3D Printed Dental Models

A comparative analysis

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The aim of this study is to compare two different methods used for obtaining printed dental models -intraoral scanning and extraoral scanning; the comparative analysis was made in correlation to the accuracy of the traditional plaster cast model. Nine dental models were obtained: three plaster cast ones, three printed after intraoral scanning and there printed after impression scanning. A total of 137 measurements (arch and tooth measurements) were done on the three types of models and a statistical evaluation was performed (t-test, Fisher Test). Our results highlighted that 3D printed dental models represent a reliable option for clinical application.

Keywords: 3D printed models, intraoral scanning, extraoral scanning

Dental models represent an indispensable tool for all dentistry specialties serving as study models, diagnosis models, working models as well as forensic documents. The dental model is conventionally manufactured in the dental technique laboratory out of plaster whose hardness varies depending on the envisaged purpose of the model; it is moulded following the impression of the dental arches or edentulous ridges, thus becoming the positive reproduction of the intraoral configuration which it must replicate as accurately as possible.

The new digital technologies have been implemented also in the dental practice, ensuring a higher accuracy, predictibility and facilitating the dentistry flow treatment, thus confering significant advantages both to the doctor and the patient. Digital study models were confirmed to be a valid alternative to traditional plaster casts [1] and the use of stored patients' data only in the digital form eliminate the significant physical space for storage of plaster casts [2, 3]. 3D virtual models also facilitate the diagnosis' outline and the treatment planning, as well as the exchange of information with other professionals. On the other hand, the actual digital technologies require the use of new materials for physically obtaining the dental models, materiales whose technological characteristics and possibilities are of high importance. In this context, printed models, whose qualities have been sucessfully tested, are taking precedence over the conventional plaster cast ones. Compared to the traditional plaster cast models, the printed digital models are strong and durable, not prone to degradation and can be easily retrieved and shared [4].

The accuracy of dental models depends on the various materials, machines and protocols involved in the technological processes of their manufacturing. A printed model can be obtained after directly scanning the dental arches using an intraoral scanner, after scanning an impression of the dental arches with a laboratory scanner or after scanning a plaster cast model, if necessary.

As regards the dental 3D printing techniques, the most commonly used in dentistry are the following: stereolithography (SLA), digital light processing (DLP), selective laser sintering (SLS), selective laser melting (SLM), electron beam melting (EBM), triple jetting technology (Polyjet Printing) and fused deposition modelling printing (FDM). Compared to other systems, the SLA printing method offers very good accuracy and the smoothest printed surfaces, providing a high quality of printing but remains a relatively expensive and slow option as it can take hours to obtain a print [2]. On the other hand, polyjet printing shows more precise details with a more uniformly smooth surface than the models produced using the FDM method [5, 6], which, as a consequence, is less used in dental practice [1, 5, 6].

The 3D printing is an efficient, accessible and fast method of reproduction [7] with multiple applications in various dentistry domains: fabrication of models and surgical guides, implantology, fixed sand removable prosthodontics, restorative dentistry, orthodontics, training, instrument manufacturing [8]. The 3D printing technology is rapidly developing and represents an important topic in scientific literature; yet, printed dental models' accuracy and fidelity as well as the reproducibility of details need to be further explored. Given this context, the purpose of this scientific paper is to perform a comparative analysis of two new different methods used for obtaining printed dental models (post-intraoral scanning, respectively impression scanning), highlighting the overall accuracy of each of these models in relation to the accuracy of the traditional cast model.

Experimental part

A randomized lot of patients was selected, including 3 adult dentate patients: two females and one male. Informed consents were obtained from all patients. Three different types of dental models corresponding to the mandibular arch were produced for each patient; the dental models were classified depending on the procedures involved in their manufacturing:

-Plaster cast models (indexed M) conventionally obtained after the intraoral alginate impressions (*Orthoprint / Zhermack / Italy)* - a hard type gypsum was poured into the mould and after the set, the models were trimmed;

-Printed models (indexed MP-IM) obtained after an intraoral impression with special scannable material (*Honigum-Pro Heavy Scan / DMG / Germany*); the impressions were scanned in the laboratory *(Swing Dental Scanner / Dof Inc. / South Korea*) and the scanned data were saved as STL files; a 3D digital model was generated and imported to a 3D printer (*Form2 / FormLabs Inc. / U.S.A.*);

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Table 1
MODEL INDEXES

dental model index	model type
M1, M2, M3	PLASTER CAST
MP-IM1, MP-IM2, MP-IM3	PRINTED AFTER EXTRAORAL SCANNING
MP-IO1, MP-IO2, MP-IO3	PRINTED AFTER INTRAORAL SCANNING

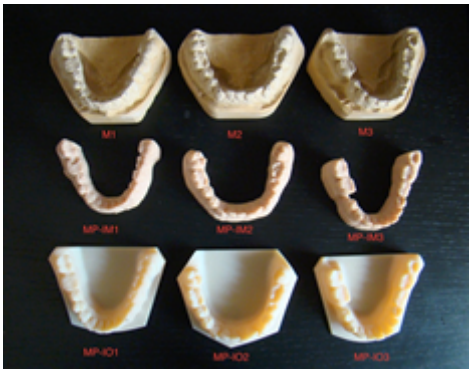

Fig. 1. The mandibular dental models obtained

-Printed models (indexed MP-IO) obtained after a digital impression (intraoral scanning - *TRIOS 3 Battery Cart / 3 Shape / Denmark)*; the scanned data were saved as STL files that were imported to a 3D printer (*Form2 / FormLabs Inc. / U.S.A.*).

In total, 9 models were obtained,presented in table 1 and figure 1.

The process of obtaining the three types of models is illustrated in a relevant diagram (fig. 2).

A set of linear measurements (corresponding to a horizontal plane) was performed on all three types of dental models by a single trained evaluator; the measurements were made using a hand-held digital calliper *(Precise Profi Scale / BURG WÄCHTER / U.K)* (fig. 3) with a measurement accuracy of 0.01mm, that was previously calibrated. Each measurement was performed twice, with a break of one day between the two measurement sessions. A total of 137 measurements were done.

The arch measurements thus performed included inter-canine width (distance between canines' cusps) and canine-first molar width (distance between canine cusp and mesial-buccal cusp) for both sides - left, right; tooth measurements were represented by canines' incisal-gingival distance (crown height -distance between canine cusp and the lowest gingival point on the buccal surface of the tooth) corresponding to both sides - left, right. Measurements were indexed as presented in table 2.

inter-canine width	CC
canine-first molar width / left side	CMl
canine-first molar width / right side	CMr
canine incisal-gingival height / left side	HCl
canine incisal-gingival height / right side	HCr

Table 2
MEASUREMENTS PERFORMED

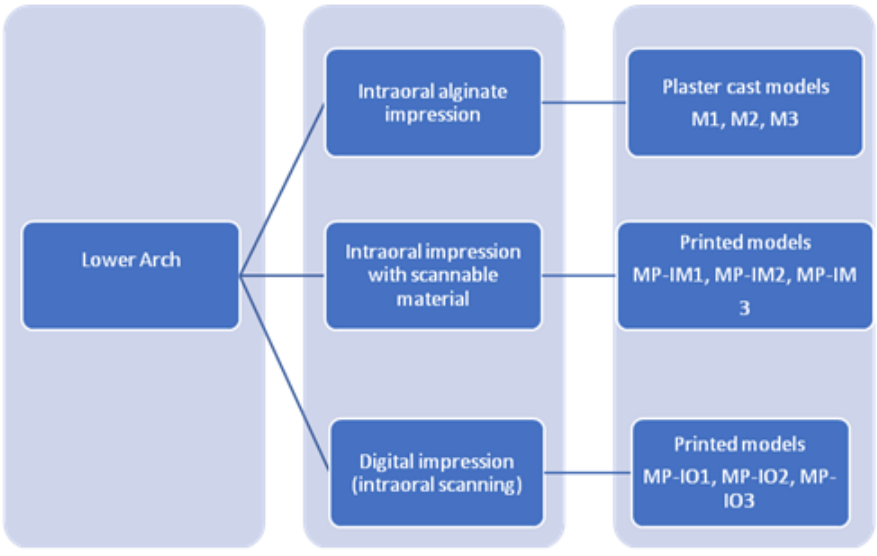

Fig. 2. Diagram illustrating the steps followed for obtaining the three types of models

Fig. 3. Hand-held digital calliper with 0.01mm accuracy used for measuring distances of specified points

Measurements of the printed dental models (printed after impression and printed after intraoral scanning) were compared with the plaster cast models, which were considered the *golden standard*; an additional comparison was made between the printed models obtained by using two different printing methods.

All resulting data were collected in *Microsoft Excel* programme and subjected to statistical evaluation (*t-test, Fisher Test*). The null hypothesis was that there are no statistically significant differences between the measurements performed on the three types of models.

Results and discussions

The results obtained following the statistical analysis indicate that most of the recorded measurements made on all model types (plaster cast models - M, printed models obtained after impression scanning - MP-IM, printed models obtained after intra-oral scanning - MP-IO) were reproducible.

No statistically significant differences were found when comparing the measurements made on the models obtained after intraoral scanning (MP-IO) and those made on plaster models (M) (table 3).

Yet, it was noted that the recorded measurements corresponding to the inter-canine width (CC) made on MP-IM models were different from the ones made on M models and these differences were statistically significant (*p=0.0308 / t-test; p=0.0276 / Fischer test*) (table 3).

Additional differences were noted for the measurements of the inter-canine width (CC) as well as for the measurements of the canine-first molar width / left side (M-l) when MP-IM and MP-IO models were compared, and these differences were statistically significant (p=0.0099, respectively p=0.0001*; t-test*). As regards the *Fisher test* results corresponding to the CC measurements compared on MP-IM and MP-IO models, the differences were statistically significant (p=0.0198), while for the canine-first molar width / left side (CM-l) the differences were not statistically significant. In the light of the statistical analysis the initial null hypothesis was rejected.

Nevertheless, no statistically significant differences were found for the rest of the measurements, which is an important aspect for the clinical approach.

On the whole, the differences found for 78.58% of the statistically compared measurements proved to be statistically insignificant when the *t-test* was applied. Moreover, the *p value* corresponding to the comparison of the measurements of the inter-canine width (CC) made on MP-IO models and M models (*p=0.0308; t-test*) has a low relevance. On the other hand, when the *Fisher test* was used the differences found were insignificant for 85.72% of the statistically compared measurements.

In the light of our results, it can be noted that an important degree of agreement was obtained between all models and all measurements performed with the exception of: 1. the inter-canine widths (CC) that were different on MP-IM models compared to M models and to MP-IO ones; 2. canine-first molar widths / left side (CM-l) corresponding to the measurements made on MP-IM and MP-IO models; for these specific measurements, the mean differences were statistically significant.

No statistically significant differences were found between the results of all other measurements, including the situations when we compared the measurements made on the models obtained after intraoral scanning (MP-IO) and those made on plaster models (M), which were considered the *golden standard*.

These results are generally in line with the outcomes of various studies found in the scientific literature.

A few years ago, intraoral scanning was generally considered less precise than laboratory scanning (Flugge et al., 2013) because the intraoral conditions (saliva, limited spacing, head or tongue movement) contribute to the overall inaccuracy [9]. Other studies (Mangano et al., 2017) showed that intraoral scanners are recommended to replace conventional impressions only for prosthetic restorations of up to 3-5 elements on natural teeth or implants and that conventional impressions still remain *the best solution currently for long-span restorations* (fixed full arches restorations on teeth or implants) [10]. As regards the restorations on implants, digital implant models proved to be less precise in comparison with the conventional workflow [11].

Yet, recent studies confirm that models obtained from a digital intra-oral scanning have a dimensional accuracy equivalent to that of plaster stone casts models obtained after traditional impressions (M. Serag et al, 2018) [12] and that intraoral scanners have *an equally or higher accuracy and precision than conventional impressions*, and these can be used when restoring *up to ten units, without extended edentulous spans* (R. Nedelcu et al., 2018) [13].

In vitro studies [14-18] as well as in vivo studies [19, 20, 21] reported good, equal or even better marginal fit for the fixed prosthetic restorations obtained after intraoral scanning compared to the marginal fit of the fixed prosthetic restorations obtained after extraoral scanning (impressions scanning).

In the same line, our results pointed out that statistically significant differences were noticed for inter-canine widths (CC) when comparing printed models obtained after impression scanning (MP-IM) with both plaster models (M) and the ones obtained after intraoral scanning (MP-IO). The most frequent statistically significant differences between performed measurements were noticed for the MP-IM models.

Table 3

RESULTS OBTAINED FOLLOWING THE STATISTICAL ANALYSIS

		Difference between Means	CI 95% Dunnet		t statisti	P -Value	t-test resolution	F statis	p-value	Fisher resolution
Inter-canine width CC	MP-IM - M	0,8178	0,073	1,5625	-2,423	0,0308	S	5,87	0,0276	S
	MP-IO - M	-0,0844	-0,8292	0,6603	0,328	0,7469	NS	0,11	0,7469	NS
	MP-IM - MP-IO	0,9022	0,1636	1,6408	-2,59	0,0099	S	6,71	0,0198	S
canine-first molar width / left side CMl	MP-IM - M	0,908	-2,999	4,815	-0,517	0,612	NS	0,27	0,612	NS
	MP-IO - M	-0,854	-4,761	3,052	0,536	0,5996	NS	0,29	0,5996	NS
	MP-IM - MP-IO	1,762	-1,703	5,228	-4,616	0,0001	S	1,16	0,297	NS
canine incisal-gingival height / left side HCl	MP-IM - M	0,0367	-1,6331	1,7065	-0,05	0,9607	NS	0	0,9607	NS
	MP-IO - M	-0,4167	-2,0865	1,2531	0,606	0,553	NS	0,37	0,5529	NS
	MP-IM - MP-IO	0,4533	-1,0533	1,9599	-0,638	0,5327	NS	0,41	0,5326	NS
canine-first molar width / right side CMr	MP-IM - M	0,6844	-3,6788	5,0477	-0,36	0,7235	NS	0,13	0,7234	NS
	MP-IO - M	-0,1656	-4,5288	4,1977	0,093	0,9269	NS	0,01	0,9269	NS
	MP-IM - MP-IO	0,85	-3,1618	4,8618	-0,512	0,6156	NS	0,2	0,6593	NS
canine incisal-gingival height / right side HCr	MP-IM - M	0,4067	-1,5336	2,3469	-0,502	0,6224	NS	0,25	0,6224	NS
	MP-IO - M	-0,0078	-1,948	1,9325	0,009	0,9929	NS	0	0,9929	NS

Moreover, our results showed that the reproducibility of the measurements performed on the analysed study models was 78.58% in case of the statistical analysis by using *t-test* (Student) and 85.72% in case of the statistical analysis using *Fisher test,* no statistically significant differences being noted.

Regarding our results, we assume that analogue measurements could generate certain differences; thus, from our perspective, further studies that should focus on digital measurements or on scanning electron microscopy analyses are required.

As we stated before, patient-related factors [9] influence the intra-oral scanning process (data capture), resulting in final errors acquisition; apart from this, dental doctors' skills and expertise in intraoral scanning are also important. Scannable impression materials represent another important factor as they contribute to obtaining reliable reproductions, which are difficult to achieve by the means of intraoral systems.

On the other hand, most of the recent studies conclude that intraoral scanning provides higher *precision* and *trueness* when compared to the conventional impression or to extraoral scanning [12, 13, 22, 23]. It was also shown that the new generations of printers produce clinically acceptable models that represent a good, viable option for clinical applications [24, 25].

Last but not least, the 3D printing, as an additive process, is believed to be superior to the cutting process, thus allowing the possibility to prepare more complex models and dental restorations that are unfeasible in the subtractive process [26, 27]. Technical advancement in the performance of 3D printing has been significant in the last years [28-30] and a current trend toward lower prices has also been noticed [26]. In this favorable context, 3D printing in dentistry is expected to reach its best in the near future.

Conclusions

Within the limitations of the present study, the following conclusions were drawn:

- 3D printed models can be considered a reliable option for clinical applications;

- no statistically significant differences were noticed when comparing the measurements made on the models obtained after intraoral scanning and those made on plaster models;

- the measurements performed on printed models obtained after extraoral scanning (impression scanning) showed statistically significant differences when compared to the traditional plaster cast models or to the ones obtained after intraoral scanning.

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