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The advanced model definition and analysis of orthodontic parameters on 3D digital models

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SUMMARY

Introduction/Objective Digital 3D modeling is slowly becoming an everyday orthodontic practice, and after two decades of research and development it is a basic element of e-orthodontics.
The aim of this study was development and use of geometric entities on 3D digital models for diagnosing, planning and monitoring of orthodontic therapy, by using CAD (computer aided design) systems.
Methods Statistical analysis and synthesis of 54 orthodontic parameters (28 in the upper and 26 in the lower jaw), defining three hypotheses and their testing, the application of the t-test.
Results All three hypotheses are confirmed, convenience of using geometric entities, higher accuracy of 3D digital models, and more substantial displacement of teeth in the first six months of therapy (Student's t-test). After the first six months, distances in the x–y plane (occlusal plane) were bigger in both the upper and the lower jaw; additionally, the distances in the y–z plane (medial plane) decreased on the left and right side, so we can say that the first phase of therapy had success and that both jaws are wider. At the next four controls, parameters showed slight progress that was not statistically significant. Overall, after 11 months of therapy, there was a considerable improvement in the x–y plane, while changes in distances of clinical crown heights were very small. This could be explained by the fact that, during therapy, by using different arches, upper molars were pushed inside, toward the palate. Analyzing 3D computer models, we could notice that in this plane displacement of the upper left first molar was larger.
Conclusion The use of geometric entities for defining orthodontic parameters gives us new possibilities for accurate and reliable analysis of patient's orthodontic condition.
Keywords: orthodontics; 3D modeling; diagnosis; therapy

INTRODUCTION

Research of development and use of 3D digital models in orthodontics have been going on for almost two decades [1]. There are two approaches today [2–5]. The first is the use of specialized software for orthodontics (Ortho CAD and others), developed by producers of dental equipment for generating 3D models and their analysis. Their basic characteristic is standardized use in already defined procedure, which puts the user in position of various constraints in using the system itself, and that means narrowed scope of research problems in applying and modeling. The second approach is the use of software for general purpose in CAD modeling (ProEngineer, CATIA, Siemens NX, and others), which are, primarily developed for engineering modeling, but can also be used in orthodontics. Their advantage is that they do not limit users in any way, but the disadvantage is that users must know how to use them, which could be an additional challenge for dentists.

At the beginning of the development and application of 3D modeling, the first approach was dominant, and today the second approach is used much more, and is applied in the study presented in this paper [2, 6].

Today, 3D modeling has found its wide application in orthodontics: (i) general model of application, at the beginning of development of 3D models (laser scanning, space analysis by using computers, diagnosis and planning of orthodontic therapy, Bolton analysis by using 3D models) [1, 7–10]; this approach was present by the first decade of the 21st century, and since then, thanks to the development and application of ICT technologies in orthodontics, today we have the additional areas of application of 3D modeling; (ii) analysis and synthesis of orthodontic parameters on digital and plaster models (accuracy, repeatability, validation, reliability, etc.)[2, 11–18]; (iii) occlusion analysis, planning and following orthodontic therapy using 3D models [19–27], and (iv) analyzing teeth displacement by 3D models of reverse engineering [24].

Our research presented in this paper is related to the second and third part of the approach to the development and application of 3D computer models in orthodontics.

Defining orthodontic parameters, in order to establish orthodontic diagnosis and follow orthodontic therapy by using 3D digital computer models, is performed according to a procedure similar to the one shown in Figure 1.

The purpose of this paper is to determine geometric entities (GEs) which are used to define orthodontic parameters, and then to use them to establish the diagnosis and to plan

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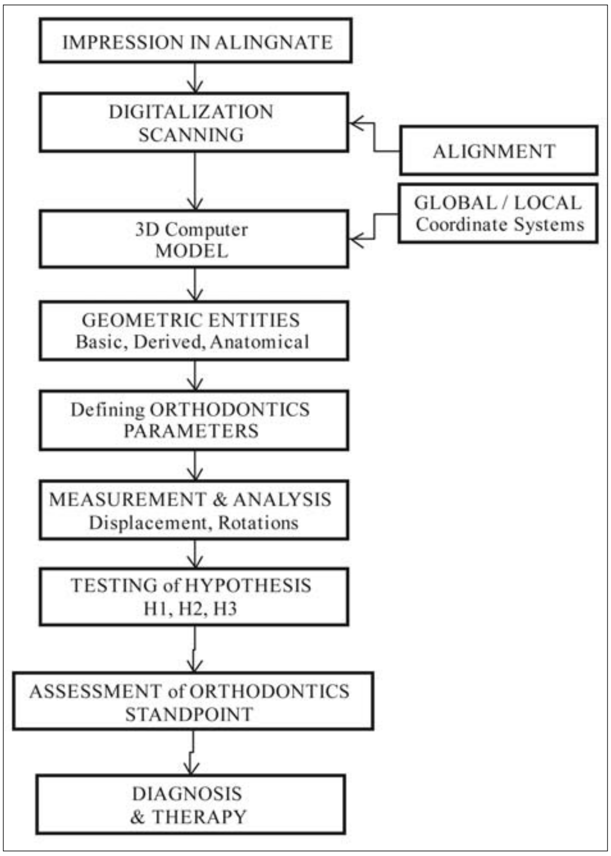

Figure 1. Flowchart of the formation of orthodontic therapy by 3D digital models

orthodontic therapy. The novelty in our research is the use of GEs as a tool for 3D modeling [4]. The whole concept is tested on 54 orthodontic parameters that were monitored during one year. Scanning was done on an ATOS scanner (GOM GmbH, Braunschweig, Germany), accuracy under 10 micrometers, and 3D modeling was done using PLM NX10 Software (Siemens PLM Software, Plano, TX, USA).

For defining orthodontic parameters on 3D digital models we used original approach, which is based on GEs: basic, derived, and anatomical [4]. The first group consists of points (coordinates), lines, axes, and curved lines. They refer to both tooth and the jaw. Derived GEs are the origin, the coordinate axes, and coordinate plane [occlusal (x–y), medial (y–z), and tuber (z–x) plane], and just like in the previous case, they are related to tooth and/or jaw, and anatomical entities – points, curve lines, and surfaces – as a rule relate to the tooth.

Finally, this study describes GE application through planning and monitoring of orthodontic treatment, but with determined values of tooth position movements (the study introduced translation in three planes, and along three axes; rotation will be included in some of the studies to follow), as well as the results of the treatment. Subject and aim of the study are GEs and their application on a concrete example, building a personal e-orthodontic model.

METHODS

Starting from the well-known facts pertaining to a new way of defining orthodontic parameters, i.e. through GEs, characterized by (i) the unambiguous way of presenting (always defined in the same way in global coordinate system – GCS), (ii) determined in more precise way (always at the same point for each control), and (iii) more accurate measuring (up to one tenth of a micrometer, or one ten thousandth of a meter), which is two or three classes more precise than the conventional way of measuring in orthodontics, we can define the following hypotheses:

H1: *GEs (basic, derived, anatomical) are an advanced method of defining orthodontic parameters*;

H2: *This way of defining, following, measuring, and analyzing orthodontic parameters can provide more accurate results in defining, diagnosing, and monitoring of orthodontic therapy*;

H3: *Values of standard deviations of orthodontic parameters which we monitored (28 for the upper and 26 for the lower jaw) are greater in the first six months of the therapy than in subsequent six months.*

These researches are based on defining all kinds of orthodontic parameters, which are in connection with orthodontic planes [4, 28].

In the occlusal plane (x–y plane) we defined, measured, followed, and analyzed the following parameters of the upper/lower jaw:

1. Inter-canine distance; measured as distance between:
   (1) Occlusal cusps of the upper canines (G1);
   (2) Occlusal cusps of the lower canines (D1);
2. Inter-premolar distance; measured as distance between:
   (1) Tips of buccal cusps of the upper and lower first and second premolars (G2, D2, G3, D3);
   (2) Tips of palatal cusps of the upper first and second premolars (D4, D5, G4, G5);
   (3) Tips of lingual cusps of the lower first premolars (G4, G5);
   (4) Tips of mesial lingual cusps of the lower second premolars;
3. Inter-molar distance; measured as distance between:
   (1) Tips of mesial palatal cusps of the upper first molars (G6, G8);
   (2) Tips of mesial buccal cusps of the upper first molars (G5, G7);
   (3) Tips of mesial lingual cusps of the lower first molars (D8);
   (4) Tips of distobuccal cusps of the upper and lower first molars.

In the medial plane (y–z plane) the following parameters were defined: in the upper arch, the distance from the tip of mesial palatal cusp of the upper second molar to:

(1) The tip of mesial palatal cusp of the upper first molar (G9, G14);
(2) The tip of palatal cusp of the upper first and second premolar (G10, G11, G15, G16);
(3) The tip of cusp of the upper canine (G12, G17);
(4) The mesial incisor edge of the upper lateral incisor (G13, G18).

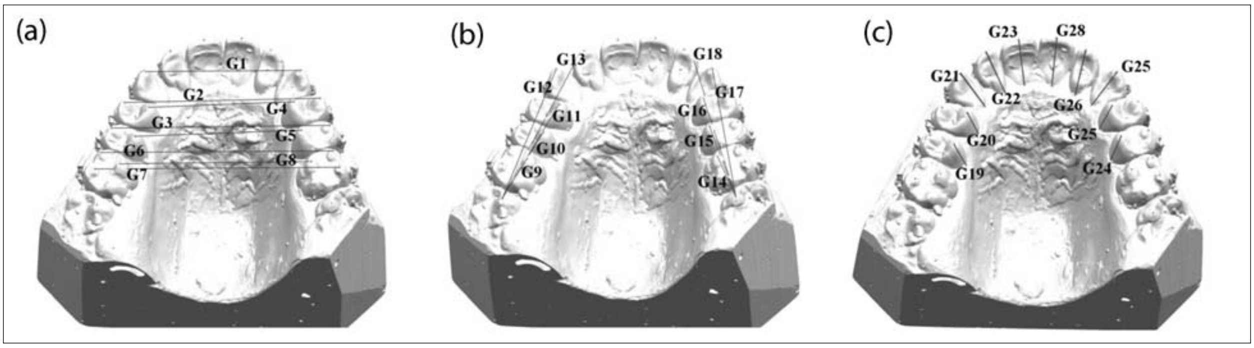

Figure 2. Orthodontic parameters for the occlusal plane (a), medial plane (b), and tuber plane (c) on the upper jaw – 28 in total

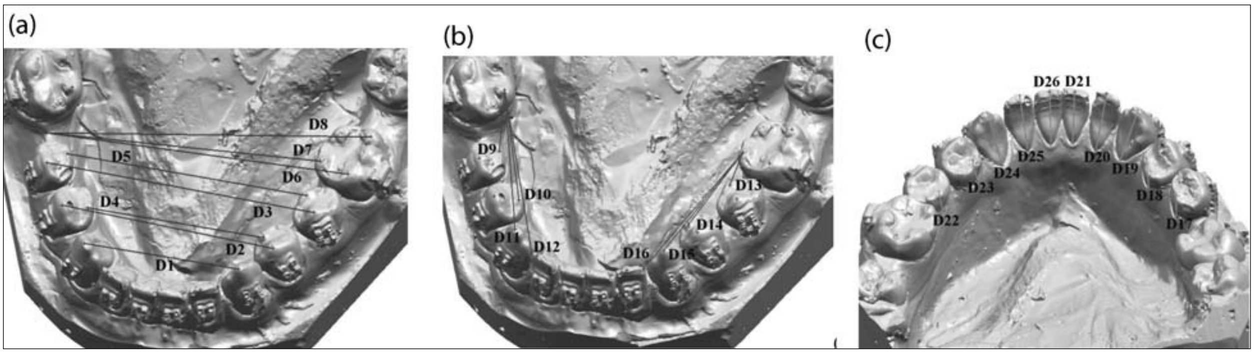

Figure 3. Orthodontic parameters for the occlusal plane (a), medial plane (b), and tuber plane (c) on the lower jaw – 26 in total

These parameters were measured on both sides of the upper dental arch. In the lower dental arch, the distance was measured between the tip of mesial lingual cusp of the lower second molar and:

(1) The tip of mesial lingual cusp of the lower first molar and second premolar (D9, D14);
(2) The tip of lingual cusp of the lower first premolar (D10, D11, D15, D16);
(3) The tip of cusp of the lower canine (D12, D17);
(4) The mesial incisor edge of the lower lateral incisor (D13, D18).

Finally, for the tuber plane (z–x plane), the following parameters were defined: clinical crown height of all teeth, in the upper and lower dental arches, from the second premolar to the second premolar, including them, measured as distance between the tip of cusp for posterior teeth (point on the middle of incisor edge for frontal teeth) and the point of maximum concavity of gingival line on the labial surface. The parameters defined for the upper jaw are G19 to G28, and D17 to D26 for the lower jaw.

Because brackets were placed on teeth, there was difficulty determining clinical crown height on teeth. Also, we noticed some defects in plaster models, which made marking parameters difficult, especially on the gingival line. Thus, we decided to monitor clinical crown height from the inside, i.e. from the lingual and palatal side. Although these displacements are smaller than the ones from the outside, they were taken into consideration so as not to lose the parameters in the z–x plane.

Examples of defining all parameters for all three orthodontic planes are shown in Figures 2 and 3. For the upper jaw, 28 parameters are shown (Figure 2). For the lower jaw, 26 parameters are shown (Figure 3). In this way, the study included a total of 54 parameters by which we can track a patient's orthodontic condition in an unambiguous manner.

RESULTS

At the first inspection of patient NN, there was a correlation between the upper and the lower jaw in the third class by Angle, along with the missing first lower molar on the left side and second lower molar on the right side [25]. In the upper jaw, all teeth were present. By measuring parameters and analyzing plaster models, it was concluded that the best solution for the patient was to combine orthodontic and surgical therapy. This means that, after receiving approval from the maxillofacial clinic, we put in the upper and lower fixed appliances, which were to be worn for about one year, and controlled every four weeks. Surgical treatment was to be done on the lower jaw, which is more developed than the upper one. The procedure consists of shortening the upper jaw to the level where we can reach satisfactory relationship of upper and lower teeth. Because of the missing first molar on the left, the bracket was attached to the second molar on the same side.

Analysis showed the lack of space in both jaws for placing the teeth in the right position. Situation was less favorable in the lower jaw, because we already had two missing teeth, so extraction was expected as the solution. In the upper jaw, we decided to solve the space problem without extracting teeth, despite the lack of space. We evaluated that a fixed appliance could give us enough space for placing all the teeth in one proper dental arch.

In the upper jaw, both lateral incisors were placed more palatal in relation to other teeth. Also, the lack of space was noticed in the frontal region, so the arch had a sharpened look. In the lower jaw, the only visible problem was partial rotation of lower left second premolar. By rotating this tooth, more space for better placing of other teeth in the lower jaw is obtained.

DISCUSSION

Analysis of control – hypotheses 1 and 2

At first control, after reviewing the results, some differences between all the parameters were noticed. The differences were not significant, as expected; given that the first month the thinnest nitinol wire was ligated. The first six months of therapy is the leveling period, i.e. the period when teeth are arranged in a better position in the dental arch. All subsequent displacement, such as closing spaces and the like, are done in later phases of the therapy. As teeth tend to get back to their old positions, so it was noticed that values of some parameters were lower than on the initial model. The biggest differences in the x–y plane in the upper jaw were noticed in the distance between the tips of palatal cusps of first premolars, and in the lower jaw between the tips of lingual cusps of the same lower teeth (1.5 and 1.2 mm, respectively).

As for the distance in the y–z plane, there was less displacement – less than 1 mm – which is particularly evident in the lower jaw. Some distances were even smaller, because side teeth have the tendency to change their location mesially.

The smallest differences (smaller than one tenth of a millimeter) were seen by comparing clinical crown height at the first control. Since the lower lateral incisors were damaged, the heights of the clinical crowns on the master model are not taken into account, due to the impossibility of setting parameters to the incisor edge. Similar problem was identified on the upper jaw, but the damage did not affect the precise placement of points on the incisor edge.

Table 1 gives an overview of the analyzed parameters (shown in Figure 2) for all 11 controls (including the master model), of the upper jaw. The same review of these parameters (Figure 3) for the lower jaw is given in Table 2.

The second control brought an increase in the values of five of eight parameters in the upper jaw in the x–y plane. Only the distances between the first molars recorded lower values. This happened because the arch led to the displacement of molars inward, leading to a reduction of the distance. The lower jaw also had a decrease in the value of half of the monitored parameters, all in the region of canine and premolars, which means that the mentioned teeth moved toward the palate.

The distances in the y–z plane in the upper jaw recorded an increase on both the left and the right side. The differences were minimal, but, unlike at the first control, they were visible in almost all parameters. Half of the parameters in the lower jaw recorded a slight increase, while the other half showed lower values.

What is still more interesting is that the height of the clinical crown of the teeth recorded an increase in value for all teeth in both the upper and the lower jaw. That could be explained by wire influence on teeth during the first phase of leveling, where, among other things, teeth leveling in regard to height occurs.

After three months of therapy, at the second control, all values in the x–y plane were higher, except for two distances in the molar region, which recorded a slight decrease.

The fourth month brought differences in distances in the x–y plane in all parameters, except that the differences were smaller than at the first two controls. The differences were noted on the second and third decimal place. These changes were not very significant as teeth in this phase of the therapy are still in the process of leveling in the vertical and horizontal plane. The height of the clinical crown of the teeth had even smaller values than at the first three controls, which means that the teeth were lower in the horizontal plane. These differences are still small and not very significant. All this is important because these displacements don't jeopardize the stability and vitality of the teeth.

After processing the results at the fifth control, the significant fact was that all parameters in the lower jaw in all three planes in space had increased. Despite the tendency of teeth to return to their original position, all values were higher compared to the previous control and in relation to the master model.

After the first six months, it was observed that the values of the distance in the x–y plane in the upper and lower jaw had increased, and that in addition there was a decrease in the distance in the y–z plane at both the left and the right side. All this leads to the conclusion that the first phase of treatment was successfully completed and that there was an expansion in the width of both jaws.

At the following four controls, the parameters generally showed a slight increase, which was not statistically significant. Generally, after ten months of treatment, progress was evident in the x–y plane, while the smallest change is seen in the height of clinical crowns of teeth. Distance decreasing in the x–y plane was noticeable in the distances between the molar cusps in the upper jaw. The explanation might be found in the fact that during therapy, application of certain arches, the upper molars were moved inside, toward the palate. By looking at 3D digital models, it is possible to notice greater displacement of the upper left molars in this plane.

Possibilities of defining a new model of gnathometric analysis, given that we are able to use 12 different elements (points, lines, planes, curves, curved surfaces, etc.), including particularly curves and curved surfaces, which pose a great challenge to the field of orthodontics and give it numerous possibilities (e.g. monitoring changes in teeth positions through multi-leveled intersections or under different angles depending on patients' orthodontic status, and in respect of the GCS of the jaw.

Table 1. Review orthodontic parameters for the patient's upper jaw (all values are in millimeters)

Plane		Master	Controls									
			1	2	3	4	5	6	7	8	9	10
Occlusal	G1	32.01	31.53	31.98	32.85	32.77	33.49	34.92	34.66	35.27	35.65	35.63
	G2	37.32	37.58	39.05	39.55	40.97	41.38	42.80	43.60	43.54	45.15	44.96
	G3	44.48	44.95	45.07	45.79	46.10	46.76	47.70	48.34	48.82	49.32	49.8
	G4	25.83	27.34	28.67	28.93	29.72	30.61	31.74	32.48	32.74	33.49	33.95
	G5	33.96	34.37	35.02	35.21	35.51	35.9	36.49	37.28	37.53	37.79	38.30
	G6	52.18	52.00	50.98	51.48	50.41	50.53	50.68	51.06	50.94	51.92	51.63
	G7	57.22	55.05	54.53	54.03	53.5	53.58	53.45	53.77	53.11	54.10	54.41
	G8	44.65	43.70	42.81	42.57	41.87	41.84	41.75	42.03	42.17	42.03	42.24
Medial	G9	11.80	11.00	11.30	11.40	10.84	11.03	10.98	11.30	11.33	11.54	11.38
	G10	19.40	18.99	19.33	19.60	18.82	19.22	19.05	19.27	19.59	19.21	19.70
	G11	28.01	27.49	27.59	27.66	26.99	27.46	27.18	27.25	27.52	27.02	27.34
	G12	36.22	35.55	35.90	35.25	35.13	36.15	35.93	36.1	36.37	35.68	36.07
	G13	39.34	40.31	40.21	41.07	39.60	40.46	40.05	40.29	40.59	39.51	41.23
	G14	11.8	11.15	11.25	11.34	11.04	11.28	11.05	11.05	11.33	11.26	11.62
	G15	19.99	19.24	19.26	19.44	19.36	19.40	19.32	19.41	19.28	19.93	19.73
	G16	28.33	27.08	27.31	27.33	27.34	27.24	27.03	27.09	27.00	27.30	27.10
	G17	35.43	35.10	35.09	35.46	35.45	35.34	35.24	35.51	34.96	35.63	35.76
	G18	38.41	39.08	40.41	40.62	40.43	40.24	39.99	39.96	39.63	40.06	40.46
Tuber	G19	6.68	6.72	6.90	6.91	6.81	6.96	6.95	6.83	6.65	6.61	6.91
	G20	6.14	6.30	6.54	6.42	6.36	6.55	6.50	6.47	6.27	6.62	6.67
	G21	8.74	8.99	9.32	8.89	8.97	9.48	9.39	9.46	9.27	9.56	9.48
	G22	8.90	9.03	9.68	9.65	9.05	9.7	10.02	9.66	9.63	9.90	10.09
	G23	9.35	9.57	9.52	9.76	9.68	10.32	10.12	9.71	10.02	9.94	9.64
	G24	7.08	6.56	7.14	6.95	6.64	6.96	6.93	6.98	6.80	6.90	7.07
	G25	6.57	6.54	6.80	6.57	6.44	6.71	6.77	6.55	6.32	6.60	6.56
	G26	8.90	9.28	9.19	9.38	9.23	9.22	9.43	9.38	9.24	9.61	9.29
	G27	9.46	9.03	9.91	10.10	9.91	10.23	10.15	10.27	9.81	9.95	10.09
	G28	9.66	10.23	10.36	9.88	9.91	10.51	10.63	10.41	10.33	10.40	10.29

Table 2. Review orthodontic parameters for the patient's lower jaw (all values are in millimeters)

Plane		Master	Controls									
			1	2	3	4	5	6	7	8	9	10
Occlusal	D1	26.13	26.07	26.00	26.40	26.63	26.91	27.25	25.72	24.97	25.74	25.83
	D2	35.46	35.81	35.88	36.58	36.53	37.33	37.89	39.17	38.60	38.95	39.12
	D3	43.46	44.01	45.44	45.93	45.95	45.90	46.29	46.67	47.33	46.48	47.06
	D4	29.93	29.92	29.67	30.32	29.90	30.36	31.09	31.54	31.60	31.43	32.01
	D5	39.94	41.14	40.56	39.84	40.05	39.76	40.17	40.51	40.20	40.27	40.73
	D6	52.22	53.10	53.06	52.90	52.98	52.47	52.77	53.12	52.46	52.23	52.70
	D7	54.49	55.30	55.51	55.08	55.32	55.19	55.69	55.38	55.29	55.46	55.76
	D8	46.62	47.35	47.85	47.53	47.57	46.95	47.26	47.46	47.43	47.32	47.69
Medial	D9	11.29	10.79	11.45	11.79	11.97	12.16	12.13	12.42	12.50	12.08	12.36
	D10	21.36	21.16	21.17	21.26	21.87	21.91	22.10	21.78	22.12	21.43	21.35
	D11	29.74	29.40	29.05	29.36	29.15	29.32	29.52	29.65	30.12	29.01	28.95
	D12	32.91	33.35	33.24	32.99	33.08	33.34	33.40	32.72	33.37	32.75	32.86
	D13	4.78	5.16	6.09	6.05	7.31	7.14	7.63	8.31	8.39	8.01	7.69
	D14	14.56	15.13	15.75	14.77	15.35	15.31	15.76	16.15	16.4	16.70	16.48
	D15	23.29	23.74	23.45	22.32	23.02	22.70	23.71	23.93	24.77	24.84	25.04
	D16	27.26	28.02	27.49	26.79	27.65	27.11	27.67	27.42	27.90	27.93	28.15
	D17	4.97	5.19	5.25	5.44	5.49	5.28	5.19	5.35	5.59	5.23	5.52
	D18	5.40	5.28	5.5236	5.31	5.49	5.30	5.58	5.48	5.34	5.35	5.65
Tuber	D19	9.94	9.42	10.11	10.09	9.99	9.78	10.03	9.76	9.61	9.52	9.75
	D20	*	10.09	10.33	10.12	8.71	9.96	10.04	10.05	9.81	9.96	10.23
	D21	8.83	8.80	9.12	9.05	8.93	8.95	8.98	8.94	8.95	8.74	9.10
	D22	4.55	4.55	4.66	4.64	4.85	4.68	4.78	5.00	4.78	4.78	5.16
	D23	4.53	5.01	4.72	4.58	4.86	4.74	4.95	4.80	4.93	4.88	4.48
	D24	9.98	9.99	10.35	10.07	10.07	9.80	10.17	10.00	9.80	10.15	10.36
	D25	*	8.41	10.27	9.99	9.84	9.71	9.81	9.91	9.66	9.67	9.93
	D26	8.96	9.04	9.30	9.02	8.96	8.98	9.07	8.83	8.60	8.84	9.18

* Could not be measured on all models, because of the damage on some samples

Table 3. Review of standard deviation (SD) parameters for the patient's upper jaw (parameters of SD dimensions are in millimeters)

No.	Upper jaw parameters	SD (1–5)	SD (6–10)
1	G1	0.69	0.39
2	G2	1.37	0.90
3	G3	0.68	0.73
4	G4	1.09	0.78
5	G5	0.51	0.59
6	G6	0.59	0.46
7	G7	0.58	0.46
8	G8	0.69	0.17
9	G9	0.21	0.18
10	G10	0.27	0.24
11	G11	0.23	0.17
12	G12	0.38	0.23
13	G13	0.47	0.57
14	G14	0.10	0.21
15	G15	0.07	0.25
16	G16	0.09	0.10
17	G17	0.16	0.29
18	G18	0.55	0.26
19	G19	0.09	0.13
20	G20	0.09	0.14
21	G21	0.23	0.09
22	G22	0.33	0.18
23	G23	0.29	0.18
24	G24	0.21	0.06
25	G25	0.13	0.14
26	G26	0.06	0.13
27	G27	0.42	0.16
28	G28	0.25	0.11
n		28/15	28/13
Average		0.3879	0.2979
SD		0.3150	0.2271
t (mathematical) = 0.0119 / for mutually dependent samples			

Occlusal plane – G1/G8; medial plane – G9/G18; tuber plane – G19/G28

Due to GEs, the model mentioned above provides us with absolute accuracy, given that parameters are measured (defined) with precision of 0.00001 mm. In this case, the comparison of our 3D digital model and manual measurements of the same parameters were needless, given that values of both measurements are expressed in 0.001 mm, so it would be needless to analyze/compare the same range of values since the accuracy depends only on interpreted results (i.e. random variable), and not on true values of orthodontic parameters. In the 3D digital model (GE model) in our case, this issue concerning accuracy is solved, as shown in the work, through H2 hypothesis.

This analysis shows that both H1 and H2 were verified from the aspect of GE and accuracy of the results.

Hypothesis 3 testing

Testing of H3 is based on the use of parametric Student's t-test for dependent samples. We performed measurements of all parameters on 10 samples, 28 parameters for the upper jaw, and they were statistically processed. Parameters of standard deviation for one half of a year were calculated. Values are presented in Table 3.

Hypothesis H3 testing for the upper jaw was done for three levels of significance (95% – 0.05, 99% – 0.01, and 99.9% – 0.001) as shown in Table 4.

Based on the results in Table 4, we conclude that H3 is accepted as true, for all three levels of significance – which confirmed the null hypothesis H3 each time, which in this case means that the "effect" of tooth displacement in their leveling in the upper jaw was more evident in the first six months in relation to subsequent six months.

We performed measurements for the lower jaw on 10 samples, 26 parameters, as well as their statistical analysis. The parameters for standard deviation for one half of a year were calculated. The values are presented in Table 5.

As for the upper jaw and lower jaw, H3 testing was done for three levels of significance (0.05, 0.01, and 0.001) and the results, presented in Table 6, lead us to conclude that H3 is accepted as true, for all three cases.

Due to the set of orthodontic parameters, the approach presented in this study enables orthodontic analyses for individual patients – personalized e-orthodontics. We statistically treated a set of parameters (54 in total, which we can define according to need – depending on a particular case), along with sets of dental imprints for an individual patient during one year (in this specific case, this period proved to be long enough) for both jaws – period of time proved to be relevant to make valid conclusions. Also, we applied Student's t-test to the patient concerning previously mentioned sets of dental imprints and analyzed the parameters. In this way, we wanted to show that it makes sense to present a case for personalized orthodontic approach. We have not, as one usually does, analyzed various demographics (sex, age, etc., or a specific orthodontic problem), since thit was not in accordance with our concept. In the

Table 4. Review of t-test parameters for the patient's upper jaw for three levels of significance

Data analysis for case 1 (95% – 0.05), 2 (99% – 0.01), and 3 (99.9% – 0.001)					
Pg	95%	99%	99.9%	Theoretical value	Notice
Alfa	0.05	0.01	0.001		
t (mathematical) / (95% – 0.05)	0.0119		<	2.0518	Comparison
t (mathematical) / (99% – 0.01)	0.0119		<	2.7707	Comparison
t (mathematical) / (99.9% – 0.001)	0.0119		<	3.6896	Comparison
Case 1 – for a given significance threshold hypothesis – H3 is accepted as true; the difference is not statistically significant					
Case 2 – for a given significance threshold hypothesis – H3 is accepted as true; the difference is not statistically significant					
Case 3 – for a given significance threshold hypothesis – H3 is accepted as true; the difference is not statistically significant					

Table 5. Review of standard deviation (SD) parameters for the patient's lower jaw (parameters of SD dimensions are in millimeters)

No.	Lower jaw parameters	SD (1–5)	SD (6–10)	Notice
1	D1	0.34	0.74	
2	D2	0.55	0.28	
3	D3	0.74	0.38	
4	D4	0.26	0.29	
5	D5	0.52	0.21	
6	D6	0.23	0.27	
7	D7	0.14	0.18	
8	D8	0.29	0.15	
9	D9	0.48	0.16	
10	D10	0.34	0.32	
11	D11	0.13	0.43	
12	D12	0.14	0.39	
13	D13	0.79	0.31	
14	D14	0.32	0.33	
15	D15	0.51	0.53	
16	D16	0.43	0.25	
17	D17	0.11	0.15	
18	D18	0.10	0.12	
19	D19	0.26	0.17	
20	D20	*	*	Damaged sample
21	D21	0.11	0.12	
22	D22	0.09	0.15	
23	D23	0.14	0.17	
24	D24	0.17	0.19	
25	D25	*	*	Damaged sample
26	D26	0.12	0.20	
n		24/9	24/15	
Average		0.3069	0.2713	
SD		0.2034	0.1466	
t (mathematical) = 0.4082 / for mutually dependent samples				

Occlusal plane – D1/D8; medial plane – D9/D18; tuber plane – D19/D26

case of our patient, statistics showed different variations for the first six months of the treatment in relation to the second six months, which was H3. This enables us to make positive conclusions, which we did. It is important to stress that we performed statistical data treatment for various time intervals (two, three, four, five, and six months), and the period of six months proved to be relevant for the comparison.

We can finally say that we obtained the same result for the lower jaw and all three levels of significance; thus, every time H3 was confirmed, which in this case means the same as for the upper jaw, the "effect" of teeth moving during their leveling in the upper jaw was more evident in the first six months of therapy then in the second six months.

CONCLUSION

The distances in the y–z plane marked a slight increase, which did not exceed a few tenths of a millimeter. The only major difference is noticeable in the distance between the second upper molar and lateral incisors, on both the right and the left side. At the beginning of the therapy, visible defect in the upper jaw was the position of the lateral incisors towards the palate, i.e. their palatal position. During the therapy we got a significant improvement in correction of their position. After ten months, both teeth were brought to a much better position in the dental arch.

In the lower jaw, differences were noticed in the distances on the right side. The distance on the left side did not change significantly. In explaining the changes on the right side we can take into consideration the lack of the first lower right molar, and the existence of space between the second molar and the second premolar. This space was not closed, but was somewhat used for placing teeth in frontal region in the correct place. During the ten months of therapy, the space was reduced, but not to a significant extent. The agreement with the patient was to preserve that space, so that it could be used for a prosthetic restoration of the missing tooth at a later time (after the completion of the therapy).

In the course of treatment there was displacement of teeth in the vertical direction along the z–x plane. As these displacements occur during therapy, they are not supposed to be significant. The results proved this. The differences are noted only on the second or third decimal place. Damage of lateral incisors at the lower master model enabled us to have values of clinical crown height at the beginning of the therapy. Despite the fact that later models were satisfactory, due to the lack of initial values, these teeth were excluded from the analysis. There was damage to the teeth on other models, but after marking all entities, we determined that these damages were not significant and did not affect the validity and accuracy of the results.

Finally, we can reach several conclusions pertaining to our GE approach.

Table 6. Review of t-test parameters for the patient's lower jaw for three cases

Data analysis for case 1 (95% – 0.05), 2 (99% – 0.01), and 3 (99.9% – 0.001)					
Pg	95%	99%	99.9%	Theoretical value	Notice
Alfa	0.05	0.01	0.001		
t (mathematical) / (95% – 0.05)	0.4082		<	2.0687	Comparison
t (mathematical) / (99% – 0.01)	0.4082		<	2.8073	Comparison
t (mathematical) / (99.9% – 0.001)	0.4082		<	3.7676	Comparison
Case 1 – for a given significance threshold hypothesis – H3 is accepted as true; the difference is not statistically significant					
Case 2 – for a given significance threshold hypothesis – H3 is accepted as true; the difference is not statistically significant					
Case 3 – for a given significance threshold hypothesis – H3 is accepted as true; the difference is not statistically significant					

Advancement of the existing coordinate system definition model according to the recommendations of the American Board of Orthodontics [28]. In this research, we define the GCS, following the recommendations of the American Board of Orthodontics, as well as the local coordinate system (LCS) (for each tooth), that enables additional analysis of orthodontic parameters (relating to the tooth, which, for example, had the biggest movements, etc.). Of course, all of these analyses, as well as those mentioned inthe previous section, were performed in 3D space, which enabled additional dimensional and angular analysis through GE (e.g. angle of tooth axe movement in relation to GCS or LCS axe, etc.).

Advanced simulation. 3D digital model from a CAD system provides various simulations of tooth positions within the jaw of a patient, as a result of its movements (translation, rotation) due to orthodontic treatment. Based on this, GE application makes it possible to perform various analyses we intend to present in some future studies.

Analysis of orthodontic parameters in three planes (in space). Previous researches on 3D models encompassed defining, measuring, and analyses of orthodontic parameters along just one plane, typically the x–y plane. Our analyses encompassed these analyses along all three planes, which is a new approach. What are the benefits? Given that teeth are distributed in space, more accurate results of their position are gained when their movements are monitored along three axes (x, y, z), and in three planes (x–y, y–z, z–x), as we did in the course of this research.

REFERENCES

1. Choi DS, Jeong YM, Jang I, Jost-Brinkmann PG, Cha BK. Accuracy and reliability of palatal superimposition of three-dimensional digital models. Angle Orthod. 2010; 80(4):685–91.
2. Majstorović N, Mačužić J, Radić D, Glišić B. 3D Modelling In Orthodontics – One Approach. In: Majstorović VD (ed.). Proceedings of the 7th International Working Conference "Total Quality Management – Advanced and Intelligent Approaches", 3rd–7th June 2013, Belgrade, Serbia, Session 4: Young PhD researchers. Belgrade: Mechanical Engineering Faculty; 2013. p. 245–52.
3. Mačužić J, Majstorović N, Glišić B. Application and Accuracy of 3D-Modelling in the Field of Orthodontics. Proceedings of the 35th International Conference on Production Enginering, Kraljevo–Kopaonik, September 23–28. Kraljevo: Faculty of Mechanical and Civil Engineering in Kraljevo; 2013. p. 235–40.
4. Majstorović N, Mačužić J, Glišić B. Referent geometric entities in orthodontics on 3D models. Serbian Dentel Journal. 2014; 61(2):102–12.
5. Majstorović N, Mašužić J, Glišić B. Using 3D Modeling in Assessment of Teeth Nivelation. In: Trajanović M, Stanković M (eds.). Proceedings of the 6th ICT International Conference – Synergy of Science and Innovation. Serbia, Niš, 14–16 October 2014. Niš: Regional Chamber of Commerce; 2014. p. 186–200.
6. Hayashi K, Chung O, Park S, Lee SP, Rohit CL, Sachdeva C, et al. Influence of standardization on the precision (reproducibility) of dental cast analysis with virtual 3-dimensional models. Am J Orthod Dentofacial Orthop. 2015; 147(3):373–80.
7. El-Zanaty HM, El-Belialy AR, El-Ezz AM, Attia KH, El-Belialy AR, Mostafa YA. Three-dimensional dental measurements: An alternative to plaster models. Am J Orthod Dentofacial Orthop. 2010; 137(2):259–65.
8. Horton HM, Miller JR, Gaillard PR, Larson BE. Technique comparison for efficient orthodontic tooth measurements using digital models. Angle Orthod. 2010; 80(2):254–61.
9. Grauer D, Cevidanes LH, Tyndall D, Styner MA, Flood PM, Proffit WR. Registration of orthodontic digital models. In: McNamara JA Jr, Hatch N, Kapila SD (eds.). Effective and Efficient Orthodontic Tooth Movement. Monograph 48. Craniofacial Growth Series. Ann Arbor: Center for Human Growth and Development; University of Michigan; 2011. p. 377–92.
10. Barbero B, Ureta E. Comparative study of different digitization techniques and their accuracy. Computer-Aided Design. 2011(43):188–206.
11. Jang SY, Kim M, Chun, YS. Differences in molar relationships and occlusal contact areas evaluated from the buccal and lingual aspects using 3-dimensional digital models. Korean J Orthod. 2012; 42(4):182–9.
12. Choi JI, Cha BK, Jost-Brinkmann PG, Choi DS, Jang IS. Validity of palatal superimposition of 3-dimensional digital models in cases treated with rapid maxillary expansion and maxillary protraction headgear. Korean J Orthod. 2012; 42(5):235–41.
13. Kihara T, Tanimoto K, Michida M, Yoshimi M, Nagasaki T, Murayama T, et al. Construction of orthodontic setup models on a computer. Am J Orthod Dentofacial Orthop. 2012; 141(6):806–13.
14. Im J, Cha JY, Lee KJ, Yu HS, Hwang CJ. Comparison of virtual and manual tooth setups with digital and plaster models in extraction cases. Am J Orthod Dentofacial Orthop. 2014; 145(4):434–42.
15. Grünheid T, Patel N, De Felippe NL, Wey A, Gaillard PR, Larson BE. Accuracy, reproducibility, and time efficiency of dental measurements using different technologies. Am J Orthod Dentofacial Orthop. 2014; 145(2):157–64.
16. Atia MA, El-Gheriani AA, Ferguson DJ. Validity of 3 shape scanner techniques: a comparison with the actual plaster study casts. Biom Biostat Int J. 2015; 2(2):00026.
17. Westerlund A, Tancredi W, Ransjö M, Bresin A, Psonis S, Torgersson O. Digital casts in orthodontics: A comparison of 4 software systems. Am J Orthod Dentofacial Orthop. 2015; 147(4):509–16.
18. Cho SH, Schaefer O, Thompson GA, Guentsch A. Comparison of accuracy and reproducibility of casts made by digital and conventional methods. J Prosthet Dent. 2015; 113(4):310–5.
19. Sousa MV, Vasconcelos EC, Janson G, Garib D, Pinzan A. Accuracy and reproducibility of 3-dimensional digital model measurements. Am J Orthod Dentofacial Orthop. 2012; 142(2):269–73.
20. Luu NS, Nikolcheva LG, Retrouvey JM, Flores-Mir C, El-Bialy T, Carey JP, et al. Linear measurements using virtual study models – a systematic review. Angle Orthod. 2012; 82(6):1098–06.
21. Kim S. Digital models made from two different scanning processes. 3M Unitek Orthodontic Products. 012-192 0902, 2013. Accessed August, 2015. Available from: http://multimedia.3m.com/mws/
22. Beuer F, Schweiger J, Daniel Edelhoff D. Digital dentistry: an overview of recent developments for CAD/CAM generated restorations. Br Dent J. 2014; 204(9):505–11.
23. Nalcaci R, Kocoglu-Altan AK, Bicakci AA, Ozturk F, Babacan H. A reliable method for evaluating upper molar distalization: Superimposition of three-dimensional digital models. Korean J Orthod. 2015; 45(2):82–8.
24. Pachêco-Pereira C, De Luca Canto G, Major PW, Flores-Mir C. Variation of orthodontic treatment decision-making based on dental model type. A systematic review. Angle Orthod. 2015; 85(3):501–9.
25. Park JU, Balk SH, Park JU. Classification of Angle Class III malocclusion and its treatment modalities. Int J Adult Orthod Orthognath Surg. 2001; 16(1):19–29.
26. Bailey E, Nelson G, Miller AJ, Andrews L, Johnson E. Predicting tooth-size discrepancy: A new formula utilizing revised landmarks and 3-dimensional laser scanning technology. Am J Orthod Dentofacial Orthop. 2013; 143(4):574–85.
27. Jacquet W, Nyssen E, Ibel G, Vannet BV. On the augmented reproducibility in measurements on 3D orthodontic digital dental models and the definition of feature points. Aust Orthod J. 2013; 29(1):28–33.
28. The American Board of Orthodontics (ABO) Digital Model Requirements. Accessed July 2015. Available from: https://www.americanboardortho.com

Нови модел за дефинисање и анализу ортодонтских параметара на 3*D* дигиталним моделима

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САЖЕТАК

Увод/Циљ 3*D* моделирање постаје све више свакодневна ортодонтска пракса, која после две деценије истраживања и развоја бива базни елемент е-ортодонције.

Циљ рада је био да се изврши развој и покаже примена геометријских ентитета (ГЕ) на 3*D* моделима за дијагнозу, планирање и праћење ортодонтске терапије применом општих компјутерски дизајнираних система.

Методе Статистичка анализа и синтеза 54 ортодонтска параметра (28 за горњу вилицу и 26 за доњу вилицу), дефисање три хипотезе и њихово тестирање, примена т-теста.

Резултати Потврђене су све три хипотезе: погодност за примену ГЕ, већа тачност 3*D* модела и веће померање зуба у првих шест месеци терапије (т-тест). После првих шест месеци уочено је да су вредности растојања у *x–y* равни (оклузална раван) у горњој и доњој вилици веће, а да је поред тога дошло до смањења растојања у *y–z* равни (медијална раван) и са леве и са десне стране, што значи да је прва фаза терапије успешно окончана и да је дошло до проширења обе вилице у ширини. У наредне четири контроле параметри су углавном показивали благи раст, који није био статистички толико значајан. Свеукупно кад се сагледа, након једанаест месеци терапије видљив је напредак у *x-y* равни, док су најмања померања виђена код клиничких висина круница зуба. Ово се објашњава чињеницом да су током терапије, применом одређених лукова, горњи молари увучени унутра, тј. померени према непцу. Анализом 3*D* дигиталних модела могуће је уочити да је настало веће померање код горњег левог молара у овој равни.

Закључак Примена ГЕ за дефинисање ортодонтских параметара даје нове могућности за тачну и поуздану анализу ортодонтског стања пацијента.

Кључне речи: ортодонција; 3*D* моделирање; дијагноза; терапија