10.1515/bjdm-2017-0005

BALKAN JOURNAL OF DENTAL MEDICINE BaSS ISSN 2335-0245

Examination of Scanner Precision by Analysing Orthodontic Parameters

SUMMARY

Background: *3D modelling in orthodontics is becoming an increasingly widespread technique in practice. One of the significant questions already being asked is related to determining the precision of the scanner used for generating surfaces on a 3D model of the jaw.* ***Materials and methods***: *This research was conducted by generating a set of identical 3D models on Atos optical 3D scanner and Lazak Scan laboratory scanner, which precision was established by measuring a set of orthodontic parameters (54 overall) in all three orthodontic planes. In this manner we explored their precision in space, since they are used for generating spatial models – 3D jaws.* ***Results***: *There were significant differences between parameters scanned with Atos and Lazak Scan. The smallest difference was 0.017 mm, and the biggest 1.109 mm.* ***Conclusion***: *This research reveals that both scanners (Atos and Lazak Scan), which belong to general purpose scanners, based on precision parameters can be used in orthodontics. Early analyses indicate that the reference scanner in terms of precision is Atos.*

Key words: Scanning, 3D modelling, Orthodontics, Precision

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ORIGINAL PAPER (OP)
Balk J Dent Med, 2017; 21:32-43

Introduction

Examination of scanner precision represents a significant aspect of its utilisation. Nowadays, it is performed via the following approaches: (i) calibration and precision analysis using the relevant international standard (laser measurement systems)[1-6], (ii) comparison of the precision of two scanners, with different levels of nominal precision, using measurements of real parameters[7], and (iii) indirect examination by comparison of orthodontic parameter precision by using manual and 3D models[8-9]. This paper uses the second approach, the comparison of two scanners on the examples of the measurement of the same parameters and the analysis of obtained results[10]. The advantage of this model lies in the fact that a scanner is analysed on real examples for which it will be later used.

The aim of this paper was to examine and determine the precision of two general scanners (Atos optical 3D scanner[11] and Lazak Scan laboratory scanner[12]) which could be used for the analysis and synthesis of orthodontic parameters on 3D models.

Materials and Methods

This research was conducted by generating a set of identical 3D models on Atos optical 3D scanner and Lazak Scan laboratory scanner, measuring and analysing 54 orthodontic parameters[10,13]. Impressions from a group of 25 patients were randomly collected at the Clinic for Orthodontics within the Faculty of Dentistry, Belgrade.

Jaw models were cast in the light reflecting plaster and therefore were ideal for the scanning even without the use of anti-reflection protection, as it was important to obtain accurately scanned plaster models (from a "cloud" of points gathered by scanning), primarily of teeth and gingival margin. Correctly positioned referential geometrical entities (RGEs) were used for measuring orthodontic parameters of the global coordinate system of the jaw (GCSJ)[13].

At the beginning of model scanning, the area of scanner measurement was first defined, accompanied by the calibration of Lazak Scan by the following procedures: setting the camera in the desired position and adjusting the camera focus for the projection. After that, the calibration plate was rotated, whereby the scanner independently generated images every few seconds. The calibration plate was moved over the entire measured area and then rotated so that the scanner would be at different angles. That is how an adequate algorithm was clearly defined, with the aim of adjusting the scanner to the space where scanning would be performed. In order to achieve model precision on occlusal surface, Lazak Scan was placed in such a way that beams aimed downwards in the direction of the plaster model with an angle of 55°, attaining a significantly smaller reflection of inner, outer and occlusal tooth surfaces. Each plaster model was scanned from 20 angles. Furthermore, 16 projections were positioned-rotated clockwise at approximately 22.5°.

After scanning and completing the 3D jaw model on the Lazak Scan, whilst operating Flex Scan 3D software from different angles/positions, the alignment of obtained models using the "Align" function was performed (Figure 1). This was achieved by using means of photogrammetric points on the impression, the entire jaw geometry and part of the 3D model (tooth) geometry. This procedure allowed removal of the redundant and unclear elements as well as various points in space, as a consequence of the alignment. In the subsequent step, by dint of the "Combine" function, a cleared individual scan was added to the set of scans (Figure 2). In this step we also chosed the surface roughness parameter and the texture. Finally, using the "Finalise" function, we obtained the final 3D model from a set of scans. This final model could later be improved and adjusted if necessary (Figure 3).

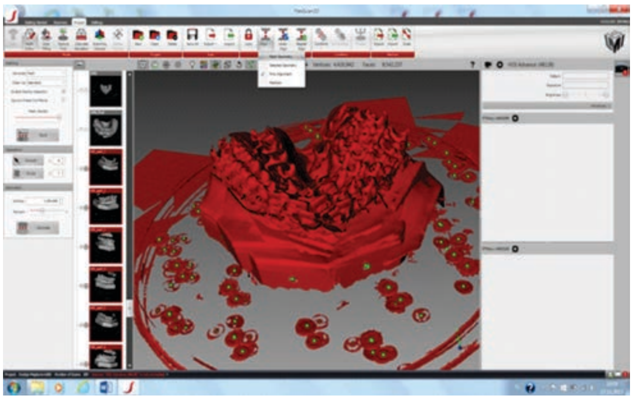

Figure 1. Merging scans into a set of scans – an example of an upper jaw

Once orthodontic planes were defined, the "Manual" function was selected for coordinate system orientation, whereby the directions of X, Y and Z axes were established (Figure 4). When determining the coordinate system on upper jaw models it is necessary to define the direction of X axis on the left (the model is observed from the side of the tooth) and Z axis in accordance with the model because its direction depends on the patient's head and not jaw; and Y axis is directed to the incisors. The alignment/connecting was done using the "Main Alignment by Coordinate Systems" function (Figure 5). The model was positioned in such a way that GCSJ was aligned to the coordinate system of the scanner (their axes were parallel).

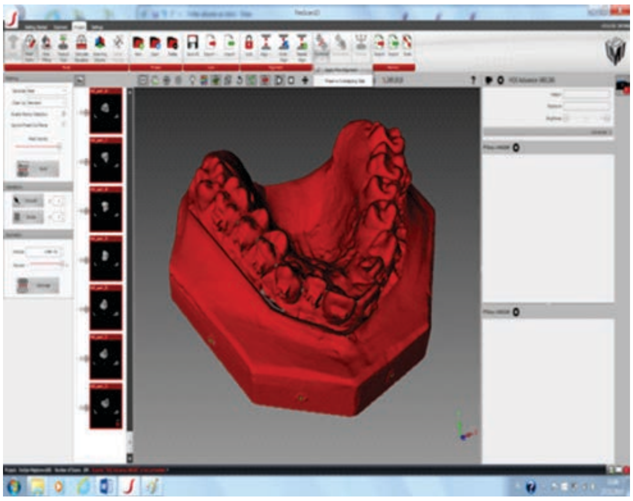

Figure 2. Connecting sets of scans using the "Combine" function for the upper jaw

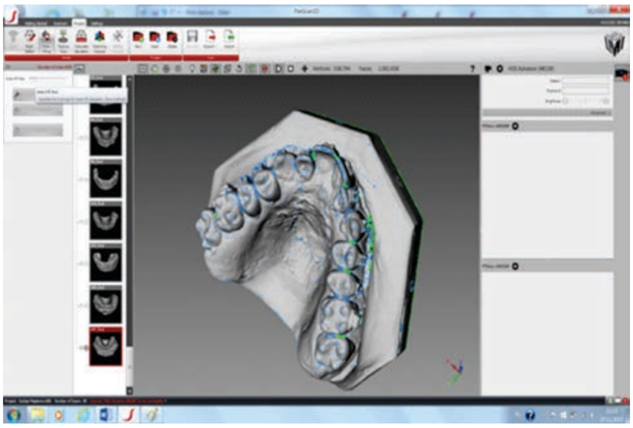

Figure 3. Independent filling of holes using the "Hole Filling" function - blue spots are ready to be filled, whilst green ones are not – an example of an upper jaw

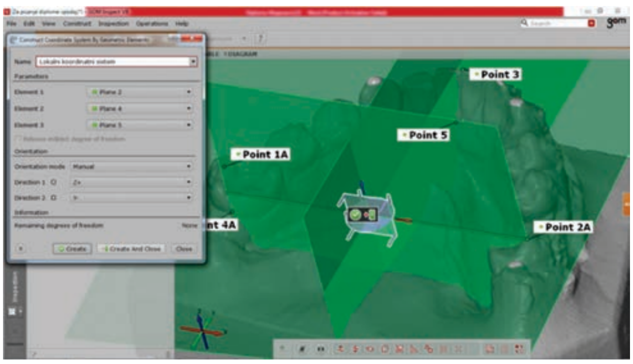

Figure 4. An example of a dialogue for defining the coordinate system on a lower jaw model

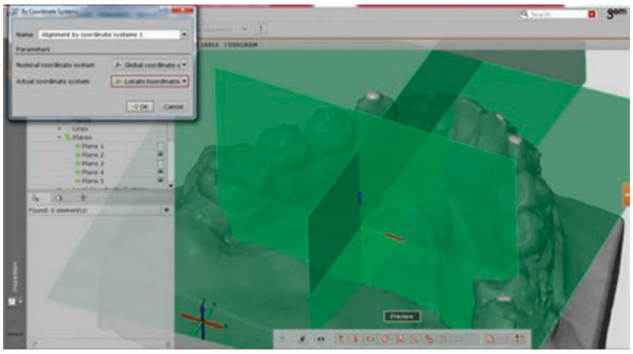

Figure 5. Alignment of coordinate systems (scanner – jaw) – lower jaw

After all coordinate systems and orthodontic planes were defined, using different intersections and projections, we could determine RGE and the points on tooth surface (most often anatomical points) for establishing orthodontic parameters in all three planes. We specified sets of linear orthodontic parameters using RGE[10] to define orthodontic planes in space. If the bumps on the gingival margin were developed as a result of the presence of air bubbles in the negative on the plaster model (Figure 6), the lowest points on the gingival margin, not covered in bumps, should be used. RGM 7 was a mark used only for points on lower jaw models, representing the best mesial point on the edge between teeth and gums (Figure 7-9).

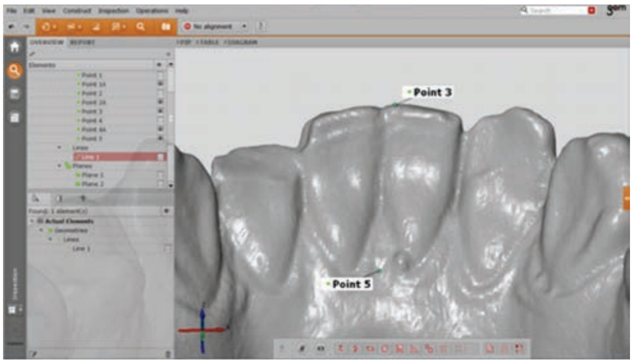

Figure 6. The position of the point for setting the median plane on a lower jaw model

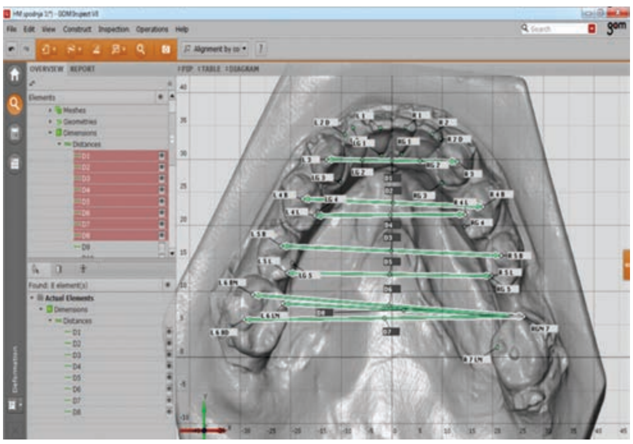

Figure 7. Defined orthodontic parameters from D1 to D8 on a 3D lower jaw model

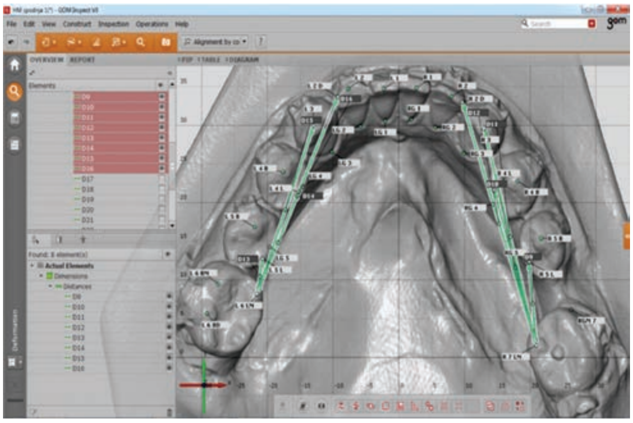

Figure 8. Defined orthodontic parameters from D9 to D16 on a 3D lower jaw model

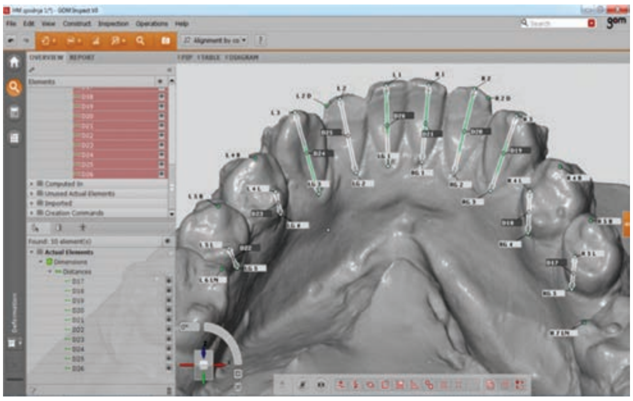

Figure 9. Defined orthodontic parameters from D17 to D26 on a 3D lower jaw model

In order to define/determine orthodontic parameters on the whole model (jaw) by the Atos system, we first performed the alignment by using means of the entire geometry of the model (jaw). This was realised in a way that we "import" the digital model and then define the global coordinate system on it with the help of RGEs. In the next step we defined orthodontic planes using at the same time the defined global coordinate system. This procedure utilises the "Change Actual Mesh to CAD Data" function. The same procedure was applied to the CAD model obtained by Lazak Scan. The alignment was conducted by means of the overall geometry of the jaw model, using the "Prealignment" function (Figure 10). On the surface of the model obtained by Lazak Scan we choosed the points which were located on the teeth, paying special attention not to select the filled spaces between the teeth and on their outer surfaces (Figure 11). In the next step we used the "Main Alignment by Local Best Fit" function, whereby we perform the exact alignment bearing in mind the chosen surfaces of the jaw model. In the end we provided a comparison of the surfaces using the "Surface Comparison on CAD" function, whereby we defined the interval/ tolerance for the desired value of error (on the scanned surface), defined in the interval of ±0,15 mm.

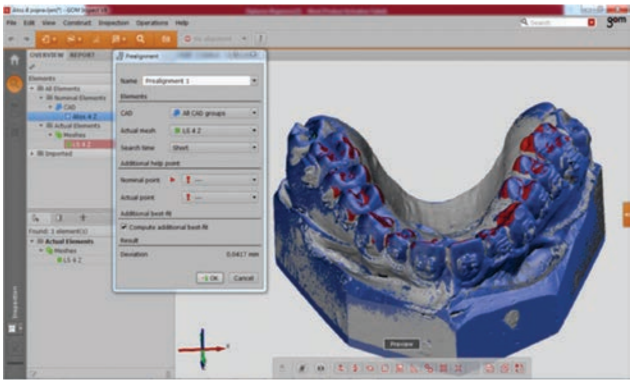

Figure 10. Using the "prealignment" function – an example of an upper jaw

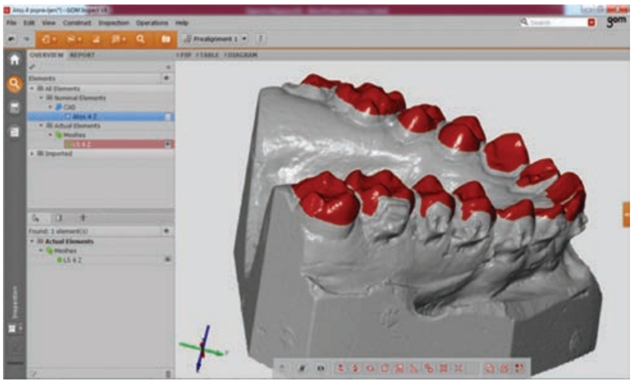

Figure 11. The representation of the selected surface for alignment using CAD model. The chosen surfaces are coloured red – upper jaw

Results

The results of measurements in Table 1. and Table 2. are related to lower jaw orthodontic parameters from D1 to D26 acquired using GOM Inspect on 3D models, scanned with Atos. Table 3. and Table 4. contain data regarding the same parameters obtained by 3D models scanned with Lazak Scan for the same jaw. Table 5. and Table 6. include the differences difference between orthodontic parameters D1 – D26, obtained by Atos and LazakScan, for the lower jow, while the differences in orthodontic parameters for upper jaw G1 - G28 in model 4 Atos and LazakScan are shown in Table 7.

Table 1. Mean values (mm) of orthodontic parameters D1 - D26, measured on 3D models, scanned using Atos scanner for the lower jaw (the first seven models)

Par / Model	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
D1	26.241	25.977	26.570	26.521	27.271	27.181	25.492
D2	35.612	35.711	36.543	36.621	37.141	38.091	38.894
D3	44.032	45.374	45.851	46.181	46.196	46.693	47.170
D4	29.781	28.892	30.166	29.448	30.235	30.978	31.261
D5	40.792	40.421	40.083	39.350	39.571	39.992	40.211
D6	53.521	53.842	53.151	53.398	53.097	53.723	53.565
D7	55.453	55.910	55.212	55.391	55.111	55.597	55.521
D8	47.958	48.380	48.211	48.071	47.561	48.301	48.040
D9	10.961	11.811	11.538	12.483	12.134	12.291	12.582
D10	21.323	21.672	20.851	22.473	21.975	22.363	22.081
D11	29.379	29.544	28.720	29.556	29.577	29.891	29.898
D12	33.681	34.061	32.933	33.522	33.726	34.215	33.189
D13	4.734	5.961	5.272	7.718	7.697	8.612	8.267
D14	14.976	16.011	13.991	15.763	15.732	16.315	16.128
D15	23.546	23.792	21.451	23.423	22.867	24.239	24.132
D16	28.528	27.960	26.550	27.920	27.790	28.330	27.750
D17	5.227	5.363	5.232	5.316	5.179	5.544	5.346
D18	5.156	5.062	4.771	5.712	5.326	5.548	5.291
D19	9.325	10.042	10.138	10.045	9.942	10.114	9.949
D20	10.123	10.422	10.341	8.710	10.130	10.211	10.252
D21	8.861	9.097	9.112	8.931	8.936	8.965	8.997
D22	4.868	4.960	4.632	4.621	4.521	4.781	4.869
D23	4.723	4.788	4.841	4.546	4.885	4.874	4.890
D24	9.951	10.361	9.88	10.050	9.940	10.040	10.02
D25	8.362	10.262	10.081	9.867	9.863	9.922	9.938
D26	8.923	9.314	9.048	8.961	8.887	9.152	8.981

Table 2. Mean values (mm) of orthodontic parameters D1 - D26, measured on 3D models, scanned using Atos scanner for the lower jaw (the remaining six models)

Par/ Model	Model 8	Model 9	Model 10	Model 11	Model 12	Model 13
D1	24.691	26.030	26.082	26.741	26.935	26.666
D2	38.522	38.430	38.942	39.011	39.030	38.790
D3	46.991	46.894	47.675	46.536	47.432	47.161
D4	30.922	31.340	31.532	32.050	31.480	31.382
D5	40.061	40.563	40.812	40.471	40.467	40.463
D6	53.021	52.960	53.490	53.753	53.361	53.282
D7	55.292	55.101	55.483	55.562	55.401	55.335
D8	47.793	47.561	48.040	48.123	48.056	47.872
D9	12.437	12.136	12.723	13.188	12.921	12.772
D10	22.356	21.742	21.591	21.460	22.123	22.167
D11	30.415	29.310	29.547	29.285	29.739	30.012
D12	33.921	33.402	33.460	33.590	33.751	33.956
D13	8.813	8.441	8.120	7.863	8.458	8.581
D14	16.821	17.041	17.093	16.476	17.148	16.925
D15	25.358	25.155	25.250	24.562	25.145	25.187
D16	28.561	28.393	28.901	28.310	29.113	28.856
D17	5.332	5.501	5.612	5.676	5.495	5.551
D18	5.235	5.402	5.690	5.491	5.426	5.460
D19	9.731	9.690	9.992	9.770	9.867	10.058
D20	9.843	9.991	10.361	10.150	10.012	10.060
D21	9.227	8.712	9.120	9.034	9.057	9.011
D22	4.496	4.801	4.993	4.921	5.110	5.338
D23	4.741	5.312	4.377	4.969	4.962	5.290
D24	9.982	10.187	10.320	10.194	10.228	10.313
D25	9.657	9.751	9.960	10.042	9.873	9.901
D26	8.643	8.821	9.186	9.283	9.082	9.133

Table 3. Mean values (mm) of orthodontic parameters D1 - D26, measured on 3D models, scanned using LazakScan scanner for the lower jaw (the first seven models)

Par / Model	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
D1	25.963	25.702	26.553	26.498	27.191	27.305	25.552
D2	35.751	35.702	36.530	36.497	37.021	37.970	38.710
D3	43.661	45.202	45.450	45.840	45.830	46.455	46.721
D4	29.763	30.001	29.461	29.496	30.301	30.771	31.260
D5	40.567	40.191	39.503	39.661	39.470	39.910	40.333
D6	53.918	53.260	53.390	53.691	53.005	53.367	53.377
D7	55.491	55.191	55.262	55.558	55.002	55.383	55.335
D8	47.814	47.714	48.190	47.841	47.481	48.050	47.740
D9	10.878	12.002	11.771	11.540	12.501	12.350	12.361
D10	21.132	21.011	21.001	21.961	21.810	21.936	21.670
D11	29.337	29.560	29.254	29.288	29.450	29.546	29.661
D12	33.526	33.810	33.461	33.230	33.925	34.110	33.387
D13	4.869	5.730	5.421	7.290	7.670	8.538	8.560

Par / Model	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
D14	14.831	14.911	14.010	15.430	15.732	16.254	16.226
D15	23.492	23.312	21.280	22.951	22.787	23.850	23.950
D16	28.351	28.292	26.560	27.662	27.801	28.336	27.467
D17	4.828	5.322	5.051	4.850	5.041	5.080	5.066
D18	4.922	5.110	4.892	5.310	4.760	5.041	4.992
D19	9.128	9.830	9.981	9.760	9.582	9.810	9.618
D20	9.927	10.061	10.071	8.462	9.430	9.852	9.635
D21	8.563	8.964	9.051	8.657	8.601	8.702	8.692
D22	4.921	4.690	4.222	4.541	4.171	4.650	4.968
D23	4.134	4.230	4.380	4.450	4.441	4.492	4.542
D24	9.838	10.091	9.690	9.842	9.754	9.792	9.770
D25	8.144	9.930	9.781	9.520	9.354	9.342	9.661
D26	8.959	8.949	8.945	8.787	8.728	8.742	8.711

Table 4. Mean values (mm) of Orthodontic parameters D1 - D26, measured on 3D models, scanned using LazakScan scanner for the lower jaw (the remaining six models)

Par / Model	Model 8	Model 9	Model 10	Model 11	Model 12	Model 13
D1	24.817	25.801	26.085	26.530	26.920	26.781
D2	38.212	38.312	38.910	39.043	38.861	38.670
D3	46.521	46.731	47.320	46.644	47.287	46.994
D4	30.933	31.172	31.731	32.255	31.743	31.410
D5	39.851	40.221	40.694	40.620	40.570	40.381
D6	53.158	53.040	53.623	53.642	53.741	53.735
D7	55.428	55.170	55.791	55.542	55.861	55.744
D8	47.951	47.822	48.210	47.910	48.313	48.231
D9	12.864	12.273	12.561	13.075	12.970	12.862
D10	22.168	21.510	21.323	21.212	22.150	21.865
D11	30.195	29.190	29.322	29.474	29.725	29.566
D12	33.828	33.160	33.652	33.391	33.923	33.761
D13	8.761	8.510	8.272	8.151	8.362	8.492
D14	16.663	16.940	16.801	16.704	16.866	16.553
D15	24.94	25.172	25.061	24.640	24.792	24.770
D16	28.421	28.760	29.034	28.741	28.913	28.990
D17	5.011	5.401	5.492	5.127	5.350	5.050
D18	4.891	5.370	5.612	5.443	5.191	5.051
D19	9.425	9.682	9.851	9.582	9.640	9.701
D20	9.668	9.770	10.130	9.740	9.990	9.831
D21	8.932	8.492	9.153	8.820	8.720	8.840
D22	4.489	4.671	5.101	4.950	4.802	5.230
D23	4.571	4.781	4.401	4.960	4.973	4.890
D24	9.625	9.872	9.971	9.950	9.891	9.987
D25	9.222	9.470	9.752	9.856	9.810	9.557
D26	8.327	8.627	9.011	9.542	8.991	8.966

Table 5. The difference between orthodontic parameters D1 – D26, obtained by Atos and LazakScan, for the lower jaw, for the first seven 3D models

Par / Model	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
D1	0.278	0.275	0.017	0.023	0.080	-0.124	-0.060
D2	-0.139	0.009	0.004	0.214	0.120	0.121	0.184
D3	0.371	0.172	0.401	0.34	0.356	0.238	0.419
D4	0.018	-1.109	0.705	-0.048	-0.066	0.207	0.001
D5	0.225	0.230	0.580	-0.311	0.101	0.082	-0.122
D6	-0.397	0.582	-0.239	-0.293	0.092	0.356	0.188
D7	-0.038	0.719	-0.050	-0.167	0.109	0.214	0.186
D8	0.144	0.666	0.021	0.230	0.080	0.251	0.300
D9	0.083	-0.191	-0.233	0.943	-0.367	-0.059	0.221
D10	0.191	0.661	-0.150	0.512	0.165	0.427	0.411
D11	0.042	-0.016	-0.534	0.268	0.127	0.345	0.237
D12	0.155	0.251	-0.528	0.292	-0.199	0.105	-0.198
D13	-0.135	0.231	-0.149	0.428	0.027	0.074	-0.293
D14	0.145	1.101	-0.019	0.333	0	0.061	-0.098
D15	0.054	0.480	0.171	0.472	0.080	0.389	0.182
D16	0.177	-0.392	-0.010	0.258	-0.011	-0.006	0.283
D17	0.399	0.041	0.181	0.466	0.138	0.464	0.280
D18	0.234	-0.048	-0.121	0.402	0.566	0.507	0.299
D19	0.197	0.212	0.157	0.285	0.360	0.304	0.331
D20	0.196	0.361	0.270	0.248	0.700	0.359	0.617
D21	0.298	0.133	0.061	0.274	0.335	0.263	0.305
D22	-0.053	0.270	0.410	0.080	0.350	0.131	-0.099
D23	0.589	0.558	0.461	0.096	0.444	0.382	0.348
D24	0.113	0.270	0.190	0.208	0.186	0.248	0.250
D25	0.218	0.332	0.300	0.347	0.509	0.580	0.277
D26	-0.036	0.365	0.108	0.174	0.159	0.410	0.270

Table 6. The difference between orthodontic parameters D1 – D26, obtained by Atos and LazakScan, for the lower jaw, for the remaining six 3D models

Par / Model	Model 8	Model 9	Model 10	Model 11	Model 12	Model 13
D1	-0.126	0.229	-0.003	0.211	0.015	-0.115
D2	0.910	0.118	0.032	-0.032	0.169	0.120
D3	0.470	0.163	0.355	-0.108	0.145	0.167
D4	0.059	0.168	-0.199	-0.205	-0.263	-0.028
D5	0.210	0.342	0.118	-0.149	-0.103	0.082
D6	-0.137	-0.080	-0.133	0.111	-0.380	-0.453
D7	-0.136	-0.069	-0.308	0.020	-0.460	-0.409
D8	-0.158	-0.261	-0.170	0.213	-0.257	-0.359
D9	-0.427	-0.137	0.162	0.113	-0.049	-0.090
D10	0.188	-0.038	0.268	0.248	-0.027	0.302
D11	0.220	0.120	0.225	-0.189	0.014	0.446
D12	0.093	0.242	-0.192	0.199	-0.172	0.195
D13	0.052	-0.069	-0.152	-0.288	0.096	0.089
D14	0.152	0.101	0.292	-0.228	0.282	0.372

Par / Model	Model 8	Model 9	Model 10	Model 11	Model 12	Model 13
D15	0.418	-0.017	0.189	-0.079	0.353	0.417
D16	0.140	-0.367	-0.133	-0.431	0.200	-0.134
D17	0.321	0.100	0.120	0.549	0.145	0.501
D18	0.344	0.032	0.078	0.048	0.235	0.409
D19	0.306	0.008	0.141	0.030	0.227	0.357
D20	0.175	0.221	0.231	0.410	0.022	0.229
D21	0.295	0.220	-0.033	0.214	0.337	0.171
D22	0.007	0.130	-0.108	-0.029	0.308	0.108
D23	0.170	0.531	-0.024	0.009	-0.011	0.400
D24	0.357	0.315	0.349	0.244	0.337	0.326
D25	0.435	0.218	0.208	0.186	0.063	0.344
D26	0.316	0.184	0.175	-0.259	0.091	0.167

Table 7. The differences in orthodontic parameters for upper jaw G1 - G28 in model 4 Atos and LazakScan

Parameter	Atos Upper model 4	LS Upper model 4	Difference	Abs. Value Raz.
G1	32.771	32.733	0.038	0.038
G2	40.175	40.101	0.074	0.074
G3	45.798	45.777	0.021	0.021
G4	29.64	29.885	-0.245	0.245
G5	35.721	35.793	-0.072	0.072
G6	50.310	50.458	-0.148	0.148
G7	53.48	53.361	0.119	0.119
G8	41.712	41.798	-0.086	0.086
G9	10.910	10.840	0.070	0.070
G10	18.696	18.763	-0.067	0.067
G11	26.987	26.842	0.145	0.145
G12	34.961	34.850	0.111	0.111
G13	41.620	41.613	0.007	0.007
G14	11.128	11.081	0.047	0.047
G15	19.313	19.092	0.221	0.221
G16	27.311	27.244	0.067	0.067
G17	35.520	35.271	0.249	0.249
G18	41.601	41.798	-0.197	0.197
G19	6.918	6.810	0.108	0.108
G20	6.329	6.091	0.298	0.298
G21	8.990	8.754	0.236	0.236
G22	9.194	8.938	**0.256**	**0.256**
G23	9.721	9.550	0.171	0.171
G24	6.934	6.842	0.092	0.092
G25	6.617	6.655	-0.038	0.038
G26	9.260	9.110	0.150	0.150
G27	9.921	9.741	0.180	0.180
G28	9.846	9.670	0.176	0.176

There were significant differences between parameters scanned with Atos and Lazak Scan. The smallest difference was 0.017 mm, and the biggest 1.109 mm. The results shown in Figure 12 and Figure 13, exhibiting predominantly yellow, green and light blue, practically signify that the precision of both scanners is satisfactory, with the comparison being performed in relation to the 3D model from the Atos scanner which possesses a greater nominal precision.

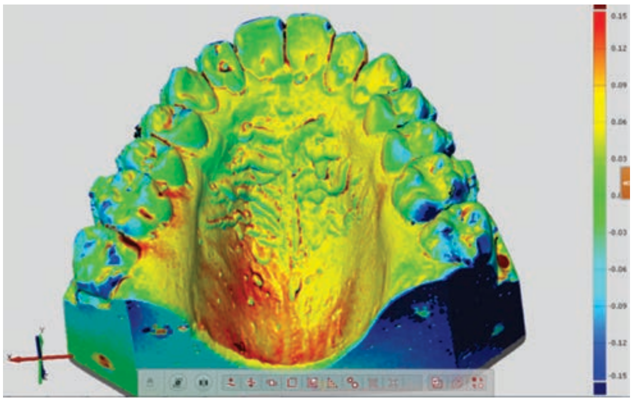

Figure 12. Comparison of surface differences using the "Surface Comparison on CAD" function– upper jaw

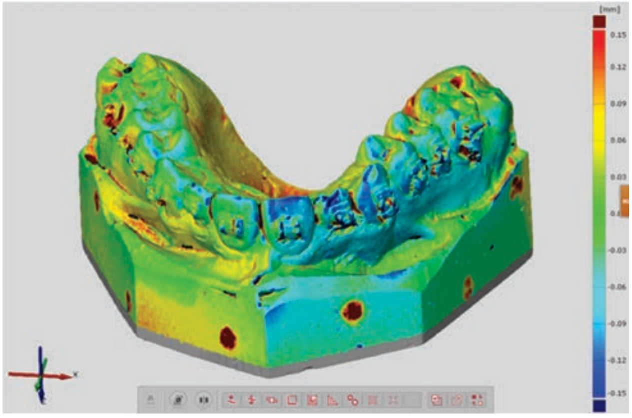

Figure 13. Comparison of surface differences – another angle of view / upper jaw

The difference between α, β i γ angles of the "master" model and 2-13 models of the upper and lower jaw scanned with Atos are presented in Table 8 and Table 9. The differences (mm) in median points position between the "master" model and 2-13 models of the upper jaw are shown in Table 10.

Table 8. The difference between α, β i γ angles (°) of "master" model and 2-13 models of upper jaw scanned with Atos

Rot. rav.	M2 – M1	M3 – M1	M4 – M1	M5 – M1	M6 – M1	M7 – M1	M8 – M1	M9 – M1	M10	M11 –M1	M12 –M1	M13 –M1
Θx	1.77	0.40	-0.71	-0.93	-2.17	-2.95	-4.41	-5.49	-5.00	-5.91	-4.97	-5.07
Θy	0.09	0.08	0.03	0.13	0.17	0.28	0.20	0.22	0.19	0.13	0.13	0.05
Θz	-0.26	0.14	-0.07	0.18	-0.02	0.00	-0.39	-0.40	0.12	0.34	0.26	0.19

Table 9. The difference between α, β i γ angles (°) of "master" model and 2-13 models of lower jaw scanned with Atos

Rot. rav.	M2 – M1	M3 – M1	M4 – M1	M5 – M1	M6 – M1	M7 – M1	M8 – M1	M9 – M1	M10 –M1	M11 –M1	M12 –M1	M13 –M1
Θx	-1.25	**1.30**	-1.11	-0.80	-0.89	0.07	1.14	0.48	0.73	0.45	1.28	1.04
Θy	-0.31	**1.16**	-0.41	-0.52	-0.38	-0.72	-0.88	-1.07	-0.88	-1.07	-1.02	-0.96
Θz	-0.15	0.13	0.11	0.41	0.04	0.27	-0.04	-1.28	-1.25	-1.08	-1.21	-1.34

Table 10. The differences (mm) in median points position compared to the origin of the coordinate system, and between the "master" model and 2-13 models of the upper jaw

S.K.	M2 – M1	M3 – M1	M4 – M1	M5 – M1	M6 – M1	M7 – M1	M8 – M1	M9 – M1	M10 – M1	M11 – M1	M12 – M1	M13 – M1
Δx	0.55	0.65	0.70	0.73	0.46	0.75	1.44	1.43	1.16	0.77	0.60	0.33
Δy	0.18	0.15	0.23	0.37	0.07	0.20	0.42	0.73	0.59	0.63	0.40	0.36
Δz	0.11	0.06	0.12	0.20	0.16	0.12	0.05	-0.07	-0.01	-0.08	-0.11	-0.11
$Y_{θx}$	-0.11	-0.02	0.04	0.06	0.13	0.18	0.27	0.34	0.31	0.36	0.30	0.31
Y_{ost}	0.28	0.18	0.19	0.31	-0.06	0.02	0.15	0.39	0.28	0.26	0.10	0.05

Discussion

In the system of 3D models there are three coordinate systems– the coordinate system of the scanner (CSS), global coordinate system of the jaw (GCSJ) and local coordinate system of the jaw (LCSJ). Prior to any measurement on 3D models, these systems have to be determined, i.e. defined and interconnected. The coordinate system of the scanner is defined as per rules regarding the scanner, and it can be absolute (the origin is always in the same point), and relative (the origin can be in any point of the scanner work space). More accurate measurement results are obtained by relative coordinate system, which was used in this research. As GCSJ is defined, the orthodontic planes can be determined. The GCSJ is defined and set in accordance with the American Board of Orthodontics (ABO) regulations[13], with RGE used for its definition, by using the "Construct Coordinate System" function.

This research utilised examples of 3D models obtained by Atos professional scanner[11] and 3D models created by the Lazak Scan scanner[12]. If we know that the Atos scanner precision equals +/-0.01 mm, and the Lazak Scan scanner equals +/-0.05 mm, we can see the differences in the position of points of up to +/-0.12 mm. In order to clarify the differences in accuracy, we carried out measurements of orthodontic parameters on 3D models of the same jaws by GOM Inspect comprehensive software, for both types of 3D models obtained from both scanners.

Measurement results revealed the most significant difference regarding the second model parameters D4 and D14. L 4 L point was probably inaccurately positioned due to the damage to the lingual side of a tooth. It can be ignored since it is a consequence of plaster model damage. The tip of R 4 L was damaged on that model, and it was related to D4, D10 and D18 parameters. The RGM 7 point was also approximately positioned, which caused a discrepancy in values of D6-D8 parameters. Parameters G13 and G18 were defined using L 2 D and R 2 D points, which were also positioned according to calculations (easy to set the exemplary model), since the lateral incisor on the model was broken, as in the example of G13 parameter on model 4.

Because there was some significant damage and uneven surfaces on plaster models, we got different values for parameters both on different plaster models and on 3D models of the same plaster models obtained on both scanners. The discrepancy in values resulted from incorrect positioning of the points RG x, LG x and RGM 7. The analysis of this inaccuracy clearly indicates that, when the same point is on models from both scanners, the position of points is improved by placing the same point on the same models on both scanners. The results show that the most significant deviation in value of parameters was 0.256 mm, with the average deviation of 0.129 mm. This can be explained by means of measurement inaccuracy of both scanners, which was analysed earlier.

Due to tooth damages, we could not position the points for marking a great number of orthodontic parameters on two teeth in the lower jaw, so for that reason we placed them elsewhere, but these changes had no impact on the accuracy of the obtained results, since we examined scanner precision and not orthodontic characteristics of a patient's teeth and jaw. Hence the position of orthodontic parameters on upper jaw models remained as defined in theory, and lower jaw models had two orthodontic parameters fewer than anticipated, also due to teeth damages, without the possibility of replacing them with other points.

It is more demanding to determine the exact position of L 2 D and R 2 D points, not because of the tip of the tooth, but due to the occlusal edge and distal surfaces of lateral incisors. That should be emphasised because we did not take the highest point but the one on the edge of the tooth, which always had to be defined in the same manner. Points on broken teeth were set by using means of intersections and projections, whereby a high level of precision was achieved. We encountered certain problems in the set-up, as it was difficult to define points LG x, RG x and RGM 7 on Lazak Scan, since the line between the gums and teeth was not clear enough. First we concluded that it was hard to precisely mark the RGM 7 point, so we chosed the optimal mesial point which was best positioned in Y-direction. Points L 4 L, L 5 L, R 4 L and R 5 L were marked as the highest point had it been possible, and that was performed on the basis of evaluation. Due to the fact that lower models do not contain points R 6 LM, R 6 BM and R 6 BD, R 7 LM should be used for calculation and rotation of orthodontic planes. When it comes to lower models, points RG 4, RG 5, LG 4, LG 5, L 6 BD, L 6 BM, L 6 LM and R 7 LM were used for all the analyses.

For example, when it comes to Atos, the upper jaw model had the L 3 point at 0.049 mm more to the left, whilst on Labod Scan the same point was 0.051 more to the right, which constituted the discrepancy in the point position of 0.100 mm. Similarly, in the R 3 point, the discrepancy between G1 parameters on both scans was approximately 0.200 mm. In our example something similar occurred in the G4 parameter, where the discrepancy in the value of orthodontic parameter was 0.245 mm. The greatest discrepancy was 0.256 mm at the G22 parameter, since it depends on the R 2 D point, which is more difficult to position on a particular tooth.

Apart from the errors regarding linear distances, directly related to defined orthodontic parameters, there were also errors in tooth/jaw rotation compared to the global coordinate system, and they are the following: α angle – rotation in relation to the X axis, β angle – rotation in relation to the Y axis, γ angle – rotation in relation to the Z axis. The analysis of data led to the conclusion that there was a significant shift of the occlusal plane in the first model of the upper jaw, which was noticeable due to the change of α angle between the first and the second model. The change of angle occured as a consequence of numerous bumps on the gingival margin. We also deduced that the difference between the angles is 0.5 degrees, which was not far from anticipated values and could even be negligible due to its low value. The γ angle exhibited a difference of 0.74 degrees (greater than the one for the β angle, and the expected one) which was a consequence of an inaccurate positioning of points on the distal surfaces of first permanent molars.

Differences between angles β and γ were larger on lower jaw models compared to the upper jaw ones. That is a result of uneven surfaces on tooth tips and the occurrence of bumps on the gingival margin on the plaster model, thereby generating additional rotation, best observed on model 3 of the lower jaw because of the Y-axis rotation. Another irregularity was observed here, arising from the incorrect positioning of the R 7 LM point due to the tooth damage. There were also substantial deviations from the anticipated values of rotation around the Y and Z axes. Whilst analysing the model and the position of points it was evident that the lack of a tooth in the jaw had an impact on the position and orientation of orthodontic planes. Rotations were therefore strikingly realistic and constitute a lifelike representation of the position of orthodontic planes.

The differences in the X axis direction were related to the points for positioning the median plane, influencing the dental arch shape. The differences in the Z axis direction were largely within the anticipated values (±0,100 mm), whilst the differences in the Y axis direction were exactly as expected. We predicted a difference in the Y direction of $Y_{\theta x} \pm 0{,}1$ mm. Analysing the results, we inferred that the θx angle changed in almost linear fashion, which should imply the linearity of changes in differences in Y direction shifts. The Y_{ost} value represents a shift in the global coordinate system in the Y direction of Δy, from which we subtracted the $Y_{\theta x}$ shift, originating from the rotation around the X axis. The shift in Y_{ost} was a consequence of incorrectly positioned origin of the coordinate system via distal surfaces on first molars due to not entirely precise positioning of RG 4, RG 5, LG 4 and LG 5 points (hampered by the bumps on the gingival margin and plaster models). We expected the shift to be in the range of ±0,100 mm, and the deviation to be greater. In order to understand these results, on model 9 we performed the alignment of the second and the ninth models via the first molar on the left. It was clearly observed that the rotation between the left and the right molars occurred, as a shift in the position of distal points on the molars, used for setting the position of the tuber plane and, in accordance with that, the origin of the global coordinate system.

We can conclude that the differences between surfaces of the same models scanned with Atos and Lazak Scan are expected to be in the region of ±0.060 mm. In order to determine/calculate all orthodontic parameters, for the entire 3D model, it is necessary to do a mutual alignment of both models. Each model has to be defined as a CAD file after scanning, and the alignment can be easily achieved by defining/determining orthodontic planes and the GCSJ for both models, and then carry out the alignment via the GCSJ. Alignment could be also achieved taking into account the overall model geometry, as the option is suitable for application on models obtained from the same plaster model, or part of the model s geometry, as it provides numerous possibilities by using comprehensive software equipment.

Conclusions

This research reveals that both scanners (Atos and Lazak Scan), which belong to general purpose scanners, based on precision parameters can be used in orthodontics. Early analyses indicate that the reference scanner in terms of precision is Atos. The procedure of generating 3D models, whilst taking into account the scanner precision, would include the following steps:

Efforts should be made to create a plaster mould with no irregularities on tooth tips or gingival margin,

If necessary, the final 3D model should to be formed using cleaning and smoothing. Each irregularity due to excessive material on tooth tips can significantly influence measurement results,

The final 3D model should be compose out of a small number of recorded projections, because the errors on tips/edges of a tooth turn into radial a transition view, which impedes the positioning of anatomical points on tooth,

It is important to precisely define and position orthodontic planes, because any rotation of the occlusal plane leads to positioning of different points on tooth tips. The procedure of positioning orthodontic planes has to be repeated if the highest point on the tip of distal buccal cusp above the plane is too high (0.01 mm). The initial step, the adjustment of the coordinate system of the jaw, greatly influences the determination of RGE, which form the base for establishing the orthodontic parameters.

One of the courses for future research will include the enhancement of repeatability of the adjustment of the coordinate system of the jaw. Prospective research in this field could be focused on examining the precision of these scanners based on the example of the orthodontic parameters of the class of the curve and the surface.

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Received on October 29, 2016.
Revised on December 1, 2016.
Accepted on January 28, 2017.

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