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# Accuracy of printed dental models made with 2 prototype technologies and different designs of model bases

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**Introduction:** The aim of this study was to compare the accuracy of printed models from intraoral scans with different designs of model bases, using 2 types of 3-dimensional printing techniques. **Methods:** Three types of model base design were created: regular base, horseshoe-shaped base, and horseshoe-shaped base with a bar connecting the posterior region. The digital models were printed with the 3-dimensional printers using different techniques: stereolithography and triple jetting technology (polyjet). The printed models were then scanned with a computed tomography scanner and a desktop laser scanner to create the respective digital models. Evaluation of the accuracy was done by measuring the dentitions with Ortho Analyzer software (3Shape, Copenhagen, Denmark) and by model superimposition with Geomagic Qualify software (3D Systems, Rock Hill, SC). An observer measured the distances twice, with an interval of 2 weeks. The accuracy of the printed models was statistically evaluated by the mixed-effects regression model approach. **Results:** The results showed that printed models made by the polyjet printer were accurate, regardless of the design of the model base. Printed models made with the stereolithography technique with the regular model base and the horseshoe-shaped base with a bar were accurate, but the transversal distances measured on the printed models with a horseshoe-shaped base were statistically significantly smaller. **Conclusions:** Printed models with a regular base or a horseshoe-shaped base with a bar were accurate regardless of the printing technique used. Printed models with a horseshoe-shaped base made with the stereolithography printer had a statistically significant reduction in the transversal dimension that was not found in the models printed with the polyjet technique. (Am J Orthod Dentofacial Orthop 2017;151:1178-87)

Rapid prototyping was introduced in the 1980s for orthodontics as a new technique for manufacturing physical dental models based on CAD/CAM procedures. Now, several 3-dimensional (3D) printers are available that can print various 3D objects, using different techniques and materials. The most commonly used techniques for dental 3D printers are stereolithography (SLA), triple jetting technology (polyjet), and fusion deposition modeling printing. SLA printing is a type of printing where an ultraviolet laser cures resin in a desired shape.[1] During this process, the printing plate moves down in small increments, and the liquid polymer is exposed to an untraviolet laser that cures a cross section layer by layer. This process is repeated until a printed model (such as a dental model) has been made. The polyjet 3D printing process is similar to inkjet printing, but instead of jetting drops of ink onto paper, the printer jets layers of curable liquid photopolymer onto a building platform. The building platform then steps down 1 layer thickness, and more material is deposited directly on the previous layer. This process is repeated until the shape has been printed completely. Another printing technique is the fusion deposition modeling, which builds printing material layer by layer from the bottom upward by heating from a continuously extruding thermoplastic filament. Because this method results in poor-quality prints with a distinguishable layered surface, this technique is less used in dentistry.[1] According to a study, polyjet printing showed more adequate details with a more uniformly smooth surface than the models made with the fusion deposition modeling method.[2]

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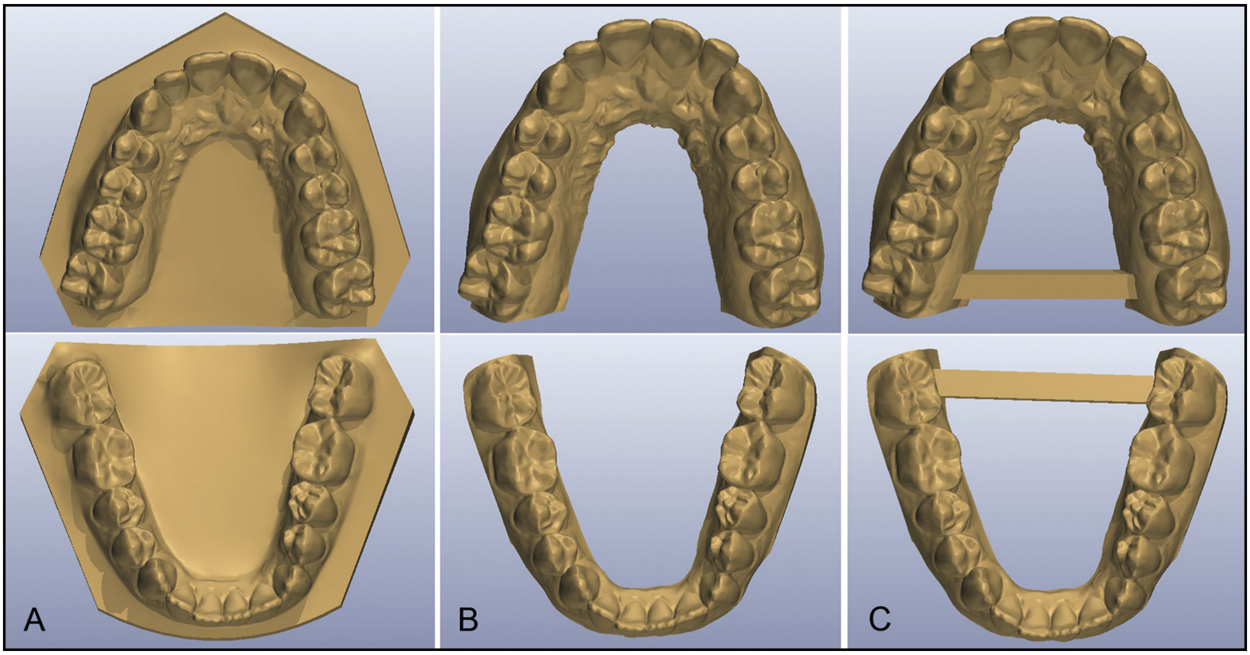


**Fig 1.** Design of bases of the digital models: **A,** regular (ABO) base; **B,** horseshoe-shaped base; **C,** horseshoe-shaped base with a bar.

There are only a few studies published on the accuracy of printed models compared with plaster models.[1,3-5] These studies concluded that the printed models can be used as a replacement for plaster models, but it is unclear whether the samples used in these studies (only 1 pair,[4] 4 pairs,[3] 6 pairs,[5] and 10 pairs[1] of models) were sufficient to draw definitive conclusions.

Different model base designs are used in orthodontics, such as the regular base, according to the requirements of the American Board of Orthodontists (ABO) and the horseshoe-shaped base, which is used to improve the vacuum-formed method of aligner fabrication.[6] The printed models for aligner fabrication should also be manufactured with a high temperature-resistant material that allows the production of a clear aligner without distortion during vacuum forming under heat. An accurate printed model is fundamental for orthodontic appliance fabrication. Inaccurate models will result in inaccurate orthodontic appliances and can cause unplanned tooth movements, such as undesirable expansion or contraction of the arches during aligner treatment.

The influence of model base design on the accuracy of printed models has not been tested yet. There are doubts about whether a horseshoe-shaped base can be as accurate as a regular base in the printed models, but no information on this topic is available in the literature. The aim of this study was to compare the accuracy of printed models with different model base designs made with 2 types of 3D printing techniques: SLA and polyjet methods.

## MATERIAL AND METHODS

A power study, applying the formula described by Pandis[7] assuming 80% power and an alpha of 0.05, showed that 10 pairs of printed dental models for each group were needed to show statistical differences of 1.25 mm in measurements with a 1.0-mm standard deviation. A sample of 10 volunteers who met the criteria for inclusion (fully erupted and complete permanent dentitions including all maxillary and mandibular permanent second molars) and without the exclusion criteria (marked dental anomalies in size and shape; severe gingival recessions; severe dental crown abrasions, attritions, and erosions; or fixed orthodontic retention) was randomly selected from a larger sample of scanned patients. The volunteers were informed about the study procedures and signed an informed consent form before participation. The ethical committee of Federal Fluminense University approved this study in 2016.

The dentitions of the volunteers were scanned with a TRIOS color intraoral scanner (3Shape, Copenhagen, Denmark) according to the manufacturer's instructions. The maxillary arch was scanned first and then the mandibular arch, and finally the occlusion was scanned.

After the scanning procedure, the stereolithographic files were stored in a computer. The 10 pairs of digital models were exported to Appliance Designer Software (3Shape) to design 3 types of bases for each pair of models: a regular base according to the ABO requirements, a horseshoe-shaped base, and a horseshoe-shaped base with a bar in the second molar area connecting the posterior regions of the arches (Fig 1). This latter design (a mix of the other 2 designs of model bases) was intended to evaluate whether a bar connecting the molars in the posterior regions of the model could influence the accuracy of the printed models. A total of 30 sets of digital models were available for printing.

The digital models were sent to 2 dental laboratories that used different printing and model scanning techniques. The 30 digital models were printed with a digital light-processing 3D printer (Ultra 3SP Ortho; Envisiontec, Gladbeck, Germany) containing a light-curing methacrylic resin (E-Denstone; Envisiontec) and using a build layer thickness of 0.10 mm. This 3D printer uses the SLA technique with the technology called scan, spin, and selectively photocure. All digital models were also printed with a polyjet technique 3D printer (Objet Eden260VS; Stratasys, Eden Prairie, Minn) with a 0.016-mm layer thickness. For the polyjet printing, a photopolymer resin (Full Cure 720; Stratasys) was used.

The printed models were then scanned by the same company that made the printed models. The models printed with the Envisiontec 3D printer (SLA models) were scanned by the company with a Flash computed tomography scanner (FCT-1600; Hytec, Los Alamos, NM). The printed models made with the Stratasys 3D printer (polyjet models) were scanned with the R700 laser scanner (3Shape). The printed models with the regular base (printed with both techniques) were considered the gold standard for the 2 comparisons methods, superimpositioning and measuring, because only this base design was studied in the literature.[1,3-5] Furthermore, the superimposition between the original digital models from intraoral scanning and the scanned printed models with a regular base showed that these printed models with an ABO base were similar and accurate, with average differences of 0.01 mm in both the SLA and polyjet models.

The digital models from the scanned printed models were exported to Geomagic Qualify software (3D Systems, Rock Hill, SC) to perform a model superimposition and exported to Ortho Analyzer software (3Shape) for measuring distances. Figure 2 illustrates the design of the study.

In the Geomagic software, the bases of the digital models were cut apical to the gingival margin to prevent distortions of the superimposition caused by the base.

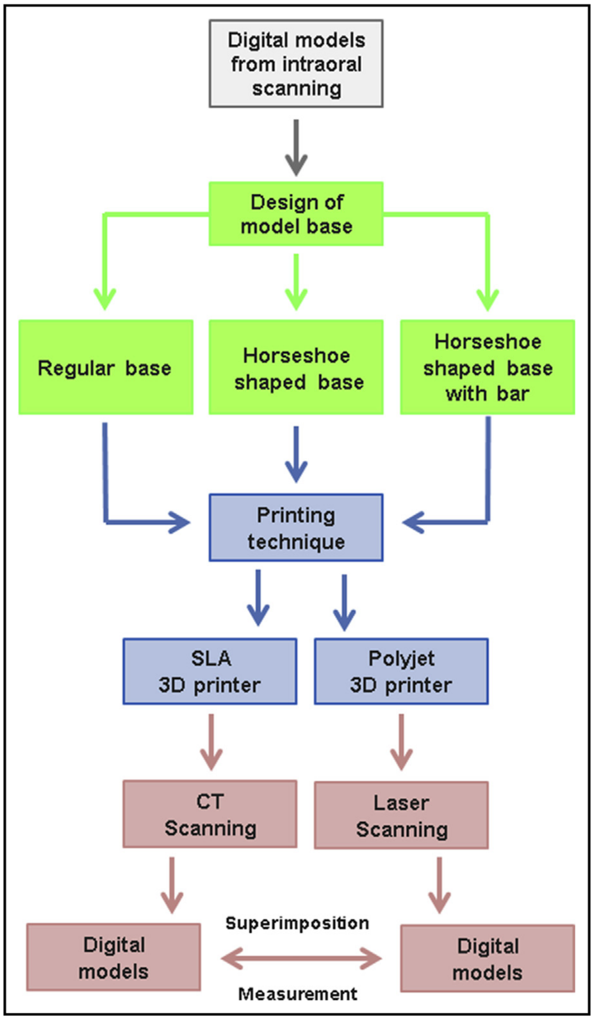


**Fig 2.** Schematic figure, illustrating the design of this study.

The models were then superimposed on the dentition using the automatic best-fit surface alignment tool of the software. After superimposition, the model edges were trimmed with cutting planes to create common borders. Color displacement maps were generated to confirm accurate crown superimpositions and to measure the differences between the models. The superimposition data were obtained by calculation of the distance of captured points between each superimposed digital model. Geomagic Qualify software shows the means and maximum distances between the models (both positive and negative) and the standard deviations, measured in the color map analysis. The limits used in the color map were 0.50 mm (Fig 3).

Five distances on the maxillary and mandibular dentitions were measured with the Ortho Analyzer software: between the canines, first premolars, second

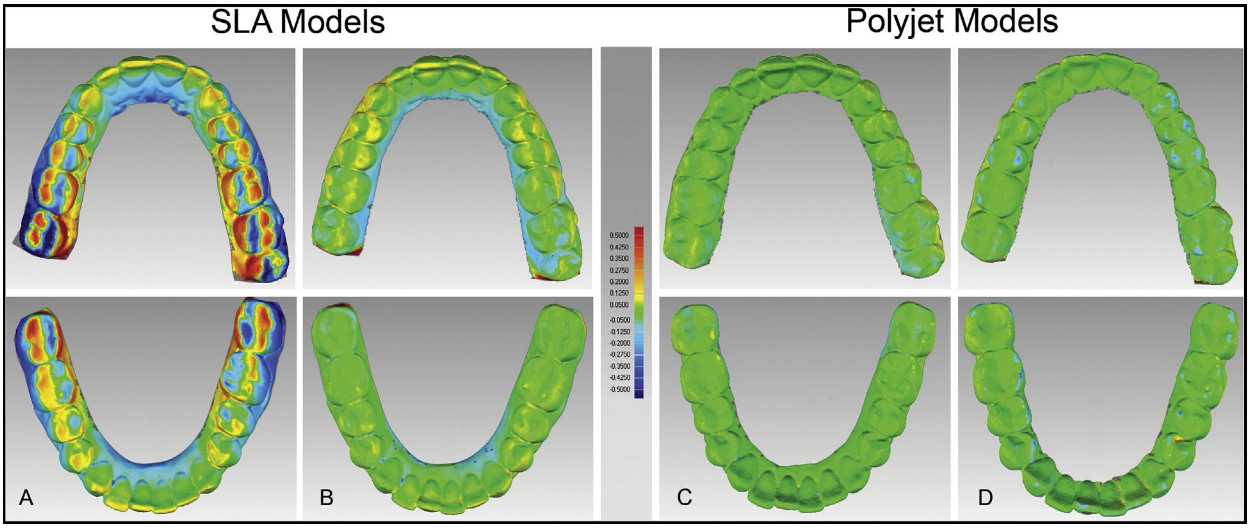


**Fig 3.** Color displacement maps of model superimpositions of scanned printed models made with the SLA printing techniques: **A,** regular base vs horseshoe-shaped base; **B,** regular base vs horseshoe shaped base with a bar. Color displacement maps of model superimpositions of scanned printed models made with the polyjet printing techniques: **C,** regular base vs horseshoe-shaped base; **D,** regular base vs horseshoe-shaped base with a bar.

premolars, first molars, and second molars (Fig 4). All measurements were performed twice by a trained and calibrated examiner (L.T.C.), with an interval of 2 weeks.

### Statistical analysis

The statistical analysis was performed with the R software (version 3.3.1; R Core Team, Vienna, Austria). The accuracy of the models printed with the SLA and the polyjet techniques was demonstrated by verifying the lack of both systematic (no bias) and random errors (high precision) between the measurements made on the models with different bases. The lack of systematic differences (bias) between the measurements made on the models with different bases were evaluated according to the similarity between the average intraclass correlation coefficient (ICC) and Cronbach's alpha, through the mixed-effects regression model framework.[8] Cronbach's alpha is insensitive to rater differences that are linear changes. It can be compared with the average ICC to detect consistent rater bias. A greater difference between the 2 coefficients indicates a greater rater bias. The average ICC is the reliability calculated by taking an average of the raters' measurements. The average ICC means reproducibility if the test was repeated several times and the mean value was calculated. The lack of random

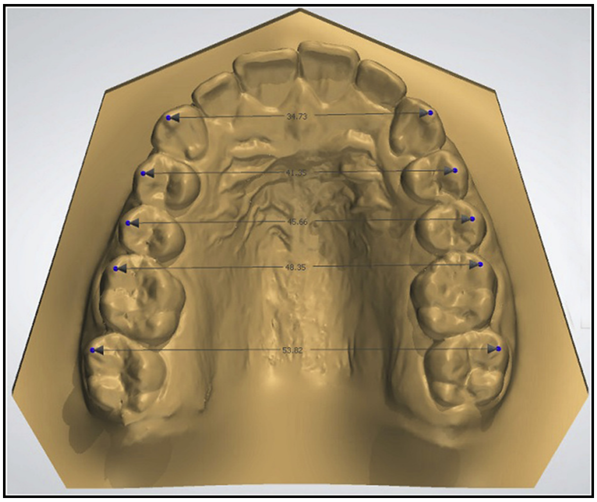

**Fig 4.** Measurements used for maxillary and mandibular models. Intercanine distance: distance between the cusp tip of the left canine and the cusp tip of the right canine; interfirst and intersecond premolar distances: distances between the buccal cusp tips of the left premolar and the buccal cusp tips of the right premolars; interfirst and intersecond molar distances: distances between the mesial buccal cusp tips of the left molar and the mesial buccal cusp tips of the right molars.

errors (high precision) was evaluated through the single ICC. The single ICC is the reliability calculated from 1 measurement and means reproducibility if the

**Table I.** Measurements according to printing technique, intraexaminer performance, and type of arch, base, and distance

| | | | SLA | | | | Polyjet | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Measurement 1 | | Measurement 2 | | Measurement 1 | | Measurement 2 | |
| Arch | Base | Distance (mm) | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Maxilla | Regular | Intercanine | 32.78 | 2.33 | 32.70 | 2.40 | 33.01 | 2.24 | 32.87 | 2.24 |
| | | Interfirst premolar | 40.77 | 2.59 | 40.71 | 2.57 | 40.71 | 2.80 | 40.73 | 2.82 |
| | | Intersecond premolar | 46.10 | 2.60 | 45.99 | 2.62 | 46.18 | 2.58 | 46.33 | 2.62 |
| | | Interfirst molar | 50.49 | 3.74 | 50.27 | 3.64 | 50.69 | 3.72 | 50.42 | 3.67 |
| | | Intersecond molar | 56.84 | 4.24 | 56.72 | 4.31 | 56.86 | 4.11 | 56.86 | 4.23 |
| | Horseshoe-shaped | Intercanine | 32.33 | 2.28 | 32.34 | 2.27 | 32.87 | 2.18 | 32.88 | 2.26 |
| | | Interfirst premolar | 39.99 | 2.59 | 39.84 | 2.56 | 40.69 | 2.49 | 40.69 | 2.47 |
| | | Intersecond premolar | 45.27 | 2.69 | 45.02 | 2.84 | 46.34 | 2.59 | 46.23 | 2.68 |
| | | Interfirst molar | 49.46 | 3.73 | 49.46 | 3.72 | 50.56 | 3.56 | 50.55 | 3.64 |
| | | Inter second molar | 55.48 | 4.38 | 55.52 | 4.44 | 57.16 | 4.23 | 57.09 | 4.28 |
| | Horseshoe-shaped with bar | Intercanine | 32.76 | 2.26 | 32.77 | 2.35 | 33.01 | 2.19 | 33.02 | 2.13 |
| | | Interfirst premolar | 40.58 | 2.54 | 40.46 | 2.51 | 40.79 | 2.61 | 40.88 | 2.41 |
| | | Intersecond premolar | 46.08 | 2.57 | 45.97 | 2.67 | 46.18 | 2.62 | 46.31 | 2.66 |
| | | Interfirst molar | 50.27 | 3.62 | 50.10 | 3.66 | 50.49 | 3.73 | 50.52 | 3.64 |
| | | Intersecond molar | 56.76 | 4.23 | 56.58 | 4.11 | 57.00 | 4.34 | 56.98 | 4.37 |
| Mandible | Regular | Intercanine | 25.11 | 2.31 | 25.04 | 2.39 | 25.20 | 2.13 | 24.95 | 2.16 |
| | | Interfirst premolar | 32.74 | 1.95 | 32.71 | 1.86 | 32.93 | 1.75 | 32.89 | 1.72 |
| | | Intersecond premolar | 38.23 | 2.44 | 38.20 | 2.37 | 38.23 | 2.38 | 38.16 | 2.33 |
| | | Interfirst molar | 44.33 | 2.89 | 44.28 | 2.87 | 44.28 | 2.77 | 44.15 | 2.79 |
| | | Inter second molar | 50.49 | 3.12 | 50.40 | 3.15 | 50.48 | 2.98 | 50.42 | 3.00 |
| | Horseshoe-shaped | Intercanine | 25.09 | 2.31 | 24.94 | 2.33 | 25.38 | 2.18 | 25.34 | 2.08 |
| | | Interfirst premolar | 32.54 | 1.78 | 32.37 | 1.68 | 32.88 | 1.99 | 32.69 | 1.96 |
| | | Intersecond premolar | 37.78 | 2.23 | 37.77 | 2.21 | 38.54 | 2.30 | 38.39 | 2.37 |
| | | Interfirst molar | 43.54 | 2.60 | 43.55 | 2.63 | 44.29 | 2.88 | 44.09 | 2.85 |
| | | Intersecond molar | 49.28 | 2.47 | 49.28 | 2.52 | 50.53 | 3.02 | 50.39 | 3.09 |
| | Horseshoe-shaped with bar | Intercanine | 24.97 | 2.29 | 24.95 | 2.34 | 25.34 | 2.27 | 25.24 | 2.32 |
| | | Interfirst premolar | 32.50 | 1.74 | 32.49 | 1.75 | 32.91 | 1.80 | 32.74 | 1.87 |
| | | Intersecond premolar | 37.97 | 2.22 | 37.91 | 2.27 | 38.37 | 2.41 | 38.16 | 2.55 |
| | | Interfirst molar | 44.01 | 2.68 | 43.89 | 2.70 | 44.44 | 2.80 | 44.33 | 2.89 |
| | | Intersecond molar | 50.09 | 2.86 | 49.84 | 2.86 | 50.55 | 3.09 | 50.47 | 2.95 |

*SD*, Standard deviation.

test is performed at one of several occasions, respectively. ICC values above 0.75 usually show high reliability. The same approach was used to measure the intraexaminer performance.

The lack of systematic differences was also evaluated by comparing the models with a horseshoe-shaped base and with a horseshoe-shaped base with a bar, with the models with a regular base, considering the base component as a fixed effect by the mixed-effects regression model approach.[8] The mixed-effects regression model approach was also used to estimate the variance of each measurement variation component and to compare the accuracy of the techniques through the bases' variances.

The paired *t* test was used to evaluate the differences between the superimposition on the scanned printed models with the 2 printing techniques. *P* values less than 0.05 were considered to be significant.

## RESULTS

Table I is a summary of the descriptive statistics of the linear measurements. In the SLA printed models, similar values are shown between the models with the regular base and the horseshoe-shaped base with a bar. On the other hand, the models with a horseshoe-shaped base had smaller values compared with the other 2 types of model base. In the polyjet printed models, we found small differences in the transversal measurements among the 3 types of model base.

Table II shows the interbase and the intraexaminer performance evaluation according to the ICC. The mixed-effect models were adjusted for each arch (maxilla and mandible) and for each distance (from intercanine to intersecond molar distances). For both printing techniques, there were no systematic

**Table II.** Interbase and intraexaminer performance evaluation according to the ICC

| | | | *SLA* | | | *Polyjet* | | |
|---|---|---|---|---|---|---|---|---|
| *Type* | *Arch* | *Distance* | *Single** | *Average†* | *Alpha‡* | *Single** | *Average†* | *Alpha‡* |
| Interbase | Maxilla | Intercanine | 0.979 | 0.993 | 0.996 | 0.973 | 0.991 | 0.990 |
| | | Interfirst premolar | 0.963 | 0.987 | 0.997 | 0.982 | 0.994 | 0.994 |
| | | Intersecond premolar | 0.951 | 0.983 | 0.995 | 0.992 | 0.997 | 0.997 |
| | | Interfirst molar | 0.973 | 0.990 | 0.996 | 0.995 | 0.998 | 0.998 |
| | | Intersecond molar | 0.969 | 0.989 | 0.999 | 0.996 | 0.998 | 0.998 |
| | Mandible | Intercanine | 0.988 | 0.996 | 0.996 | 0.961 | 0.986 | 0.987 |
| | | Interfirst premolar | 0.964 | 0.988 | 0.989 | 0.966 | 0.988 | 0.988 |
| | | Intersecond premolar | 0.978 | 0.992 | 0.995 | 0.980 | 0.993 | 0.994 |
| | | Interfirst molar | 0.963 | 0.987 | 0.994 | 0.988 | 0.996 | 0.996 |
| | | Intersecond molar | 0.899 | 0.964 | 0.978 | 0.993 | 0.997 | 0.997 |
| | General | | 0.996 | 0.998 | 0.999 | 0.999 | 0.999 | 0.999 |
| Intraexaminer | Maxilla | Intercanine | 0.995 | 0.997 | 0.997 | 0.984 | 0.992 | 0.992 |
| | | Interfirst premolar | 0.995 | 0.997 | 0.998 | 0.995 | 0.997 | 0.997 |
| | | Interecond premolar | 0.993 | 0.996 | 0.997 | 0.995 | 0.997 | 0.997 |
| | | Interfirst molar | 0.995 | 0.997 | 0.997 | 0.995 | 0.997 | 0.997 |
| | | Intersecond molar | 0.998 | 0.999 | 0.999 | 0.997 | 0.998 | 0.998 |
| | Mandible | Intercanine | 0.996 | 0.998 | 0.998 | 0.988 | 0.994 | 0.994 |
| | | Interfirst premolar | 0.984 | 0.992 | 0.992 | 0.986 | 0.993 | 0.994 |
| | | Intersecond premolar | 0.997 | 0.998 | 0.998 | 0.990 | 0.995 | 0.995 |
| | | Interfirst molar | 0.995 | 0.997 | 0.997 | 0.993 | 0.996 | 0.997 |
| | | Intersecond molar | 0.997 | 0.998 | 0.998 | 0.994 | 0.997 | 0.997 |
| | General | | 0.999 | 0.999 | 0.999 | 0.999 | 0.999 | 0.999 |

*ICC single; †ICC average; ‡Cronbach's alpha.

differences (no bias) because the values of the average ICC and Cronbach's alpha were very close, and the lack of random errors (high precision) was confirmed since all ICC values were above the acceptable minimum of 0.75. Although both techniques showed satisfactory results, the polyjet printing technique had better results. The intraexaminer performance evaluation had high reliability and no systematic errors (no bias), since the minimum ICC value was 0.984.

Table III shows the variability of measurement variation components according to the mixed-effects regression model. The mixed effect model follows a similar structure to that presented in Table II, however, with the variables base and printing technique as fixed effects and the variables individuals, distance, and arch as random effects. In both arches, in most of the distance types, the polyjet printing technique showed less variability according to the model bases. For the maxillary arch, the variabilities were 0.06, 0.18, 0.26, 0.23, and 0.50 for the SLA technique and 0.00, 0.00, 0.00, 0.00, and 0.01 for the polyjet technique, considering, respectively, the intercanine, interfirst premolar, intersecond premolar, interfirst molar, and intersecond molar distances. For the mandibular arch, the variabilities considering the different model bases were 0.00, 0.02, 0.05, 0.14, and 0.33 for the SLA technique and 0.02, 0.00, 0.01, 0.01, and 0.00 for the polyjet technique, considering the same distance types. In general, in the maxillary arch, the SLA technique had a variability of 0.21, whereas the polyjet technique had a variability of 0.00. In the mandibular arch, SLA showed a variability of 0.06, and the polyjet technique had a variability of 0.00. Therefore, regarding the different types of model base, the measurement differences in the SLA models were progressively increasing from the anterior to the posterior regions of the arches. The polyjet models had greater accuracy of the parameters between the different types of model base.

Table IV gives the mixed-effects regression model analysis considering the base as a fixed effect. In the SLA printer, there was a systematic error on the printed models with the horseshoe-shaped base compared with the models with a regular base ($P = 0.000$). So, considering the same moment, the same individual, the same arch, and the same type of distance, the horseshoe-shaped base had a distance −0.702 mm (95% confidence interval, −1.00, −0.41 mm) smaller compared with the distance of the regular base. In addition, there was no systematic error of the models with the horseshoe base with a bar compared with the regular base ones ($P = 0.183$). With the polyjet printer, there were no systematic errors in the models with a horseshoe-shaped base ($P = 0.684$) and the models with the horseshoe-

**Table III.** Variability of measurements variation components according to the mixed-effects regression model, considering individual, bases, intraexaminer performance, and types of distance as random effects (mm)

| | | *Maxillary arch* | | | | | | *Mandibular arch* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *SLA* | | | *Polyjet* | | | *SLA* | | | *Polyjet* | | |
| *Distance* | *Variation source* | *Var* | *SD (mm)* | *95% CI (mm)* | *Var* | *SD (mm)* | *95% CI (mm)* | *Var* | *SD (mm)* | *95% CI (mm)* | *Var* | *SD (mm)* | *95% CI (mm)* |
| Intercanine | Individuals | 5.31 | 2.30 | 1.26; 3.40 | 4.77 | 2.18 | 1.20; 3.14 | 5.36 | 2.32 | 1.27; 3.39 | 4.66 | 2.16 | 1.13; 3.13 |
| | Base | 0.06 | 0.24 | 0.00; 0.45 | 0.00 | 0.00 | 0.00; 0.12 | 0.00 | 0.02 | 0.00; 0.10 | 0.02 | 0.12 | 0.00; 0.29 |
| | Examiner | 0.04 | 0.21 | 0.17; 0.25 | 0.10 | 0.32 | 0.26; 0.38 | 0.05 | 0.23 | 0.18; 0.28 | 0.14 | 0.38 | 0.30; 0.45 |
| Interfirst premolar | Individuals | 6.50 | 2.55 | 1.44; 3.64 | 6.67 | 2.58 | 1.43; 3.77 | 3.13 | 1.77 | 0.97; 2.64 | 3.33 | 1.82 | 0.98; 2.71 |
| | Base | 0.18 | 0.42 | 0.04; 0.80 | 0.00 | 0.04 | 0.00; 0.14 | 0.02 | 0.13 | 0.00; 0.26 | 0.00 | 0.00 | 0.00; 0.12 |
| | Examiner | 0.05 | 0.23 | 0.18; 0.27 | 0.09 | 0.31 | 0.24; 0.36 | 0.09 | 0.30 | 0.24; 0.36 | 0.10 | 0.32 | 0.25; 0.38 |
| Intersecond premolar | Individuals | 7.03 | 2.65 | 1.41; 3.86 | 6.85 | 2.62 | 1.43; 3.76 | 5.20 | 2.28 | 1.20; 3.34 | 5.62 | 2.37 | 1.30; 3.49 |
| | Base | 0.26 | 0.51 | 0.05; 0.96 | 0.00 | 0.00 | 0.00; 0.08 | 0.05 | 0.22 | 0.00; 0.42 | 0.01 | 0.12 | 0.00; 0.26 |
| | Examiner | 0.08 | 0.28 | 0.22; 0.33 | 0.04 | 0.21 | 0.17; 0.25 | 0.05 | 0.22 | 0.18; 0.27 | 0.09 | 0.31 | 0.24; 0.37 |
| Interfirst molar | Individuals | 13.45 | 3.67 | 2.04; 5.38 | 13.34 | 3.65 | 1.96; 5.15 | 7.35 | 2.71 | 1.51; 3.99 | 7.94 | 2.82 | 1.52; 4.16 |
| | Base | 0.23 | 0.48 | 0.03; 0.92 | 0.00 | 0.00 | 0.00; 0.09 | 0.14 | 0.37 | 0.00; 0.73 | 0.01 | 0.09 | 0.00; 0.20 |
| | Examiner | 0.12 | 0.34 | 0.27; 0.41 | 0.06 | 0.24 | 0.19; 0.29 | 0.11 | 0.33 | 0.26; 0.40 | 0.07 | 0.27 | 0.22; 0.32 |
| Intersecond molar | Individuals | 18.33 | 4.28 | 2.36; 6.47 | 18.09 | 4.25 | 2.40; 6.03 | 7.68 | 2.77 | 1.47; 4.08 | 9.07 | 3.01 | 1.60; 4.43 |
| | Base | 0.50 | 0.71 | 0.10; 1.36 | 0.01 | 0.12 | 0.00; 0.24 | 0.32 | 0.57 | 0.00; 1.11 | 0.00 | 0.00 | 0.00; 0.09 |
| | Examiner | 0.05 | 0.22 | 0.18; 0.26 | 0.05 | 0.23 | 0.18; 0.28 | 0.39 | 0.62 | 0.51; 0.75 | 0.06 | 0.24 | 0.19; 0.29 |
| General | Individuals | 8.45 | 2.91 | 1.66; 4.22 | 8.22 | 2.87 | 1.49; 4.09 | 4.26 | 2.06 | 1.13; 3.09 | 4.54 | 2.13 | 1.15; 3.09 |
| | Distance | 82.05 | 9.06 | 3.25; 15.44 | 84.53 | 9.19 | 3.41; 15.58 | 93.68 | 9.68 | 3.62; 16.61 | 95.99 | 9.80 | 3.67; 16.45 |
| | Base | 0.21 | 0.45 | 0.00; 0.89 | 0.00 | 0.00 | 0.00; 0.21 | 0.06 | 0.24 | 0.00; 0.49 | 0.00 | 0.00 | 0.00; 0.19 |
| | Examiner | 1.63 | 1.28 | 1.17; 1.39 | 1.65 | 1.28 | 1.18; 1.39 | 1.53 | 1.24 | 1.13; 1.33 | 1.55 | 1.24 | 1.14; 1.34 |

*Var*, Variance; *SD*, standard deviation.

**Table IV.** Evaluation of the mixed-effects regression model analysis with base as a fixed effect

| *Printing technique* | *Model base* | *B** | *SE (β)* | *95% CI* | P *value* |
|---|---|---|---|---|---|
| SLA | Regular | | | | |
| | Horseshoe | −0.702 | 0.149 | −1.00; −0.41 | 0.000 |
| | Horseshoe with bar | −0.199 | 0.149 | −0.49; 0.09 | 0.183 |
| Polyjet | Regular | | | | |
| | Horseshoe | 0.061 | 0.149 | −0.23; 0.35 | 0.684 |
| | Horseshoe with bar | 0.070 | 0.149 | −0.22; 0.36 | 0.638 |

Significant a $P < 0.05$.
*Regression coefficient.

shaped base with a bar ($P = 0.638$) compared with the regular base models.

Table V shows the paired *t* test evaluation of the model superimpositions between the different designs of model bases with the SLA and polyjet printing techniques. It was found that, in the SLA printing technique, some parameters had statistically significant differences, whereas in the polyjet technique, there were no statistically significant differences among the parameters.

## DISCUSSION

In this study, printed models from digital models made with an intraoral scanner were used because intraoral scanning is increasingly used to make digital dental models, and some of the errors that can occur in the traditional impression-taking procedure can be avoided. Several studies confirmed the accuracy of digital models from intraoral scanning compared with plaster models, so the intraoral scans can be used as an alternative for plaster models.[9-13]

Although digital models have several advantages compared with plaster models, such as ease of data storage and data transmission, some orthodontists like to use physical dental models.[14] Printed models provide both visual and tactile information and can be used for diagnostic, therapeutic, and education purposes. Physical models are also used for appliance manufacturing such as functional removable appliances, rapid expansion appliances, aligners, and indirect bonding trays.[5,15]

Several software programs are available for patient analysis and diagnostics on digital models. For treatment planning, segmentation of the dental crowns is required to create a virtual setup.[16-18] A virtual setup

**Table V.** Comparison by paired *t* test between model superimpositions of different designs of bases with the SLA and polyjet printing techniques

| | | | SLA | | | Polyjet | | |
|---|---|---|---|---|---|---|---|---|
| *Arch* | *Parameter* | *Base* | *Mean* | *SD* | P *value* | *Mean* | *SD* | P *value* |
| Maxilla | Average deviation | Regular × horseshoe | 0.001 | 0.032 | 0.111 | 0.010 | 0.004 | 0.588 |
| | | Regular × horseshoe with bar | 0.025 | 0.016 | | 0.012 | 0.005 | |
| | Average positive differences | Regular × horseshoe | 0.176 | 0.044 | 0.018 | 0.088 | 0.012 | 0.187 |
| | | Regular × horseshoe with bar | 0.116 | 0.046 | | 0.101 | 0.011 | |
| | Average negative differences | Regular × horseshoe | −0.186 | 0.048 | 0.000 | −0.086 | 0.019 | 0.801 |
| | | Regular × horseshoe with bar | −0.083 | 0.030 | | −0.091 | 0.014 | |
| Mandible | Average deviation | Regular × horseshoe | 0.038 | 0.036 | 0.801 | 0.004 | 0.003 | 0.227 |
| | | Regular × horseshoe with bar | 0.034 | 0.027 | | −0.004 | 0.005 | |
| | Average positive differences | Regular × horseshoe | 0.212 | 0.075 | 0.210 | 0.078 | 0.013 | 0.125 |
| | | Regular × horseshoe with bar | 0.160 | 0.082 | | 0.101 | 0.017 | |
| | Average negative differences | Regular × horseshoe | −0.186 | 0.050 | 0.006 | −0.078 | 0.013 | 0.070 |
| | | Regular × horseshoe with bar | −0.111 | 0.047 | | −0.112 | 0.022 | |

Significant at $P < 0.05$.

can then be used to simulate orthodontic treatment to manufacture customized orthodontic appliances. The use of rapid prototyping in dentistry is growing and usually consists of 2 phases. The orthodontic appliances are designed with computer software (CAD) and then a computer-aided manufacturing (CAM) phase fabricates the appliances. Three-dimensional objects such as dental models and dental appliances can be produced with a rapid prototyping process using different printing materials, such as wax, plastics, ceramics, and metals. The fabrication of complex objects with these printing techniques can be fast, efficient, and relatively inexpensive.

Advantages of the SLA printing process include high part-building accuracy, smooth surface finish, fine building details, and high mechanical strength. The disadvantage of the SLA process mentioned in the literature is the necessity to "postcure" the printed parts to improve the stability of the printed object, since the laser of the printing device cannot cure the printing material completely. It has been published that laser diameter, laser path, and finishing such as residual polymerization and transformation of photo-cured materials, and creation and removal of supporting structures (to avoid unsupported or weakly supported structures), can cause differences in the accuracy of printed objects.[19] Shrinkage of the printed object during building and post-curing of the printed models, as well as thickness of the layers have also been mentioned.[5] In our study, the printed models made with the SLA 3D printer were postcured with a 400-W ultraviolet lamp for 20 seconds. It can be speculated that this postcuring process could have caused compression of the models without a solid base or a connection bar between the posterior regions. Dental models printed with the polyjet printing technique are fully cured during the building process, and postcuring is not needed. A disadvantage of the use of a polyjet printer for dental model printing is the higher cost of printing, compared with the SLA printer.

In the SLA printing technique, the models with a horseshoe-shaped base had a statistically significant reduction in the transversal dimensions, compared with the printed models with the regular base. On the other hand, the printed models with the regular or horseshoe-shaped base with a bar did not have statistically significant differences among the parameters studied. The polyjet printed models had no parameter with statistically significant differences between the different designs of the model base.

The color map analysis of the superimposition of the SLA printed models between the regular and horseshoe-shaped bases had an intense blue color on the buccal area of the superimposed models; this showed that the models with a horseshoe-shaped base (test) were smaller than the models with a regular base (reference). The other model superimpositions, including the polyjet model superimpositions and the SLA model superimpositions between the horseshoe-shaped models with a bar and the regular base models, demonstrated a prevalence of green color, which indicates insignificant differences (Fig 3). Furthermore, according to the paired *t* test, the model superimpositions of the SLA scanned printed models had statistically significant differences in some parameters; in contrast, no statistically significant difference was found in the model superimposition of the polyjet models.

These results correspond to other studies that evaluated printed dental models using the SLA technique with a regular base.[1,4,5] Scanned printed models with regular bases were accurate and similar to the digital models from intraoral scanning. Both the digital measuring and the digital model superimposition methods led to the same conclusions. The main difference we found was a reduction in the transversal dimensions on the printed models with a horseshoe-shaped base from the SLA printing technique, and the inclusion of a bar connecting the posterior regions can prevent this contraction. The models printed with the polyjet technique were accurate, regardless of the design of model base.

The difference in layer thicknesses has been mentioned as a cause of contraction of the printed models.[5] The SLA models had greater layer thickness compared with the polyjet models, but since the difference in layer thickness in the printed models in this study did not affect the accuracy of the printed models with a regular base or with a horseshoe-shaped base with a connection bar, the transversal contraction in the printed models with a horseshoe-shaped base printed with the SLA printer could be caused by the absence of a regular base or a connecting bar with solid resin in the posterior regions of these models. The larger reduced dimensions on the posterior region (intersecond molar distance) of the scanned SLA printed models with a horseshoe-shaped base suggested that the postcuring period could affect the accuracy of these models without a posterior connection bar or a regular base.

In general, some advantages of printed dental models such as low weight, low risk of fracture, and high abrasion resistance have been mentioned.[1] Disadvantages of the rapid prototyping technique (3D printing) to fabricate dental models include high costs of the 3D printer and the printing material, complicated machinery, and expertise needed to operate the printer. Furthermore, the materials used for printing stink, are toxic, and must be shielded from light to prevent premature polymerization.[2] It can be expected that the costs of printing dental models will decrease, and the costs will possibly become comparable with conventional fabrication of plaster models. Increased use of CAD/CAM techniques for making customized orthodontic appliances with appliance printing techniques can be expected.

## CONCLUSIONS

The 2 methods used to evaluate the accuracy of printed dental models in this study (superimposition and digital measuring) led to the same conclusions. Printed dental models using the polyjet printing technique are accurate, regardless of the model base design. For printed models with a horseshoe-shaped base design printed with the SLA 3D printer, statistically significant differences (transversal contraction) were found. Printed models with the SLA 3D printer with a horseshoe-shaped base with a posterior connection bar were accurate compared with printed models with a regular base. More studies are needed to evaluate the accuracy of printed models with other techniques and the accuracy of printed appliances in dentistry.

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