local coordinate system: angle ANB (to determine skeletal class), overbite, overjet, and the length of upper and lower jaw. The accuracy of scanner for generating digital models was 20 micrometers.

In their study Kasparov et al. [20] compared traditional plaster models, digital models and 3D printed copies based on different criteria. In the global coordinate system they measured: (a) x-plane intercanine distance (between cusps of canines); (b) y-plane (between intercuspal distance and mesio-palatal cusps of first permanent molars); and (c) z-plane (height of the clinical crown of canine).

Using the global coordinate system Bootvong et al. [21] measured the following parameters: overjet (distance from the labial surface of upper to the labial surface of lower incisors); overbite (distance between upper incisors and marked line on the labial surface of lower incisors); mesiodistal tooth width (distance between mesial and distal contact points of each tooth, parallel to the occlusal plane); intermolar distance (between mesio-buccal cusps of the first permanent molars); intercanine distance (between cusps of permanent canines). For digital models, criteria for distance measurements were determined on the screen and plaster models.

Anatomical geometric entities describe teeth morphology to define and establish two groups of entities (points, surfaces).

3D computer analysis done by Chen et al. [22] included 86 morphological points which were used to define 156 variable distances between points, and the distance between points and the referent plane. Defined morphological points included: middle of incisal edges of incisors, cusps of canines, cusps of premolars, buccal and palatal cusps of molars, the deepest points of the occlusal surface of premolars and molars, as well as contact points between all teeth. The distance between contact points of second molars and canines, the distance between contact points of second premolar on the left and right side, the width of arc in the area of canines, the width of arc in the area of premolars, the width of arc in the area of molars, the length of arc, Spee's curve etc.

In the following example, Bailey et al. [23] investigated the formula that could predict differences in the tooth size. Everything is based not only on the size of teeth, but also on the normal relations cusp - fossa that should be achieved as the ultimate goal of treatment. Mesiodistal width of teeth was defined as maximum distance between anatomical contact points when the tooth is in correct position. Measurements were done parallel with the occlusal virtual plane determined by all cusps of teeth that are in occlusion.

The effect of molar rotation on the arc length is shown in the study of McDonald et al. [24]. The coordinate system was oriented parallel to the occlusal plane of the models before treatment. They measured the distance between the cusps and x - and y- axes that enabled the calculation of distal, lateral and rotational changes of each molar.

Three-dimensional models based on the average shape of dental arch were constructed in the study of Nam et al. [25]. They selected 52 digitized anatomical points on the surface of virtual digital model. Through these points the curve was defined describing the shape of dental arch. After that, based on all curves, the mean curve was calculated to describe the average dental arch. Special feature of this research is that they defined 52 anatomical points which contributed to increased accuracy of measurements.

It is noticeable that all authors in their studies used more basic and derived geometric entities but the least anatomical geometric entities. In addition, in none of the studies all three groups of geometric entities were used. The current research is an attempt to present simultaneous use of all three groups of RGE as well as concepts which were used for their classification.

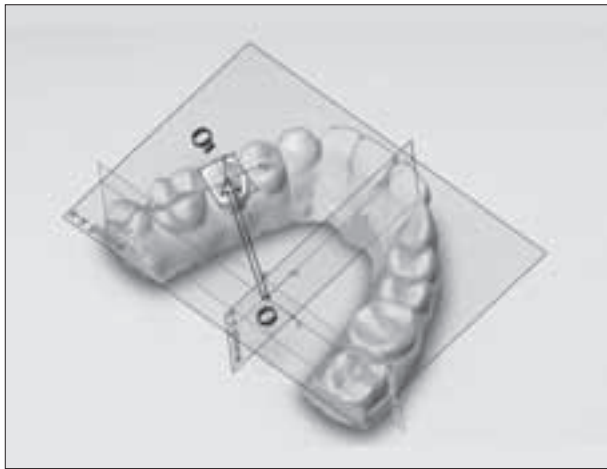


Figure 1. 3D model of dental arch of the upper jaw with global coordinate system shown

Slika 1. 3D model zubnog niza gornje vilice s prikazanim opštim koordinatnim sistemom

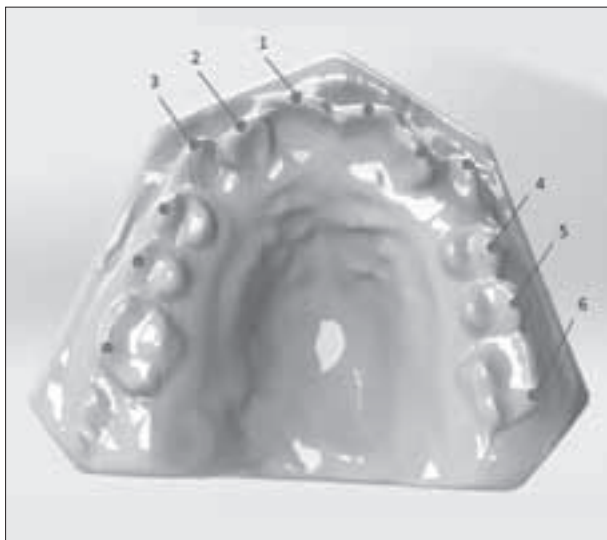


Figure 2. Points

Slika 2. Tačke

1 – middle of incisal edges of central incisors; 2 – middle of incisal edges of lateral incisors; 3 – canine cusp; 4 – buccal cusp of first premolars; 5 – buccal cusp of second premolars; 6 – buccodistal cusp of first molars

1 – sredina incizalne ivice centralnog sekutića; 2 – sredina incizalne ivice lateralnog sekutića; 3 – vrh kvržice očnjaka; 4 – vrh bukalne kvržice prvog premolara; 5 – vrh bukalne kvržice drugog premolara; 6 – vrh bukodistalne kvržice prvog molara

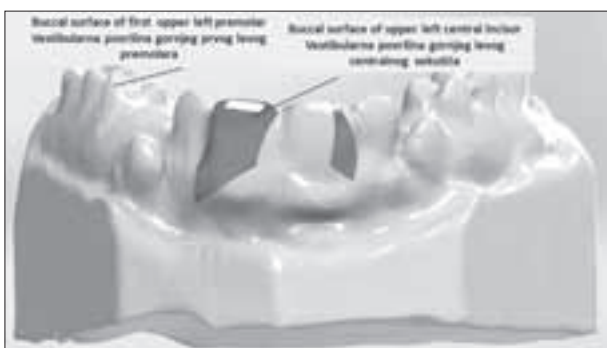


Figure 3. Curved surfaces on the model – characteristic teeth surfaces

Slika 3. Krive površine na modelu – karakteristične površine zuba

METHODS FOR DEFINING REFERENT GEOMETRIC ENTITIES

To show RGE on digital models, after obtaining consent from patients, alginate impressions were taken and plaster models were made. These models were scanned using NextEngine 3D scanner and 3D models obtained (Figure 1).

The basic geometric entities

Important points which define orthodontic parameters necessary for 3D models to be used for space analysis were marked. According to the literature, the following points were defined: middle of incisal edges of incisors, cusps of canines, buccal cusps of premolars, and distobuccal cusps of first molars (Figure 2).

A tooth represents complex spatial figure with curved surfaces and lines. Its shape and geometric accuracy depend on how scanning was performed as well as capabilities of software in which analyzes and measurements are performed (Figure 3).

Due to its appearance and method of production a model does not have straight lines if you look at the tooth or a series of teeth. On the other hand, some of orthodontic parameters can be defined as the distance between defined points. These points are used to measure distances between teeth of the same class or teeth of one class in one part of the jaw and teeth of another class in another part of the jaw (Figure 4).

In addition to being used to measure distance, these points can be used to measure the height of clinical crown. Clinical crown height is defined as the distance between the highest point on the buccal surface of the tooth and the edge of the model which represents the level of mar-

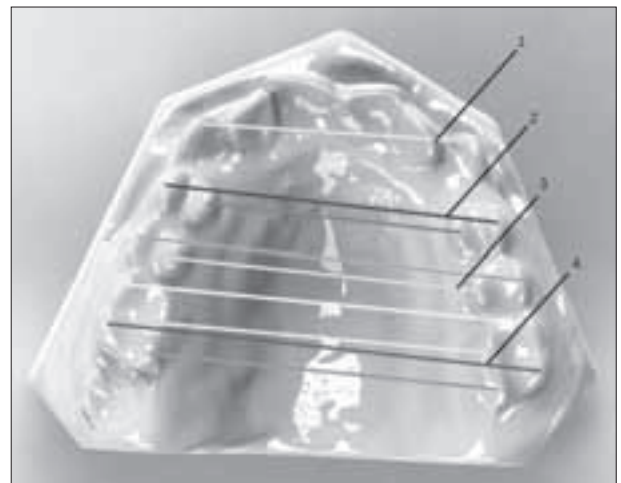


Figure 4. Straight lines on the model of upper jaw as referent geometric entities

Slika 4. Prave linije – duži na modelu gornje vilice kao referentni geometrijski entiteti

1 – distance between canine cusps; 2 – distance between buccal cusps of first premolars; 3 – distance between palatal cusps of second premolars; 4 – distance between buccodistal cusps of first molars

1 – rastojanje između kvržica očnjaka; 2 – rastojanje između bukalnih kvržica prvog premolara; 3 – rastojanje između palatinalnih kvržica drugog premolara; 4 – rastojanje između bukodistalnih kvržica prvih molara

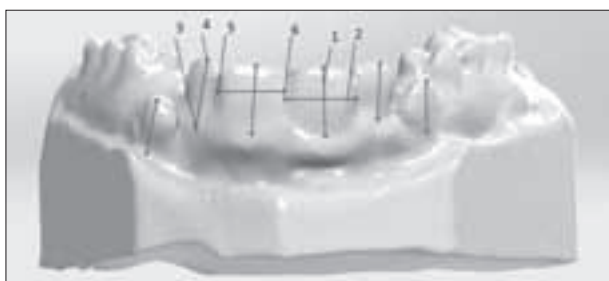


Figure 5. Teeth height measurement
Slika 5. Merenje visine zuba – definisanje duži

1 – clinical crown height; 2 – clinical crown width; 3 – the level of marginal gingiva; 4 – the highest points on the buccal surface of the tooth; 5 – distal contact point of the tooth; 6 – middle contact point of the tooth
1 – visina kliničke krunice zuba; 2 – širina kliničke krunice zuba; 3 – nivo marginalne gingive; 4 – najviše tačke na bukalnoj površini zuba; 5 – distalna kontaktna tačka zuba; 6 – medijalna kontaktna tačka zuba

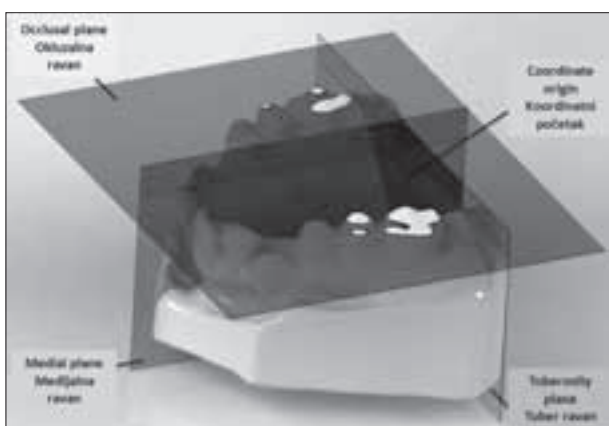


Figure 6. Coordinate system view in three planes (x-y, x-z and y-z)
Slika 6. Koordinatni sistem: pogled u tri ravni (x-y, x-z i y-z)

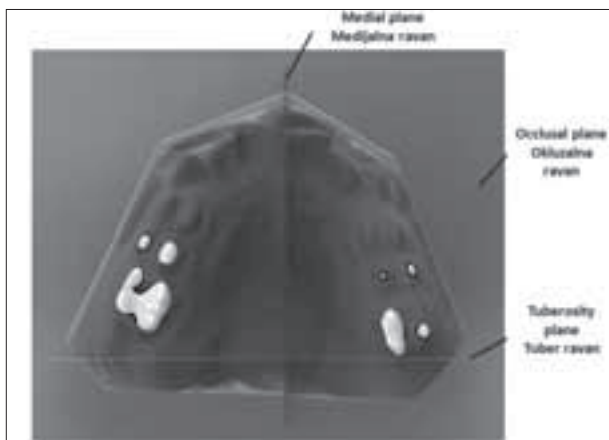


Figure 7. Coordinate system, view 2 (x-y plane) in the occlusal perspective
Slika 7. Koordinatni sistem: pogled 2 (ravan x-y), okluzalna perspektiva

ginal gingiva (Figure 5). The tooth width can also be defined as distance between that tooth and the neighboring tooth (Figure 5).

Derived geometric entities

To be able to use 3D model for space analysis (plaster model is gold standard) the global coordinate system is

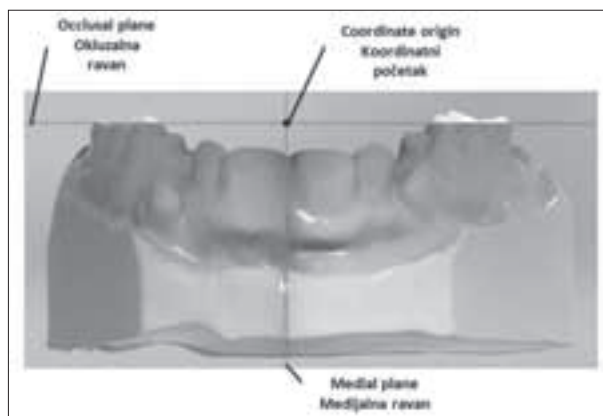


Figure 8. Coordinate system, view 3 (x-z plane) in the frontal perspective
Slika 8. Koordinatni sistem, pogled 3 (ravan x-z), frontalna perspektiva

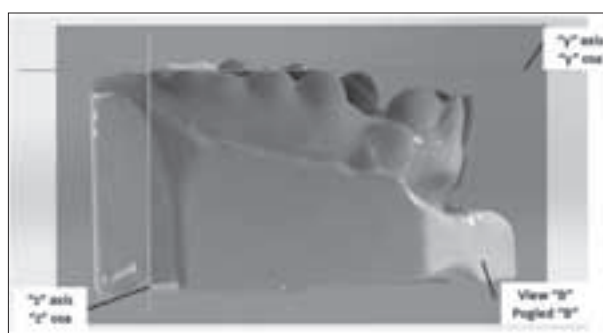


Figure 9. Coordinate system, view 4 (y-z plane) side perspective
Slika 9. Koordinatni sistem, pogled 4 (ravan y-z), bočna perspektiva

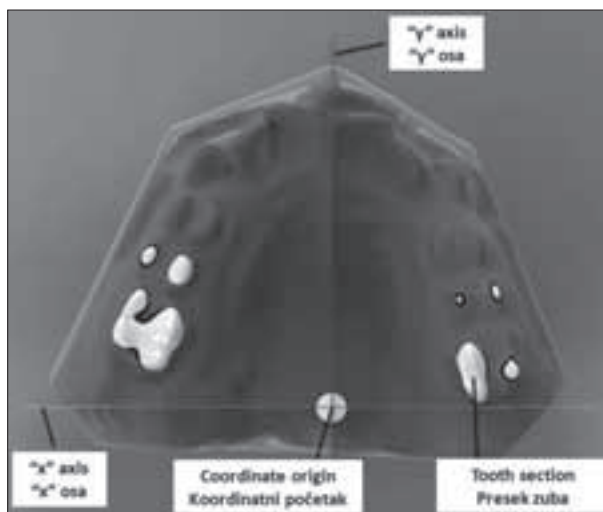


Figure 10. Coordinate origin is at the intersection of three orthodontic planes
Slika 10. Koordinatni početak se nalazi u preseku tri ortodontske ravni

defined where X-axis represents the base of medial plane which divides model into two equal halves and passes through the contact point of central incisors, Y-axis is determined by the tuberosity plane which touches the distal surface of first molars and Z-axis is determined by the occlusal plane which is parallel to the base of the model). The plane goes between the occlusal surfaces of molars and extends horizontally forward (Figure 6). This way, the global coordinate system is defined and set for all

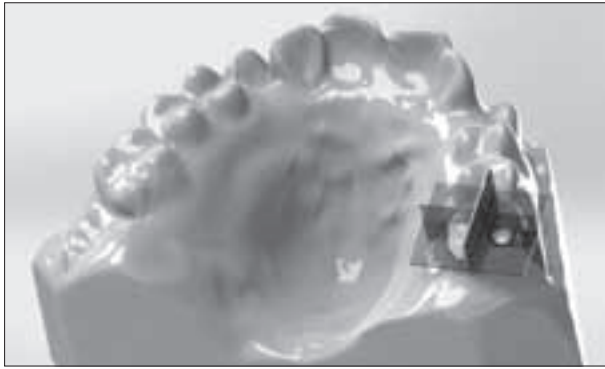


Figure 11. 3D model of upper jaw – the characteristic surfaces of teeth and the local coordinate system of the first molar
Slika 11. 3D model gornje vilice – tipične površine zuba i lokalni koordinatni sistem prvog molara

analyzes of orthodontic parameters in 3D digital model. It is important to note that in the current study “the local coordinate system” is defined for each tooth, where axes (x , y , z) are translated/rotated with respect to the global coordinate system and the coordinate origin is located on the characteristic point of the tooth.

Software for the analysis of 3D models allows model views in different perspectives and provides visual monitoring of orthodontic parameters change (Figure 7). Figures 8 and 9 show two more perspectives for the possible movements (front, side).

Both coordinate planes and coordinate origin are determined and all measurements done accordingly (along one axis, in the plane or in the space) (Figure 10). Axes that define typical orthodontic planes occlusal (x - y), tuber (y - z) and medial (x - z) are also defined.

Anatomical geometric entities

These entities define morphological shape of teeth. Each tooth has five surfaces: mesial, distal, buccal, lingual and occlusal. For measurements of the model occlusal surfaces are particularly important. Points that are used to measure appropriate distances necessary for diagnosis as well as therapy planning are defined on occlusal surfaces (Figure 11).

Using specific points on the occlusal surfaces distances are measured to assess the development of jaws. Anterior points are located in the deepest point of central fissure of the occlusal surface of first premolars, while posterior are located in the deepest point of central fissure of the occlusal surfaces of first molars. In the lower jaw points are slightly different, therefore, anterior points are located at the connection of buccal and mesial surface of second molars while posterior are found on the highest point of buccomesial or medial cusp of first molars (if there are three buccal cusps) (Figure 12).

CONCLUSION

The presented analysis and provided RGE examples allow accurate, precise and systematic 3D modeling. The use of computers in orthodontics creates a basis for development

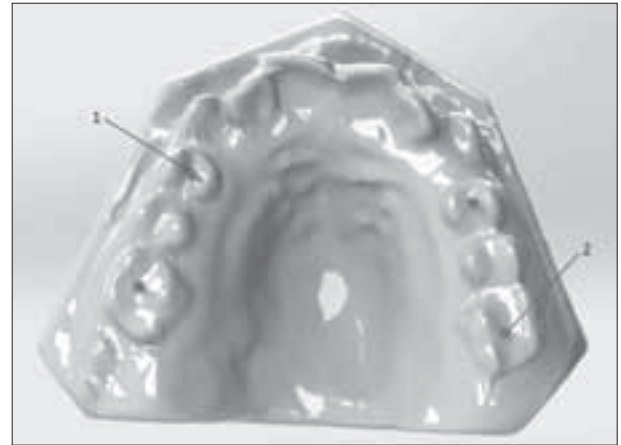


Figure 12. Marked points on first premolars and first molars (upper jaw model)
Slika 12. Obeležene tačke na prvim premolarima i prvim molarima (model gornje vilice)

1 – the deepest point in distal fissure of first premolars; 2 – the deepest point in the central fissure of first molars

1 – najdublja tačka distalne fisure prvog premolara; 2 – najdublja tačka centralne fisure prvog molara

and implementation of methods of anatomical features (AMF) in orthodontics, an actual integrated orthodontic parameter which shows that each orthodontic parameter can be defined in the global and/or local coordinate system depending on what is required.

Future research should be directed towards defining and modeling of all RGE on the 3D models and application of this model in practice for the diagnosis and monitoring of orthodontic treatment. That will introduce new approach to 3D modeling in orthodontics, which will result in simpler application of this concept in practice.

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Referentni geometrijski entiteti u ortodonciji na trodimenzionalnim modelima

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KRATAK SADRŽAJ

Trodimenzionalno (3D) modeliranje u ortodonciji nalazi sve veću primenu. Danas se za ove namene koriste problemski orijentisani sistemi CAD (OrthoCAD i drugi), kao i opšti softveri CAD za inženjerska modeliranja. Oba načina zahtevaju definisanje i korišćenje različitih geometrijskih entiteta pomoću kojih se opisuju i prate ortodontska stanja, ali još nema jednoznačnog prilaza definisanju geometrijskih entiteta, odnosno definisanju ortodontskih parametara. Cilj ovog rada je bio da se definišu i klasifikuju referentni geometrijski entiteti (RGE) na 3D modelima, te navedu konkretni primeri primene. U ortodonciji se, radi definisanja i praćenja ortodontskih parametara, koriste sledeće grupe RGE: a) osnovni geometrijski entiteti (tačka, prava, duž, ravan, kriva linija, kriva površina); b) izvedeni geometrijski entiteti (koordinatni početak, koordinatni sistem, koordinatne ravni, osa, ivica, perspektiva); i c) anatomski geometrijski entiteti (površine, tačke). U radu je kroz 11 primera prikazano kako se preko tri klasifikacione grupe RGE mogu modelirati ortodontski parametri. Prikazana analiza i primeri RGE pokazuju da je RGE sistematičan i interdisciplinarni pristup kompjuterskom modeliranju u ortodonciji, odnosno da stvara osnove za definisanje i primenu metoda anatomskih odlika u ortodonciji, pomoću kojih se može postaviti integrisani ortodontski parametar.

Ključne reči: 3D modeliranje; ortodoncija; referentni geometrijski entitet; integrisani ortodontski parametar

UVOD

Primena novih tehnologija podržanih računarom danas se sreće u različitim segmentima i oblastima stomatologije. Ove tehnologije se najčešće koriste u: CAD – projektovanju i trodimenzionalnom (3D) modeliranju (protetika, ortodoncija, endodoncija), CAE – proračunima i simulacijama u oblasti stomatologije (naponi, deformacije), odnosno korišćenju metoda konačnih elemenata (FEM), zatim CAM – proizvodnji stomatoloških nadoknada i ortodontskih bravica pomoću računara, RP – brzom izradi prototipa (fiksne nadoknade i elementi ortodontskih aparata), i CAQ – modeliranju i obezbeđenju kvaliteta stomatoloških nadoknada i ortodontskih aparata [1, 2, 3].

3D modeliranje nalazi sve veću primenu i u ortodonciji. Najčešća primena je u: CAD – 3D modeliranju zuba, vilica i ortodontskih aparata, CAE – modeliranju i proračunima napona i deformacija zuba i vilica, CAM – projektovanju i proizvodnji bravica, RP – naprednoj tehnologiji proizvodnje bravica, odnosno CAQ – modeliranju i obezbeđenju kvaliteta ortodontskih aparata. Danas se za ove namene koriste problemski orijentisani sistemi CAD (OrthoCAD i drugi), kao i opšti softveri CAD za inženjerska modeliranja. I jedan i drugi prilaz zahtevaju definisanje i korišćenje različitih geometrijskih entiteta pomoću kojih se opisuju i prate ortodontska stanja. 3D modeliranje nalazi sve veću primenu u ortodontskoj praksi i definisanju određenih ortodontskih parametara. S druge strane, nema jednoznačnog prilaza u definisanju geometrijskih entiteta pomoću kojih se definišu ortodontski parametri.

Cilj ovog rada je bio da se na osnovu podataka iz literature definišu i klasifikuju referentni geometrijski entiteti (RGE). Kao metoda korišćen je prilaz generisanja 3D digitalnog modela, a na njemu, kroz konkretni primer, prikazani su RGE. Ovaj koncept je jedinstveni prilaz ovoj problematici, koji na istovetan način povezuje softversko modeliranje u ortodonciji primenom orijentisanih i opštih sistema CAD.

REFERENTNI GEOMETRIJSKI ENTITETI

U ortodonciji se, radi definisanja i praćenja ortodontskih parametara, koriste sledeće grupe RGE: a) osnovni geometrijski entiteti (tačka, prava, duž, ravan, kriva linija, kriva površina); b) izvedeni geometrijski entiteti (koordinatni početak, koordinatni sistem, koordinatne ravni, osa, ivica, perspektiva); i c) anatomski geometrijski entiteti (površine, tačke).

Osnovni geometrijski entiteti su direktno ili indirektno korišćeni za komponovanje, merenje i analizu ortodontskih parametara pomoću 3D modela.

Kvimbi (*Quimby*) i saradnici [4] su istraživali tačnost i pouzdanost merenja ortodontskih parametara na digitalnim modelima. Merene parametre su podelili u sedam kategorija, i to: I) meziodistalna širina (najveće meziodistalno rastojanje od mezijalne anatomske kontaktne tačke do distalne anatomske kontaktne tačke svakog zuba); II) dužina luka (merena po segmentima, gde je segment A rastojanje od mezijalne kontaktne tačke desnog prvog stalnog molara do mezijalne kontaktne tačke desnog očnjaka, segment B rastojanje od mezijalne kontaktne tačke desnog očnjaka do mezijalne kontaktne tačke desnog centralnog sekutića, segment C rastojanje od mezijalne kontaktne tačke levog centralnog sekutića do mezijalne kontaktne tačke levog očnjaka, a segment D rastojanje od mezijalne kontaktne tačke levog očnjaka do mezijalne kontaktne tačke levog prvog stalnog molara); III) širina luka (u predelu molara rastojanje između meziobukalnih kvržica prvih stalnih molara, a u predelu očnjaka kao rastojanje između kvržica stalnih očnjaka); IV) incizalni razmak (rastojanje od labijalne površine mandibularnih centralnih sekutića do lingvalne površine maksilarnog centralnog sekutića); V) preklap sekutića (najveće rastojanje vertikalnog preklopa maksilarnih i mandibularnih sekutića); VI) dostupan prostor (zbir dužina segmenata u maksili i mandibuli: A+B+C+D); i VII) zahtevan prostor (zbir širina meziodistalnih širina zuba od centralnih sekutića do drugih stalnih premolara).

Al Hatib (*Al-Khatib*) i saradnici [5] su merili ortodontske parametre koji su se odnosili na veličinu zuba i dimenzije zubnog luka. Parametri su definisani na sledeći način: I) međuočnjačko rastojanje (rastojanje između vrhova kvržica očnjaka); II) međupremolarno rastojanje, kao vilice (rastojanje između bukalnih kvržica levog i desnog prvog i drugog premolara); III) međumolarno rastojanje (rastojanje između meziobukalnih kvržica desnog i levog prvog stalnog molara u obe vilice); IV) dužina luka (dijagonalna linija između vrha meziobukalne kvržice prvog molara i mezijalnog dela kontakta centralnih sekutića); V) perimetar zubnog luka (zbir dva bilateralna segmenta zubnog luka, gde je prvi segment rastojanje između distalnih mernih tačaka prvih molara i mezijalnih kontaktnih tačaka očnjaka, a drugi rastojanje između distalnih kontaktnih tačaka lateralnih sekutića i mezijalnih kontaktnih tačaka centralnih sekutića).

Holografski senzor u novom sistemu za skeniranje i merenje dentalnih modela glavna je tema rada Redliha (*Redlich*) i saradnika [6]. Ovde je merena meziodistalna širina zuba 30 pari ortodontskih modela s mešovitim i stalnom denticijom. Digitalna kompjuterska merenja meziodistalnih širina zuba stalne denticije izvedena su linearnim merenjem (iscrtavanjem transverzalne linije od okluzalne površine na poslednjim zubima i od prednje površine na prednjim zubima, na najvećoj širini u meziodistalnom pravcu) i merenjem preseka ravni (korišćenjem dve fiksirane paralelne presečne ravni s poprečnim presekom). Radi lakšeg merenja, svaka vilica je podeljena u četiri segmenta, i to: desni i levi prednji (od središnje linije do sredine očnjaka), odnosno desni i levi zadnji (od sredine očnjaka do sredine prvog molara).

Akjalčin (*Akyalcin*) i saradnici [7] su upoređivali merenja meziodistalnih širina i vertikalnih visina i bukolingvalnih širina na uzorku od 60 modela.

Rad Čoija (*Choi*) i saradnika [8] se bavi procenom stepena pomeranja zuba preklapanjem 3D digitalnih modela preko tri zuba (očnjak, prvi premolar i prvi molar). Za svaki model postavljen je koordinatni sistem, a za preklapanje modela korišćen je drugi i treći par palatalnih plika, zato što ne dolazi do promene njihovog položaja tokom terapije.

Tarazona (*Tarazona*) i saradnici [9] su upoređivali merenja urađena na digitalnim modelima i na modelima koji su dobijeni primenom CBCT. Nakon skeniranja i obrade na svim modelima obavljena su paralelna merenja. Za rad je izabrano 27 pacijenata, od kojih je većina bila planirana za hirurški zahvat i već je u svojoj dokumentaciji posedovala CBCT snimak iz nekog drugog razloga. Analiza je podrazumevala merenje: meziodistalne širine zuba (maksimalna širina između mezijalne i distalne anatomske kontaktne tačke); međuočnjačko rastojanje (linearno između vrhova kvržica očnjaka ili sredina njihovih faseta); međumolarno rastojanje (najveća razdaljina između vestibularnih površina prvih stalnih molara); dužinu zubnog luka (dužina idealne linije, koja prolazi kroz mesta idealnih kontakata svakog zuba, a zapravo povezuje najmezijalniju sa najdistalnijom tačkom svakog izabranog zuba, od prvog molara sa desne do prvog molara s leve strane, u oba zuba luka).

Džems (*James*) i saradnici [10] su se bavili poređenjem Boltonovih parametara digitalnog i gipsanog modela merenjem razlike između prednjih šest maksilarnih i šest mandibularnih zuba, kao i razlikama u širini za 12 zuba od prvog levog molara do prvog desnog molara u obe vilice.

Poređenje Boltonove analize i indeksa PAR glavna je tema rada Stivensa (*Stevens*) i saradnika [11]. Merenja su podrazu-

mevala merenje veličine zuba od prvog molara s leve do prvog molara s desne strane u oba luka. To je iskorišćeno za Boltonove analize, kao i za sva druga merenja neophodna za izračunavanje indeksa PAR. Maksimalna meziodistalna širina beležena je za svaki zub od očekivane kontaktne tačke, ako je zub bio pravilno postavljen u vilici. Incizalni razmak je meren od labijalne površine najisturenijeg gornjeg centralnog sekutića do labijalne površine najisturenijeg donjeg centralnog sekutića. Incizalni preklap je takođe meren kao najveći preklap u vertikali između gornjeg i donjeg centralnog sekutića. Merenja su vršena i na gipsanom i na digitalnom modelu.

Smit (*Smith*) i saradnici [12] su merili parametre za Boltonovu analizu. Ispitanike je činilo 180 osoba oba pola i tri rase (pripadnici bele, crne i Hispano rase) s okluzijom I klase po Anglu (*Angle*).

Na digitalnim modelima Horton (*Horton*) i saradnici [13] su vršili merenja analizom sa pet strana: okluzalno (merena je širina svih zuba u okluzalnoj ravni); uvećani okluzalni (merena je širina svih zuba koji su uvećani nekoliko puta); pogled sa strane desno (merena je širina svih zuba); pogled od napred (merena je širina zuba u tri pozicije: levi bukalni, prednji, desni bukalni); kvalitativni (model je rotiran u prostoru i za nekoliko karakterističnih položaja vršeno je merenje širine svih zuba). Sva merenja su izvedena i na gornjoj i donjoj vilici.

El Zanati (*El Zanaty*) i saradnici [14] su istraživali tačnost trodimenzionalnih ortodontskih parametara na digitalnom, gipsanom i CT modelu merenjem sledećih parametara: meziodistalna širina zuba (od prvog stalnog molara sa leve do prvog stalnog molara sa desne strane); širina luka (širina maksile u predelu lateralnih sekutića, širina mandibule u predelu lateralnih sekutića, širina maksile u predelu očnjaka, širina mandibule u predelu očnjaka, širina maksile u predelu prvih molara, širina mandibule u predelu prvih molara); prednja dužina luka maksile i mandibule; zadnja dužina luka maksile i mandibule; maksilarni i mandibularni opseg luka; odnosno debljina nepca maksile.

Procenu tačnosti analize prostora na 30 digitalnih i gipsanih modela vršili su Mullen (*Mullen*) i saradnici [15]. Merenja su podeljena na dva dela. U prvom je na gipsanim modelima merena dužina luka (zbir meziodistalnih širina svih zuba u luku od prvog molara s leve do prvog molara s desne strane), Boltonov odnos veličine zuba, kao i vreme potrebno da se analiza uradi. Na gipsanom modelu merenja su rađena digitalnim pomičnim merilom tačnosti od 0,1 mm, dok je na digitalnim modelima sve rađeno u softveru posebno dizajniranom za to.

U studiji Sjegrena (*Sjögren*) i saradnika [16] izabrano je 20 kompleta gipsanih modela. Promenljive od interesa koje su merene bile su rotacija, iskrivljenost (meziodistalna inklinacija) i nepravilnost (pomeranost kontaktnih tačaka) gornjih i donjih sekutića, rastojanje između sekutića, preklap sekutića, obim i dužina luka. Kako su pacijenti imali mešovitu denticiju, pozicija brojnih lateralnih sekutića nije mogla biti izmerena zbog nepotpunog izrastanja i teskobe.

U svojim istraživanjima Lajfert (*Leifert*) i saradnici [17] su analizirali prostor merenjem dužine luka u obliku parabole, opisane kao linije preko baza zuba od mezijalnog aspekta desnog prvog molara do mezijalnog aspekta levog prvog molara, i njenim poređenjem s izmerenom širinom zuba u zubnom luku. Širina zuba merena je digitalnim pomičnim merilom, dok je dužina luka merena komadom žice. Žica je postavljana tako da

leži preko kontaktnih tačaka poslednjih zuba, kvržica očajnika, incizalnih ivica lateralnih i centralnih sekutića, od prvog molara s desne do prvog molara s leve strane. Njena dužina predstavlja je dužinu luka dostupnu preko bazalne kosti.

Izvedeni geometrijski entiteti omogućavaju da se njihovim definisanjem vrše različite analize i simulacije ortodontskih parametara, kako u opštem koordinatnom sistemu (za vilicu), tako i u lokalnom koordinatnom sistemu (za svaki pojedinačni zub).

Devet linearnih rastojanja u opštem koordinatnom sistemu merili su Žak (*Jacquet*) i saradnici [18]. Oni su merili: jedno interočnjačko rastojanje (kao rastojanje između vrhova kvržica očajnika); četiri interpremolarne rastojanja (po dva između bukalnih kvržica gornjih i donjih prvih i drugih premolara, kao i između palatinalnih kvržica između gornjih i donjih prvih i drugih premolara); odnosno četiri intermolarne rastojanja (između meziopalatinalnih kvržica gornjih prvih molara, meziobukalnih kvržica gornjih prvih molara, distopalatinalnih kvržica gornjih prvih molara, distobukalnih kvržica gornjih prvih molara).

Neobična tehnika lingvalnog postavljanja bravica prikazana je u radu Grauera (*Grauer*) i Profita (*Proffit*) [19]. U lokalnom koordinatnom sistemu posle skeniranja posmatrani su sledeći parametri: ugao ANB (na osnovu koga se određuje skeletna klasa), preklap sekutića, razmak sekutića i dužina luka gornje i donje vilice. Tačnost skenera na kojima je generisan digitalni model bila je 20 μm .

U radu Kasparove (*Kasparova*) i saradnika [20] poređeni su tradicionalni gipsani modeli, digitalni modeli i 3D modeli štampanih kopija, koji su zasnovani na različitim kriterijumima. Izmerene dimenzije u opštem koordinatnom sistemu bile su: a) x-ravan – međuočnjačko rastojanje (rastojanje između kvržica na okluzalnoj površini očajnika); b) y-ravan (rastojanje između međukvržičnog rastojanja i meziopalatinalne prvog stalnog molara u vilici); i c) z-ravan (visina kliničke krune očajnika).

Korišćenjem opšteg koordinatnog sistema Botvong (*Bootvong*) i saradnici [21] su merili sledeće parametre: razmak sekutića (rastojanje od labijalne površine gornjih do labijalne površine donjih sekutića); preklap sekutića (rastojanje između gornjih sekutića i obeležene linije na labijalnoj površini donjih sekutića); mezdialna širina zuba (rastojanje između mezdialne i distalne kontaktne tačke svakog zuba, paralelno s okluzalnom ravni); međumolarne rastojanje (između meziobukalnih kvržica prvih stalnih molara); i međuočnjačko rastojanje (između kvržica stalnih očajnika). Za digitalne modele kriterijumi za merenje rastojanja utvrđeni su na monitoru kao i za gipsane modele.

Anatomski geometrijski entiteti opisuju morfologiju zuba na osnovu koje se definišu i uspostavljaju dve grupe entiteta: tačke i površine.

3D kompjuterska analiza Čena (*Chen*) i saradnika [22] obuhvatila je ukupno 86 morfoloških tačaka na osnovu kojih je definisano 156 promenljivih rastojanja između tačaka, odnosno rastojanje između tačaka i referentnih ravni. Definisane morfološke tačke su obuhvatile: sredine incizalnih ivica sekutića, vrh kvržica očajnika, vrhove kvržica premolara, vrhove bukalnih i palatinalnih kvržica molara, najdublje tačke okluzalnih površina premolara i molara, kao i kontaktne tačke između svih zuba. Merena su i rastojanja između kontaktnih tačaka na drugom molaru i očajniku, rastojanja između kontaktnih tačaka na

drugom premolaru s leve i desne strane, širine luka u predelu očajnika, širine luka u predelu premolara, širine luka u predelu molara, dužine luka, Speova (*Spee*) kriva itd.

Bejli (*Bailey*) i saradnici [23] su istraživali formulu kojom bi mogli da predvide razlike u veličini zuba. Sve je zasnovano ne samo na veličini zuba, nego i na normalnom odnosu kvržice i fose, koju bi trebalo postići kao krajnji cilj terapije. Za mezdialnu širinu zuba izabrano je najveće rastojanje između anatomskih kontaktnih tačaka kada je zub u pravilnom položaju. Merenja su rađena paralelno s virtuelnom okluzalnom ravni, koja je utvrđena korišćenjem svih vrhova kvržica zuba koji su u okluziji.

Efekat rotacije molara na dužinu luka prikazan je u radu Makdonalda (*McDonalda*) i saradnika [24]. Formiran je koordinatni sistem, koji je orijentisan paralelno s okluzalnom ravni modela pre terapije. Merena su rastojanja između vrhova kvržica i x i y ose, koja su omogućila računanje distalnih, lateralnih i rotacionih promena svakog molara.

Konstruisanjem 3D modela na osnovu prosečnog oblika zubnog luka u istraživanju Nama (*Nam*) i saradnika [25], na površini virtuelnih digitalnih modela uočene su i digitalizovane 52 anatomske tačke. Kroz njih je za svaki model pružena kriva koja opisuje oblik zubnog luka. Nakon toga, na osnovu svih krivih, izračunata je srednja kriva, koja opisuje prosečan zubni luk. Posebna odlika ovog istraživanja jeste ta da su definisane čak 52 anatomske tačke, što je doprinelo povećanju tačnosti merenja oblika zubnog luka.

Uočava se da su autori u svim svojim istraživanjima koristili osnovne i izvedene geometrijske entitete, a najmanje anatomske. Osim toga, ni u jednom radu istovremeno nisu korišćene sve tri grupe RGE. Ova istraživanja upravo su pokušaj da se predstavi istovremeno korišćenje sve tri grupe RGE, kao i pojmovi kojima je izvršena njihova klasifikacija, što predstavlja originalnost ovoga rada.

NAČINI DEFINISANJA REFERENTNIH GEOMETRIJSKIH ENTITETA

Radi prikazivanja RGE na digitalnim modelima, uz saglasnost pacijenta, uzeti su anatomske otisci u alginatu, izliveni i dobijeni gipsani modeli. Modeli su skenirani na 3D skeneru *NextEngine*, čime je dobijen 3D model (Slika 1).

Osnovni geometrijski entiteti

Nakon skeniranja pristupilo se obeležavanju važnih tačaka koje su neophodne da bi 3D model mogao da posluži u svrhu analize prostora, kojim se definišu ortodontski parametri. Proučavajući relevantna istraživanja iz ove oblasti u svetu i kod nas, na modelu su obeležene sledeće tačke: sredina incizalnih ivica sekutića, vrh kvržice očajnika, vrh bukalne kvržice premolara i vrh distobukalne kvržice prvih molara (Slika 2).

Kako je sam zub složena prostorna figura, na njemu se nalaze krive površine i linije. Njihov oblik i geometrijska tačnost zavise od načina na koji je skeniranje izvršeno, kao i od mogućnosti softvera u kojem se vrše analize i merenja (Slika 3).

Zbog svog izgleda i načina izrade, model gotovo da i nema pravih linija ako posmatramo zub ili niz zuba. S druge strane,

neki od ortodontskih parametara mogu se definisati kao rastojanja između definisanih tačaka. Te duži se koriste u merenju rastojanja između zuba iste klase u vilici, kao i između zuba jedne klase u jednom delu vilice i zuba druge klase u drugom delu vilice (Slika 4).

Pored toga što služe za merenje rastojanja, duži mogu poslužiti i u merenju kliničke visine krunice. Klinička visina krunice definiše se kao rastojanje između najviše tačke na bukalnoj površini zuba i ivice na modelu, koja označava nivo marginalne gingive (Slika 5). Takođe se može definisati i širina zuba kao rastojanje između tog zuba i susednih zuba (Slika 5).

Izvedeni geometrijski entiteti

Da bi 3D model mogao da se upotrebi u svrhu analize prostora (za šta se kao zlatni standard koristi gipsani model), definisan je opšti koordinatni sistem, gde su njegove ose definisane kao X-osa (koja predstavlja osnovu medijalne ravni, deli model na dve jednake polovine, a ujedno prolazi kroz kontaktnu tačku centralnih sekutića), Y-osa (određena sa tuber ravni, koja dodiruje distalne površine prvih molara) i Z-osa (koja je određena okluzalnom ravni, koja je paralelna sa bazom modela). Ravan prolazi između okluzalnih površina molara i pruža se horizontalno napred (Slika 6). Na ovaj način je definisan opšti koordinatni sistem, kao osnova za sve analize ortodontskih parametara u 3D digitalnom modelu. Ovde je važno napomenuti da je u ovom istraživanju definisan i tzv. lokalni koordinatni sistem, za svaki zub, čije ose (x , y , z) su samo translirane/rotirane u odnosu na opšti koordinatni sistem, a njegov koordinatni početak je lociran u karakterističnu tačku na zubu.

Softver u kojem se mogu raditi analize 3D modela omogućava prikaz modela u različitim perspektivama, koje obezbeđuje vizuelno praćenje promena ortodontskih parametara (Slika 7). Na slikama 8 i 9 prikazane su još dve perspektive mogućeg pomeranja (frontalna, bočna).

Kako su definisane koordinatne ravni, istovremeno je dobiten i koordinatni početak u odnosu na koji se vrše sva merenja – duž jedne ose, u ravni ili u prostoru (Slika 10). Takođe su de-

finisane ose koje zaklapaju tipične ortodontske ravni: okluzalna (x - y), tuber (y - z) i medijalna (x - z).

Anatomski geometrijski entiteti

Ovi entiteti definišu morfološki oblik zuba. Svaki zub sastoji se od pet površina: mezijalne, distalne, bukalne, palatinalne ili lingvalne i okluzalne. Za merenja na modelu naročito su važne okluzalne površine. Na njima se obeležavaju tačke koje služe za merenje odgovarajućih rastojanja neophodnih za postavljanje dijagnoze, kao i za planiranje kasnije terapije (Slika 11).

Koristeći određene tačke na okluzalnim površinama mere se i rastojanja koja služe za procenu razvijenosti vilica. Prednje se nalaze u najdubljoj tački središnje brazde okluzalne površine prvog premolara, dok se zadnje nalaze u najdubljoj tački središnje brazde okluzalne površine prvog molara. U donjoj vilici malo je drugačiji raspored, pa se prednje tačke nalaze u tački spajanja bukalne i mezijalne površine drugog molara, dok se zadnje nalaze na najvišoj tački bukomezijalne ili srednje kvržice prvog molara ukoliko postoje tri bukalne kvržice (Slika 12).

ZAKLJUČAK

Prikazana analiza i primeri RGE omogućuju, pre svega, precizno 3D modeliranje, koje je uz to jasno i vrlo sistematično. Primena komputera u ortodonciji stvara osnove za definisanje i primenu metoda anatomskih karakteristika u ortodonciji, koji je, u stvari, integrisani ortodontski parametar i pokazuje da se svaki pojedinačni ortodontski parametar može definisati u opštem i/ili lokalnom koordinatnom sistemu, u zavisnosti od toga šta je od analiza potrebno.

Buduća istraživanja treba usmeriti ka definisanju i modeliranju na 3D modelima svih RGE, odnosno primeni ovog modela u praksi za postavljanje dijagnoze i praćenje ortodontske terapije. Na ovaj način se uvodi novi prilaz 3D modeliranju u ortodonciji koji će omogućiti jednostavniju primenu ovog koncepta u praksi.