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Comparison of 3D printing MJP and FDM technology in dentistry

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ABSTRACT

Purpose: Many printers are tempting at low prices, but later their accuracy turns out to be insufficient. The study has included checking the accuracy of printing and reproducing details of 3D printers used in dental technology and dentistry such as MultiJet Printing (ProJet MP3000, 3D Systems) and Fused Deposition Modelling (Inspire S2000, Tiertime).

Design/methodology/approach: The 3D prints were created from scans of the maxillary gypsum model with the loss of left premolar. In the test, objects were set to the X and Y-axis. In order to check the dimensional differences after printing, scans of the printed models were superimposed on scans of the plaster model in the GOM Inspect V8 SR1 (Braunschweig, Germany). The focus was on the distance of scans from each other and a deviation map was created for each object.

Findings: The average absolute value of deviations for each of models were equalled: FDM- for X-axis 0.06 ± 0.04 mm, for Y-axis 0.07 ± 0.04 mm; MJP- for X-axis- 0.04 ± 0.02 mm, for Y-axis- 0.06 ± 0.02 mm. A chart of arithmetic averages calculated for each tooth for the best printouts in each series show that higher deviation values exist in case of FDM printout. The models printed in the X-axis have smaller values of deviations from those printed in the Y-axis.

Practical implications: MultiJet Printing technology can be used to create more precise models than the FDM, but these printouts meet the requirements of dimensional accuracy too.

Originality/value: CAD / CAM technology in the future will exist in every dental technology laboratory so it is important to be aware of the way the 3D printers works. By paying attention to the quality of detail reproduction, a Dental Technician is able to choose the best 3D printer for them.

Keywords: CAD/CAM, Dental materials, FDM, MJP, 3D printing

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BIOMEDICAL AND DENTAL MATERIALS AND ENGINEERING

1. Introduction

3D printing is used in many fields of medicine, including maxillo-facial surgery [1-3], orthopaedic surgery [4], implantology [5], dental techniques [6]. Images of the body parts, created from a computer tomography or magnetic resonance, serve as 3D models that can be used for diagnostic purposes and for the subsequent selection of appropriate therapeutic devices, such as bone implants [7,8].

3D scanners are mainly used or create digital models in dental techniques [9]. Modern technologies allow exchanging of information between dental office and dental techniques laboratory. In dental surgery, a scan of the mouth is made, and then the digital model is sent to the technical laboratory. It is also possible to scan a plaster model. A dental technician basing on the scan can design a virtual restoration which is later produced by numerically controlled machines. The other way is to make a 3D printout of scanned teeth and then based on it make a restoration by traditional methods [10,11]. In addition, it is possible to make a custom tray from oral cavity impressions [12]. For this purpose, 3D printers using different methods are used. SLS (Selective Laser Sintering) technology is based on the sintering of powders with a laser, FDM (Fused Deposition Modelling) uses heated plastic to create 3D objects [13,14]. PolyJet and MultiJet Printing technologies create objects from light-curing resin [15,16]. CAD/CAM is also widely used in dentistry to create parts of restoration made from zirconium oxide or titanium oxides by using a milling machine [17].

The dimension and accuracy of detail mapping of both scans and final printouts are very important in the word of the dental technician. Even small change in the size may cause that the cement will wash out and it will cause the development of caries or micro damages [18,19]. Acceptable gaps between the restoration and the tooth are 30-200 μm [20,21]. Each 3D printing technology differs not only by the method of printing and materials used in it but also the accuracy of the resulting prints and thickness of single layers of the materials being applied. The aim of this study was to compare the accuracy of the 3D printouts of FDM and MJP technologies, significantly differs from printed layer thickness.

2. Materials and methods

This study is an extension of our previous scientific work [22,23]. The maxillary gypsum model with the loss of left premolar was used for tests. Five scans of the model were made using a scanner (Ceramill Map300, Amann Girrbach, Vorarlberg, Australia). In order to check the repeatability of the scanner, the obtained scan images were imposed on each other in GOM Inspect V8 SR1 (GOM, Braunschweig, Germany). A randomly selected scan was prepared for printing in Geomagic Studio 2013 (3D Systems, Rock Hill, USA). The model obtained from the scanning process has no basis and is only a layer, which creates an image of the scanned object. The image obtained from the scanner is shown in Figure 1. The program allowed to close the solid, as shown in Figure 2, and to prepare it for further operations.

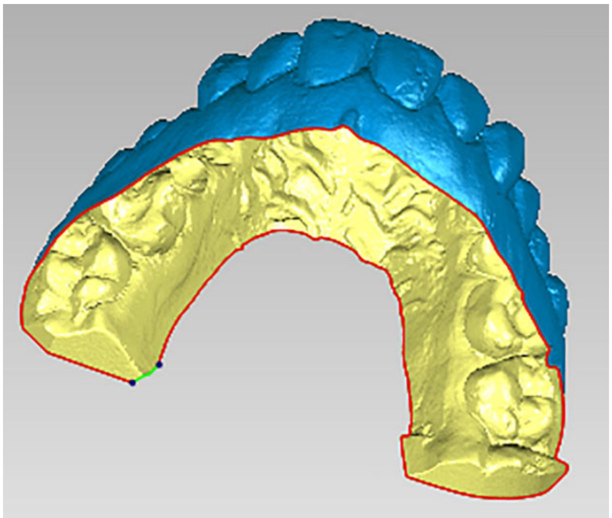

Fig. 1. 3D geometry obtained from the scanner (source: own picture)

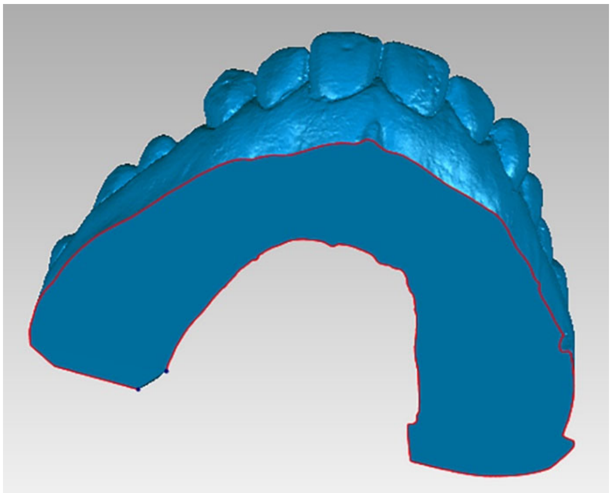

Fig. 2. 3D geometry after processing in Geomagic Studio 2013 (source: own picture)

The .stl file with the maxillary models prepared from printing was imported into the software of numerically controlled devices. In test Inspire S200 (Tiertime, Pekin, China) printer and ProJet MP3000 (3D Systems, Rock Hill, USA) printer was used. The first works in the Fused Deposition Modelling (FDM) method, the second uses MultiJet Printing technology. In the case of the first method thickness of the layer is 0.15 mm, in MJP method it is 0.03 mm. The effect of the print position relative to the axis of the printer's working space on its accuracy was also checked. In both programs, it is possible to set the model in the working space by axis. In the test, objects were set to the X and Y-axis. In the Inspire S200 device, ABS B601 (Tiertime, Beijing, China) was used to create the models, and the supporting material was ABS S301 (Tiertime, Beijing, China). In ProJet MP3000 printer for the building material the light-cured resin (VisiJet MP200, 3D Systems, Rock Hill, USA) was used, and the supporting material was wax (VisiJet S100, 3D Systems, Rock Hill, USA). This device uses resin shrinkage compensation, which involves the printer applying more material in the axes. Recommended by manufacturer value for X-axis is 0.48% and 0.39% for Y-axis (Fig. 3).

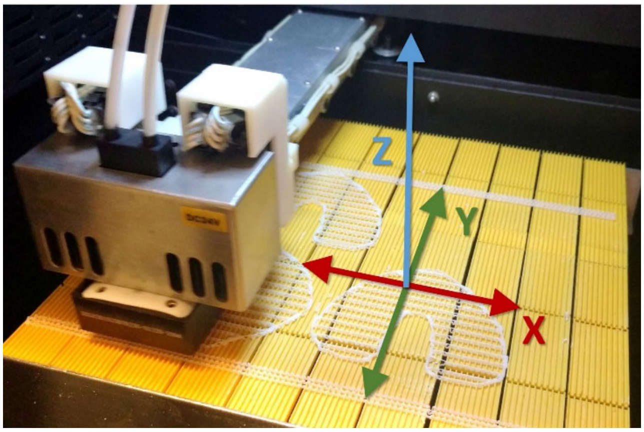

Fig. 3. Visualization of the print axis (source: own picture)

After the printing process, the created models were cleaned of supporting material. In the case of FDM technology, the supporting material should be mechanically removed. The supporting material in the form of wax in the MJP technology was removed by heating the objects to the melting point of the wax (65°C), and then the models were cleaned of the residue in an ultrasonic cleaner. Finished objects are shown in Figure 4.

The obtained models were prepared for scanning by applying matting powder (Espa I Lava, 3M, Maplewood, Minnesota, USA) to their surface. It prevents bouncing off the scanning light from the material. The same scanner was used for scanning as for image creation from gypsum models. In order to check the dimensional differences after printing, scans of the printed models were superimposed on scans of the plaster model in the GOM Inspect V8 SR1 (Braunschweig, Germany). The focus was on the distance of scans from each other and a deviation map was created for each object. The adjustment area was the entire dental arch, as shown in Figures 3 and 4. When creating the legend, a distance tolerance of 50 μm was set. For statistical purposes, a grid of measurement points was created on each tooth, where an equal distance of 0,5 mm of each point was set. From obtained results, the t-student test was performed in Statistica 13.1 (Dell, Palo Alto, USA).

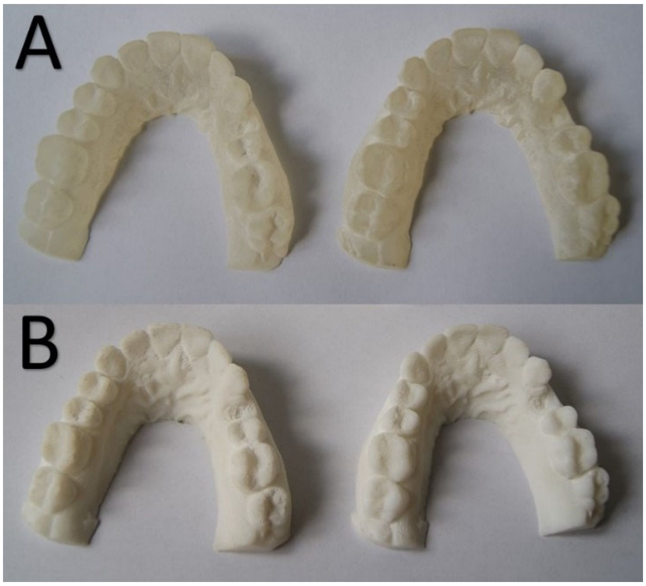

Fig. 4. Printouts obtained from A) MJP and B) FDM printer (source: own picture)

The results were analysed both for all geometry (dental arches in Figs. 5-8) as well as focusing on the individual teeth (Fig. 11).

3. Results

The results were shown in form of colourful maps. Figure 5 shows the maps obtained for FDM prints set in the X-axis and Figure 6 concerns the deviation map for the Y-axis printout. Figure 7 presents the maps obtained for MJP prints set in the X-axis, and Figure 8 concerns the deviation map for the Y-axis printout. Negative values, which are related to the displacement of the tested model in the internal side of the base model can be seen in cold colures. Positive values in warm colures show displacement of the model on the outer side. The legend is the same in each case.

The worst printout of the series from the FDM printer is the one from Y-axis because deviation values, in that case, exceeding the tolerance limit +/- 0.05 mm (colures different than green) cover the largest area. In X-axis printout the largest deviations are more distributed on teeth from 25 to 27. In series from the MJP printer, the printout in Y-axis is the worst. Additionally, in each case, deviations are mainly on molars and premolar teeth.

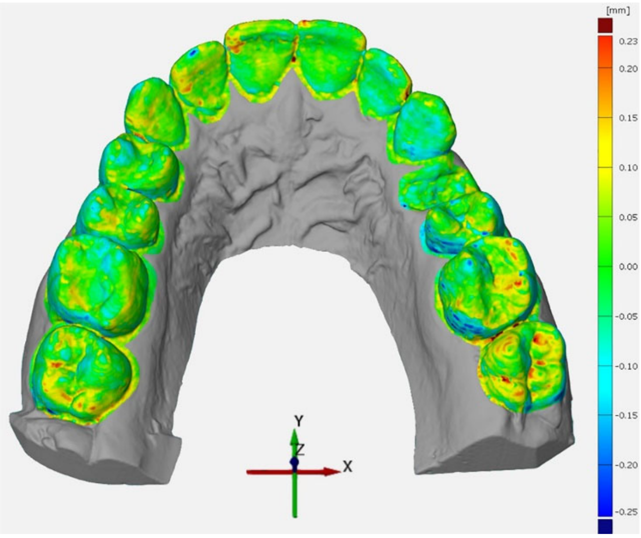

Fig. 5. Deviation maps for FDM models printed in the X-axis

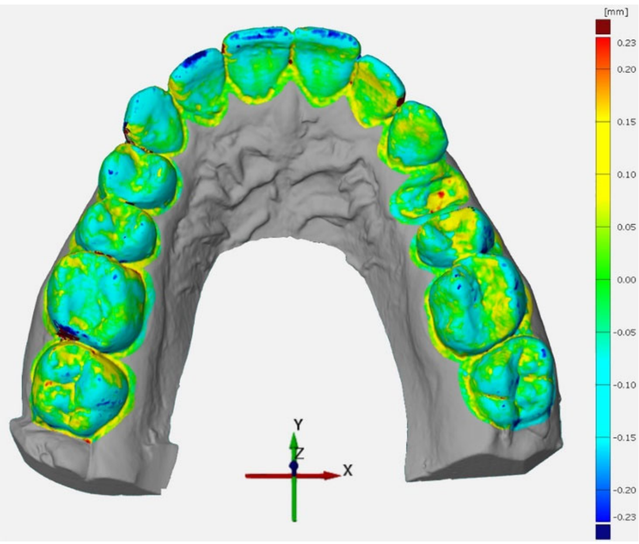

Fig. 6. Deviation maps for FDM models printed in the Y-axis

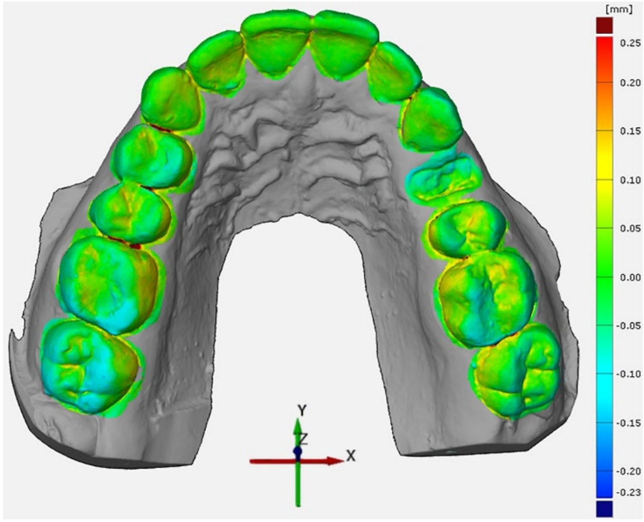

Fig. 7. Deviation maps for MJP models printed in the X-axis

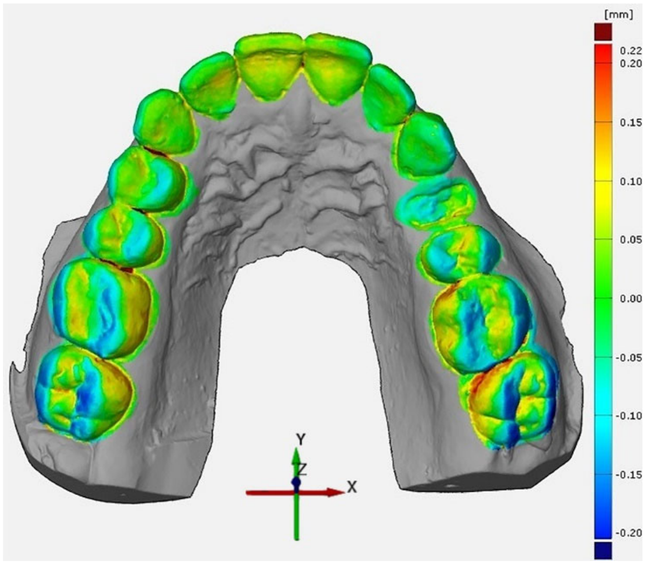

Fig. 8. Deviation maps for MJP models printed in the Y-axis

3D scans of printouts show that in case of FDM the material application tracks are more visible (Fig. 9, Fig. 10) and it corresponds to the obtained maps of deviation. Significant deviations are revealed exactly in the places of those tracks.

The average absolute value of deviations for each of models were equalled: FDM – for X-axis 0.06 ± 0.04 mm, for Y-axis 0.07 ± 0.04 mm; MJP – for X-axis- 0.04 ± 0.02 mm, for Y-axis- 0.06 ± 0.02 mm.

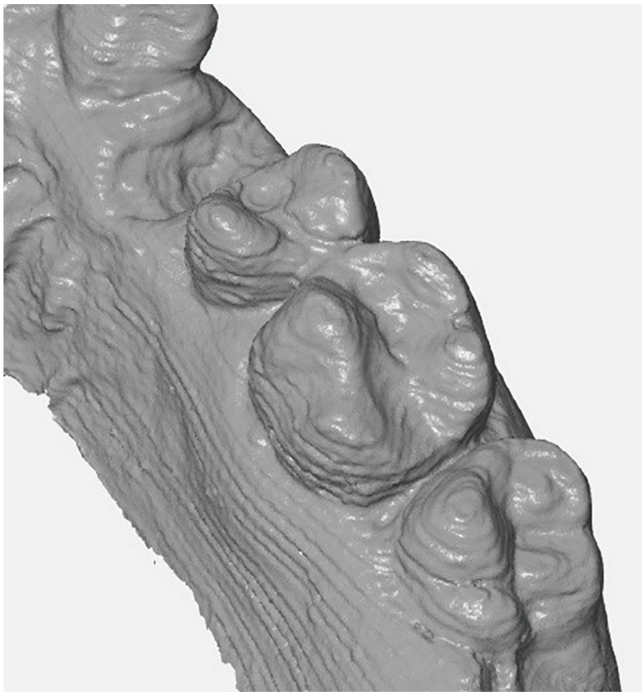

Fig. 9. 3D scans for the FDM models

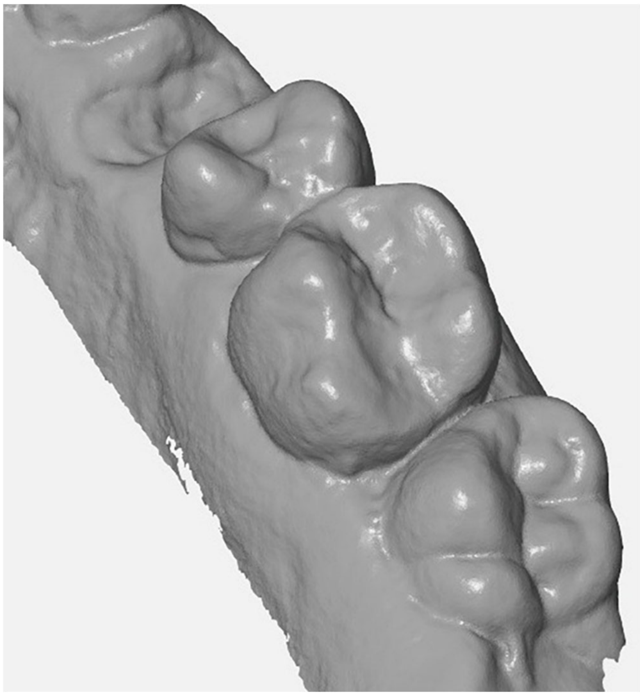

Fig. 10. 3D scans for the MJP models

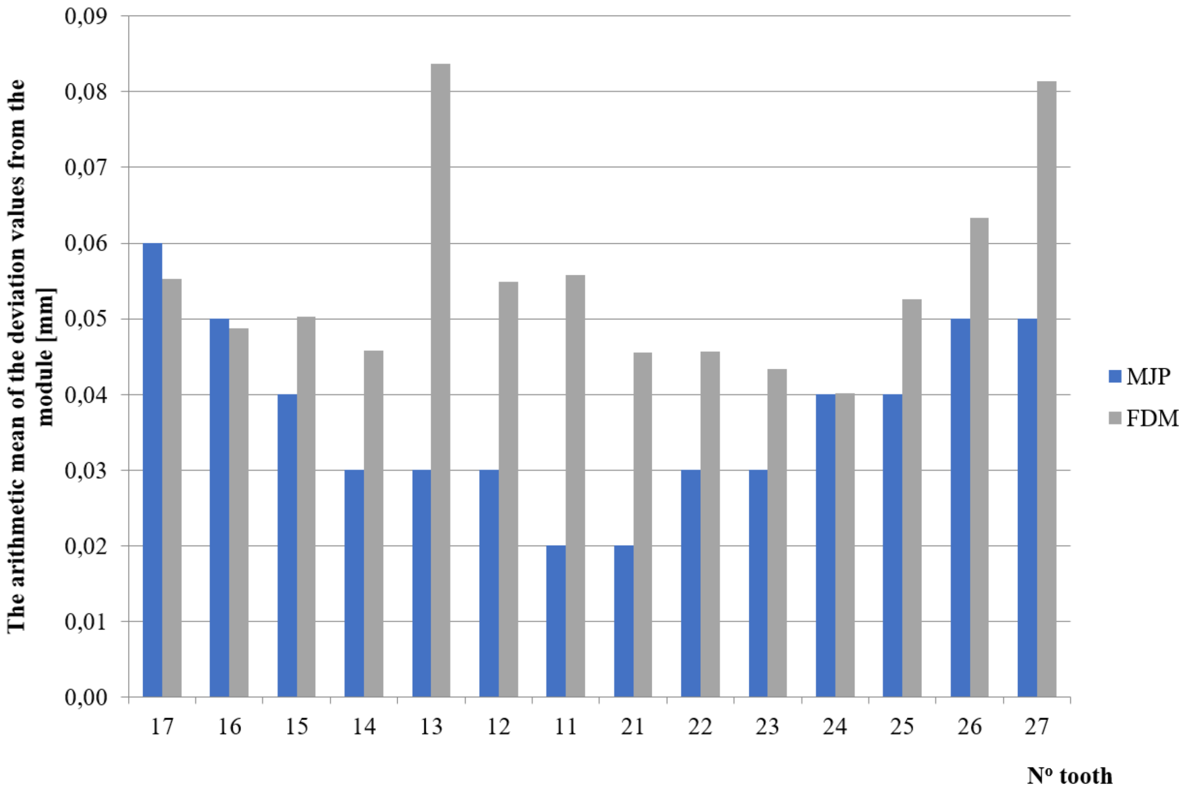

Fig. 11. The arithmetic mean values of deviation from the module calculated for each tooth

Obtained measurements were also analysed and their results are presented in a graphic form. A chart of arithmetic averages calculated for each tooth for the best printouts in each series (FDM and MJP- printout in X-axis) (Fig. 11) show that higher deviation values exist in case of FDM printout. The highest values were over 0,08 mm and were registered on the 13 and 27 teeth. The lowest values exist on 11 and 21 tooth, equal 0.02 mm and occur in the case of MJP.

Rejecting extreme results on 13 and 27 tooth (FDM) it seems that the other values are more or less evenly distributed. However, in the case of MJP, the lowest deviations occur on incisors and little by little increase towards the molars.

Table 1 and Table 2 present statistically significant results from the comparison of deviations from each series of printouts. Results from teeth with the highest deviation values are taken into account. The value of $p < 0.05$ was adopted as the level of statistical significance. The results from the t-student test confirm a statistically significant difference in the deviations occurring on teeth with the highest values of shifts.

Table 1.
Statistical significance coefficient "p" for printout in the X and Y axes from the FDM method

FDM							
Nº tooth	Axis	Tooth 13	Tooth 27	Axis	Tooth 11	Tooth 12	Tooth 13
11		<0.05	<0.05			1	<0.05
12		<0.05	<0.05		1		<0.05
13			1		<0.05	<0.05	
14		<0.05	<0.05		<0.05	0.41	<0.05
15		<0.05	<0.05		0.21	1	<0.05
16		<0.05	<0.05		<0.05	1	<0.05
17	X	<0.05	<0.05	Y	<0.05	<0.05	<0.05
21		<0.05	<0.05		<0.05	0.4	<0.05
22		<0.05	<0.05		<0.05	<0.05	0.95
23		<0.05	<0.05		<0.05	<0.05	1
24		<0.05	<0.05		0.33	1	<0.05
25		<0.05	<0.05		<0.05	<0.05	0.08
26		<0.05	<0.05		<0.05	<0.05	<0.05
27		1			<0.05	<0.05	1

Table 2.
Statistical significance coefficient "p" for printout in the X and Y axes from the MJP method

MJP										
Nº tooth	Axis	Tooth 11	Tooth 21	Tooth 17	Tooth 27	Axis	Tooth 16	Tooth 17	Tooth 26	Tooth 27
11			1	<0.05	<0.05		<0.05	<0.05	<0.05	<0.05
12		<0.05	<0.05	<0.05	<0.05		<0.05	<0.05	<0.05	<0.05
13		0.2	1	<0.05	<0.05		<0.05	<0.05	<0.05	<0.05
14		<0.05	<0.05	<0.05	<0.05		<0.05	<0.05	<0.05	<0.05
15		<0.05	<0.05	<0.05	<0.05		<0.05	<0.05	<0.05	<0.05
16		<0.05	<0.05	0.13	1			1	1	0.07
17	X	<0.05	<0.05		<0.05	Y	1		1	1
21		1		<0.05	<0.05		<0.05	<0.05	<0.05	<0.05
22		<0.05	0.07	<0.05	<0.05		<0.05	<0.05	<0.05	<0.05
23		<0.05	<0.05	<0.05	<0.05		<0.05	<0.05	<0.05	<0.05
24		<0.05	<0.05	<0.05	1		<0.05	<0.05	<0.05	<0.05
25		<0.05	<0.05	<0.05	1		1	0.8	1	<0.05
26		<0.05	<0.05	1	1		1	1		<0.05
27		<0.05	<0.05	<0.05			0.07	1	<0.05	

4. Discussion

In the FDM method deviations occur in much smaller areas than in the case of MJP. For this reason, created point cloud tags can bypass the place of deviation so that the final result of distortion can be obtained lower than the real one. Paying attention to the colour of the maps themselves, it is clear that the deviations appear in more intense colures in the case of FDM, which means that the printout obtained by that method is less accurate. Deviations in FDM are distributed much about the same on all teeth, while in MJP the change of colures to a different one than green can be seen mainly on the molar teeth. It is in the case of MJP due to material shrinkage.

The FDM printout has more sharp shapes and clearly visible material application paths, which causes the occurrence of deviations in those places. The MJP print has a more smooth edge, which removes possible deviations. In that case, the occurrence of deviation is affected only by the shrinkage and powder applied during the scan, which went into the interdental spaces. In the FDM printout, the additional element affecting the final dimensions is the shape of the printed object. Deviations occur mainly on interdental spaces, more inclined teeth walls and grooves. The obtained deviation maps are translated into the calculated arithmetic means. Teeth 27, 26 in FDM, in the X-axis series obtain one of the highest mean deviations. Tooth 13, obtains the highest deviation values (they are visible mainly from the lip side) due to the largest inclination (the steepest walls of the object).

Looking at the graph in the case of MJP (printout in the X-axis), the same can be stated as in the case of deviation maps - the smallest deviations appear at the incisors and the further towards the molars – the deviations increase.

For the calculation of arithmetic means, their modules (absolute values) were used, because in the study the occurrence of deviation was important, not their exact values (positive or negative).

The carried out research shows that the prints obtained by FDM and MJP in Y axes are worse than in X. The worst printout turned out to be Y-axis, from FDM method, while the best printout in the X-axis from the MJP method. In addition, the worst print from MJP (from the Y-axis) has accuracy comparable to the best from FDM (printout from X-axis). The results obtained from statistical calculations are confirmed by conclusions drawn only from the deviation maps - in places with the most intense red or blue colour (the greatest deviations) there is a statistically significant difference compared to the remaining teeth.

The obtained results may differ from the real dimensions because, during the test, the measurements could have been distorted in many places. The scanning accuracy itself is 0.02 mm, and the re-scanning process further increases the error.

Kasparova et. al. and Leiferd et. al. research concern the dimensional accuracy of prints from printers working with FDM technology in relation to plaster models of dentition. In both cases, digital calipers were used to determine the dimensional difference, where strictly defined places on gypsum objects were measured and then compared with printed models. In the case of a research [11], the largest dimensional differences of 0.23 mm were obtained in the front part of the model between the canines of the mandible. In the remaining tested points, average values of 0.05 mm were obtained. Research [24] shows the highest differences in dimensions of approx. 0.4 mm. These are much higher values than those obtained in the study [15], where the print accuracy test was performed on the FDM and PolyJet printer. In this test, a natural molar was used as the reference model. Scans of printed objects were superimposed on the tooth scan. For the model printed in FDM technology, average deviations of 0.047 mm were obtained. A difference of 0.038 mm was obtained for PolyJet. Using a caliper to check dimensional accuracy of irregularly shaped objects may turn out to be insufficient and not very accurate. By applying scans on each other, we can get a picture with a detailed distribution of possible deviations. This allows for a more accurate analysis of the results, taking into account the surface smoothness of the prints. Results of print deviations from the FDM printer, presented by Lee et. al., are slightly lower than those obtained in the above study. In research, they used a small-sized model with a not much-complicated shape, which may have an impact on the results. In our research, the largest differences in dimensions were obtained for the teeth with the most inclined walls and in the interdental spaces, which confirms the deterioration of accuracy depending on the shape of the objects. Printers operating in PolyJet and MultiJet Printing technologies use light-curing resin to create objects. In case of research [15] and [17] the average value of the results from PJ, printouts were obtained with a similar value to the average deviation value of MJP prints. However, when printing in MJP technology, on the maps of deviation the biggest differences are noticeable in the interdental spaces where the matting powder using in scanning could embed, causing a measurement error.

The value of deviations of the printouts sufficient for use in dental techniques is reported differently. Some authors consider the sufficient value of around 0.25 mm [15,25,26]. Taking into account the marginal integrity, i.e. the deviation of the substructure from the abutment tooth, which may vary within 0.05-0.1 mm [18], it can be considered that these values can be even smaller. The research showed that both printers meet this assumption.

5. Conclusions

The dimensional accuracy of prints is influenced by the arrangement of objects in the working space. The models printed in the X-axis have smaller values of deviations from those printed in the Y-axis. MultiJet Printing technology can be used to create precise models due to its high accuracy. Printouts from the FDM printer have the required dimensional accuracy, but ultimately should be used in the creation of, for example, custom trays, because the use of a too low number of measuring points could have an impact on the results. Therefore, in subsequent research, the number of created measuring points should be increased.

Acknowledgements

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