Precision of 3D-printed splints with different dental model offsets

Niansong Ye, Tingting Wu, Ting Dong, Lingjun Yuan, Bing Fang and Luoguo Xia
Shanghai, People's Republic of China

Introduction: The purpose of this study was to assess the precision of 3D-printed splints generated from different dental model offsets. **Methods:** Ten maxillary models were offset by given distances (0.05 mm, 0.1 mm, and 0.2 mm). Digital splints were created by means of the boolean operation. The physical splints were fabricated by means of digital light-processing (DLP) rapid prototyping technologies. A layer of impression material, which could be weighed by means of an electronic analytical balance, was placed in the airspace between the splint and the teeth. We also calculated the shell-to-shell deviations by measuring the 3-dimensional (3D) euclidean distances between the surface points of the scanned splints and the original digital splint and evaluating the results with color-mapping methods. **Results:** There was a statistically significant difference in the amounts of impression material remaining in the airspace between the 0.0-mm group and the 0.05-mm, 0.1-mm, and 0.2-mm groups ($P < 0.05$), between the 0.05-mm and the 0.1-mm and 0.2-mm groups ($P < 0.05$), and between the 0.0-mm group and the 0.05-mm, 0.1-mm, and 0.2-mm groups ($P < 0.05$). There was a statistically significant difference in shell-to-shell deviations between the 0.05-mm and the 0.1-mm and 0.2-mm groups ($P < 0.05$). **Conclusions:** 3D-printed splints generated from offset dental models (offset 0.05 mm, 0.1 mm, and 0.2 mm) can fit better on the teeth than splints from no-offset dental models. An offset of 0.1 mm is the best choice of parameter for generating the splint. (Am J Orthod Dentofacial Orthop 2019;155:733-8)

Over the past decades, dental splints or guides as high-precision technologic tools have been applied to treat various dental and surgical conditions such as bruxism and temporomandibular disorders (TMDs),[1] to change the vertical dimensions of occlusion in complex rehabilitation,[2] to place implants in oral implantology,[3] to place miniscrews in orthodontics,[4] to reposition the maxilla or mandible in orthognathic surgery,[5,6] and for indirect bonding of brackets in orthodontics.[7,8] In the conventional method of splint making, the same acrylic splint would never be made twice for the same patient, even by the same technician. In comparison, digitally based manufacturing provides consistency, fine quantitative control, and speed compared with manual methods.[9]

Rapid prototyping (RP) or 3-dimensional (3D) printing has now become the mainstream manufacturing method in dentistry owing to the significant enhancement of production efficiency and accuracy.[10] Compared with traditional computer-assisted design and manufacturing (CAD/CAM) technologies, RP allows for the creation of very complex geometric structures and has the advantages of patient-specific design, low cost, and high efficiency.[11] 3D printing uses different processing technologies and materials[10]: stereolithography, digital light-processing (DLP), selective laser sintering, fused deposition modeling, and laminated object manufacturing. For dental splint manufacture, RP is the common technology, with its low cost, high efficiency, and high accuracy (16-100 μm).[12-14] However, splints fabricated with this technology do not always fit well, which may lead to positioning errors for teeth and bone in clinical use. Few studies have reported on the precision of 3D-printed splints. The most recent related research was published in 2003,[15] when there were no dental-specific 3D printing machines and materials available. With the increasingly extensive use of 3D

Department of Orthodontics, Ninth People's Hospital Affiliated to Shanghai Jiao Tong University, School of Medicine, Shanghai, People's Republic of China
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Address correspondence to: Bing Fang, Professor and Chair, Department of Orthodontics, Ninth People's Hospital Affiliated to Shanghai Jiao Tong University, School of Medicine, No. 639 Zhizaoju Road, Shanghai, People's Republic of China; e-mail, fangbing@sjtu.edu.cn or Lunguo Xia, Department of Orthodontics, Ninth People's Hospital Affiliated to Shanghai Jiao Tong University, School of Medicine, No. 639 Zhizaoju Road, Shanghai, People's Republic of China; e-mail, xavierxlg@126.com.
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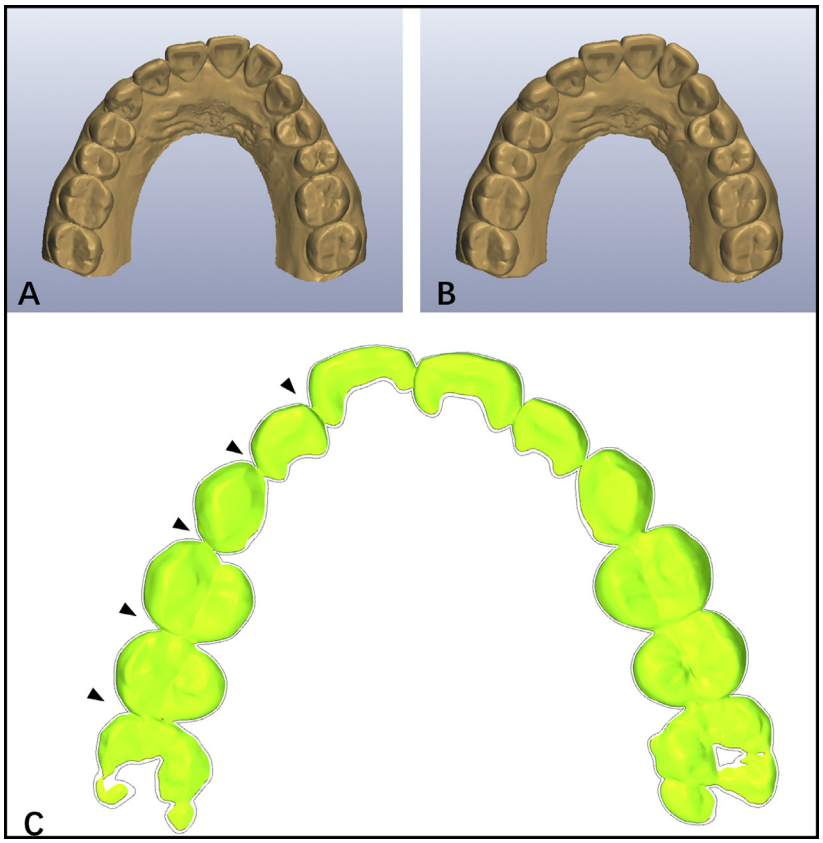

Fig 1. A, Initial dental model. **B,** Offset dental model. **C,** Initial dental model (*green*) and the offset portion (*black line*) which enlarged the initial dental model, especially in the interproximal areas (*arrowheads*), which can not be obtained clearly during model scanning; offset can reduce the impact of these areas on the splint seating.

printing in dentistry in the past 10 years, dental-specific 3D printing machines and materials have become more common. However, research on the precision of 3D-printed splints remains limited. The purpose of this study was to assess the precision of 3D-printed splints generated from different dental model offsets.

MATERIAL AND METHODS

Ten dental models with intact maxillary dentition were used. The maxillary arch model was offset by given distances (0.05 mm, 0.1 mm, and 0.2 mm) in the positive normal direction, and additional well proportioned surfaces were raised on the initial model (Fig 1). The initial model (0.0-mm group) and 3 different offset models (0.05-mm, 0.1-mm, and 0.2-mm groups) were imported into CAD software (3D Systems, Rock Hill, SC), and the same splint profiles for each subject were designed on these models, on the undercut area. To reduce the impact of the steep compensation curve, splints did not cover the second molars. Digital splints were created with the application of boolean software to the dental model[16] (Fig 2). Finally, the physical splints were fabricated by means of DLP rapid prototyping technologies (Dentlab One; Shining 3D, Hangzhou, China) containing a light-curing methacrylic resin and with a build-up layer thickness of 0.05 mm.

A layer of impression material (Elastomeric Impression Material; Huge Dental Material Corporation, Shandong, China) was placed in the splint, which was then seated on the maxillary teeth.[15] A 2-kg copper plate was pressed against the splint until the material solidified. A scalpel was used to remove the overflow materials along the edge of the splint. The impression material remaining on the dental model was inserted into the airspace between the splint and the teeth (Fig 3). Each group of models covered with splints was scanned with the use of a R700 laser scanner (3Shape, Copenhagen, Denmark). The digital models from the scanned models covered with splints were exported to Geomagic software (3D Systems, Rock Hill, SC) for model superimposition and color-mapping methods. The digital model for each scanned

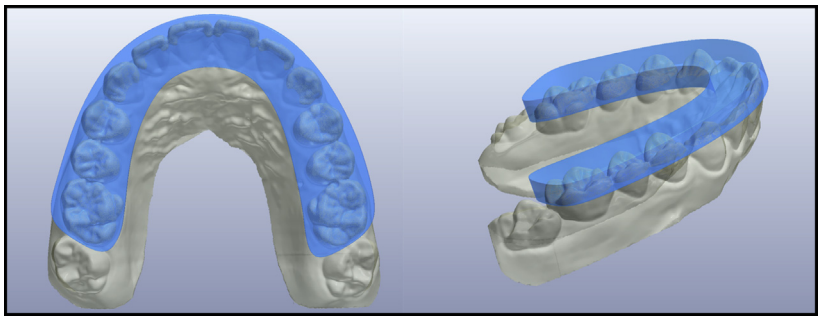

Fig 2. Digital splint generated by the boolean operation of software on the dental model.

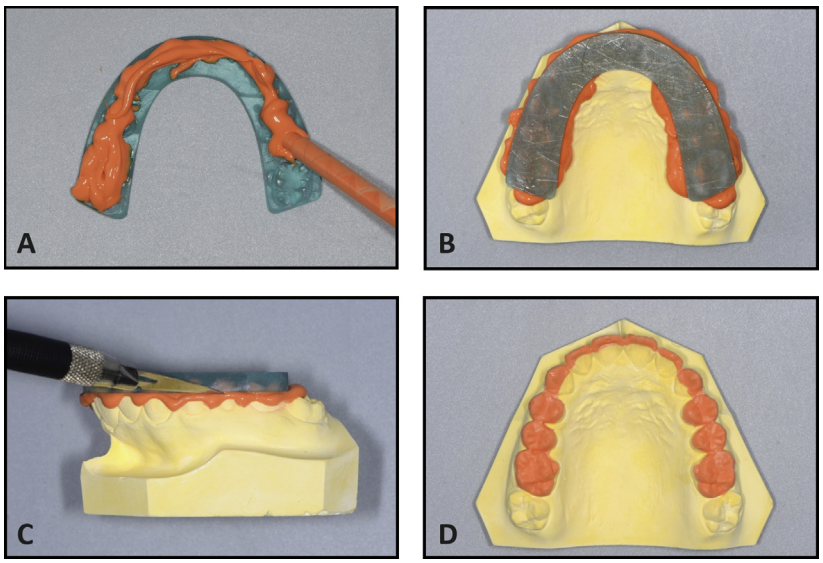

Fig 3. A, A layer of impression material was placed in the splint. **B,** A 3D-printed splint was seated on the maxillary teeth. **C,** A scalpel was used to remove the surrounding overflow material along the edge of the splint. **D,** The impression material remaining on the dental model was inserted into the airspace between the splint and the teeth.

model covered with splints was then individually superimposed on the original digital model by means of an automated best-fit algorithm. The superimposed area we used in this study was the part of the dental model that the splint did not cover. We calculated the shell-to-shell deviations by measuring the 3D euclidean distances between the superior surface points of the scanned splints and the original digital splints and evaluated the results by means of color-mapping analysis in the Geomagic software. The impression material remaining in the airspace between the splint and the teeth was completely collected and weighed with the use of an electronic analytical balance (JJ124BC; G&G Measurement Plant Manufacture, Changshu, China) with a minimum increment of 0.001 g. All measurements were made twice by the same operator (N.Y.) at least a week apart.

A standard statistical software package (SPSS version 17; Chicago, Ill) was used for data analysis. An intraclass correlation coefficient was then calculated to determine the level of intraobserver reliability. The shell-to-shell deviations and weight of impression material of each group were compared separately with the use of the Tukey test. The level of significance was set at $P < 0.05$.

RESULTS

The intraobserver reproducibility was very high (intraclass correlation coefficient = 0.99 for electronic analytical balance weighing; intraclass correlation coefficient = 0.90 for filling the impression material in the airspace). Table I presents the means and standard deviations of impression material remaining in the airspace and results of the Tukey test in the 4 groups. Table II

Table I. Means and standard deviations of impression material remaining in the airspace

Group	*0.0-mm*	*0.05-mm*	*0.1-mm*	*0.2-mm*
Impression material weight (g)	1.058 ± 0.304	0.681 ± 0.191*	0.409 ± 0.150*†	0.415 ± 0.201*†

*$P < 0.05$, compared with 0.0-mm; †$P < 0.05$, compared with 0.05-mm.

Table II. Means and standard deviations of shell-to-shell deviations

Group	*0.0-mm*	*0.05-mm*	*0.1-mm*	*0.2-mm*
Shell-to-shell deviations (mm)	0.392 ± 0.041	0.305 ± 0.034*	0.241 ± 0.038*†	0.235 ± 0.030*†

*$P < 0.05$, compared with 0.00-mm; †$P < 0.05$, compared with 0.05-mm.

presents the means and standard deviations of shell-to-shell deviations and results of the Tukey test in the 4 groups. There was a statistically significant difference in impression material remaining in the airspace between the 0.0-mm group and the 0.05-mm, 0.1-mm, and 0.2-mm groups ($P < 0.05$). There was a statistically significant difference in impression material remaining in the airspace between the 0.05-mm and the 0.1-mm and 0.2-mm groups ($P < 0.05$). There was a statistically significant difference in shell-to-shell deviations between the 0.0-mm group and the 0.05-mm, 0.1-mm, and 0.2-mm groups ($P < 0.05$). There was a statistically significant difference in shell-to-shell deviations between the 0.05-mm and the 0.1-mm and 0.2-mm groups ($P < 0.05$).

The color-coded scales (Fig 4) show the poor fit (most areas appeared blue and deep blue) in the 0.0-mm and 0.05-mm groups and show good fit (most areas appeared light blue and green) in the 0.1-mm and 0.2-mm groups. Figure 5 shows the difference in the same cross-sectional airspace between the teeth and splints in the four groups.

DISCUSSION

To quantify the fit of the surgical splints, Gateno et al created a method that uses special software to measure the airspace area (filled with impression material) at the cross-section of the teeth.[15] However, the airspace represented by the impression material was very thin and was difficult to be accurately crosscut and measured. To quantify the airspace between the teeth and the splint, we created a novel method to measure its weight. This method has good repeatability and convenience.

A digital splint was created by the boolean application of software to dental models and was fully fitted on the digital model. However, owing to the accuracy of 3D printing, model scanning errors and dental-model undercut problems led to difficulties with fit of the 3D-printed splint. In this article, we describe a novel method that offsets the dental model by given distances (0.05 mm, 0.1 mm, and 0.2 mm) in the positive normal direction, creating additional well proportioned surfaces raised on the initial model. The offset area, which enlarges the initial dental model (Fig 3, *C*), especially in the interproximal areas which can not be obtained clearly during model scanning, can reduce the impact of these areas on splint seating. According to the results, the 3D-printed splint can fit the teeth better in the 0.05-mm, 0.1-mm, and 0.2-mm groups than in the 0.0-mm group. Especially in the 0.1-mm and 0.2-mm groups, the color-coded scales showed good fit (most areas appeared light blue and green; Figs 4, *C* and *D*), and shell-to-shell deviations were very small. However, in the 0.2-mm group, the 0.2-mm dental model offset may lead to instability of seating for the 3D-printed splint on the dental model, which has more buccolingual movement. Figures 5, *A* and *B* show a thick layer of impression material between the 3D-printed splint and teeth in the 0.0-mm and 0.05-mm groups, and the color-coded scales show the most areas appearing blue and deep blue (Figs 4, *A* and *B*), indicating poor fit. Figures 5, *C* and *D* show a thin layer of impression material between the 3D-printed splint and teeth in the 0.1-mm and 0.2-mm groups, indicating that the 3D-printed splint fit well. Therefore, a 0.1-mm offset is the best choice of parameter for generating the splint.

With the development of digital technology in dentistry and maxillofacial surgery, more CAD software and third-party 3D modeling software packages are available for planning and splint design.[17] Almost all CAD software requires boolean operation to generate digital splints. However, few software packages can offset the dental model. According to the results of this study, we suggest that CAD/CAM software could add a command that can offset the initial dental model by given distances before boolean operation.

For clinical use, if the 3D-printed splint does not fit well, it can cause numerous clinical problems. In complex rehabilitation, a poorly fitting 3D-printed splint will affect the establishment of vertical dimension occlusion. A poorly fitting 3D-printed splint will also have a

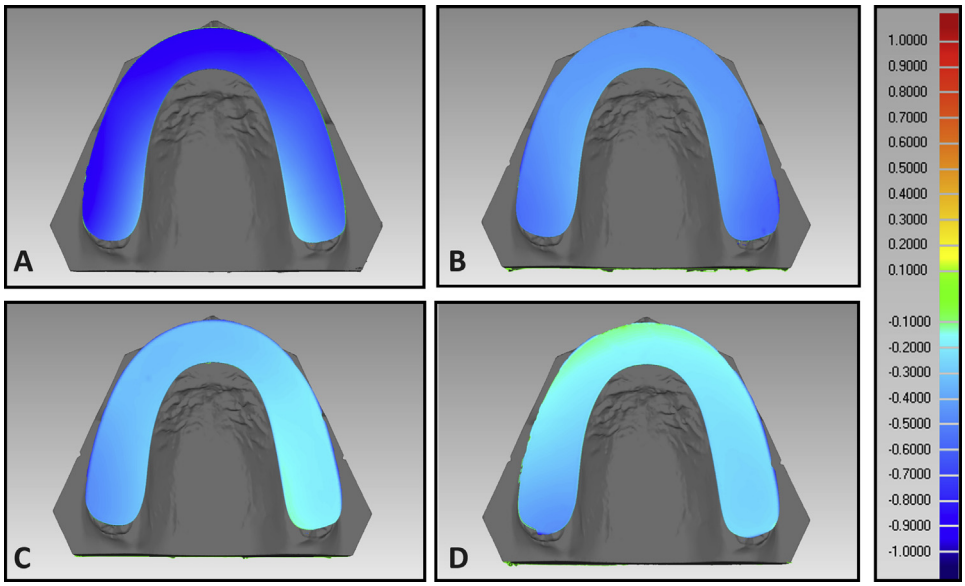

Fig 4. The color-coded scale shows the discrepancies on the surfaces of 3D-printed splints: **A,** 0-mm offset splint; **B,** 0.05-mm offset splint; **C,** 0.1-mm offset splint; **D,** 0.2-mm offset splint. Colors represent deviations of the scanned splint from the original digital splints (from −1.0 mm to 1.0 mm). The color-coded scales show the poor fit (most areas appeared blue and deep blue) in the 0.0-mm and 0.05-mm groups and show good fit (most areas appeared light blue and green) in the 0.1-mm and 0.2-mm groups.

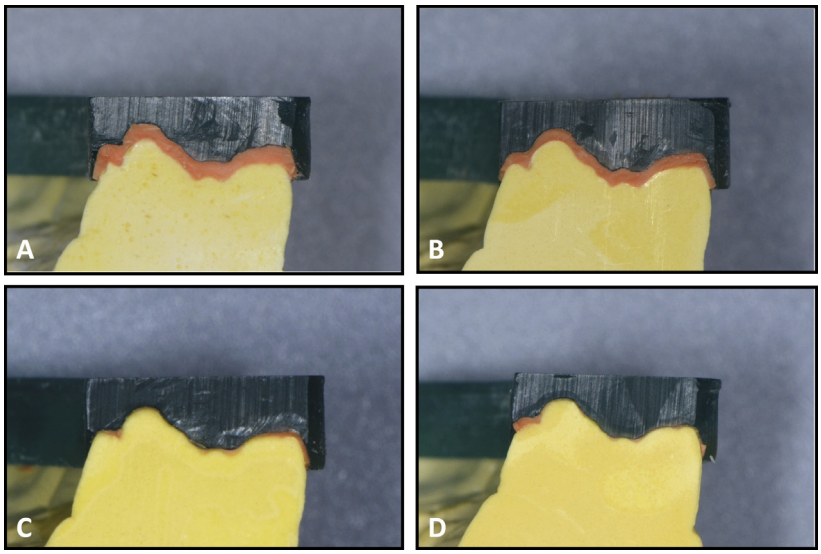

Fig 5. Cross-section of splint (*green*), airspace represented by impression material (*orange*), and posterior teeth (*yellow*): **A,** 0-mm offset splint; **B,** 0.05-mm offset splint; **C,** 0.1-mm offset splint; **D,** 0.2-mm offset splint.

significant impact on stabilization and comfort for the treatment of bruxism and TMD. In oral implantology, if the 3D-printed surgical guide does not fit well, the likelihood of transfer error during implant placement may increase. In orthodontics treatment, indirect bonding technology has traditionally been used to position customized brackets on the teeth with the use of 3D-printed jigs. If the jigs do not fit well, deviations in bracket positioning may result, affecting the arrangement of teeth. In orthognathic surgery, surgical splints play an important role in repositioning the maxilla or mandible. If a 3D-printed splint does not fit well, bone

positioning error and bite problems could result (eg, with posterior teeth open bite after surgery).

Occlusal splints are widely used in dentistry and maxillofacial surgery. However, the traditional acrylic splint is time consuming to create owing to the complicated manufacturing process, during which the inevitable polymerization shrinkage will adversely affect the fit of the splint.[2] In addition, abrasive particles and monomer vapors arising from the conventional manufacturing process are thought to be a health hazard for dentists and dental technicians. Residual monomers can also have a negative impact on the patient's health.[18,19] With the development of CAD/CAM technology, the traditional process could be completely replaced by 3D printing technology.

DLP, one of the 3D printing processes, has several advantages, including good accuracy, smooth surface, and high print speed.[10] However, this process also has some disadvantages. First, it takes time to remove the support structures, which may leave many small stumps behind. Second, alcohol must be used to clean the residual liquid material. Third, the DLP process necessitates postcuring the printed parts to improve their stability, because the light of the printing device can not completely cure the object during the 3D printing procedure. Shrinkage of the 3D-printed object often occurs during the 3D printing and postcuring processes.[20] The above 3 deficiencies would also lead to poor fit. However, compared with other 3D printing technologies, DLP has lower printing cost, smaller machine size (it sits on a desktop), and more convenient material replacement, making it suitable for dental and maxillofacial surgery use. In general, compared with traditional methods, the 3D printing method for making splints offers higher precision and better efficiency, avoids monomer fumes, and ensures easy reproducibility.

Furthermore, with the development of 3D scanning and 3D printing machines and material, it can be expected that the precision of 3D-printed objects will be greatly improved, and that the cost will likely become more acceptable.

CONCLUSIONS

Three-dimensionally printed splints generated from offset dental models (offsets of 0.05 mm, 0.1 mm, and 0.2 mm) can fit better on the teeth than can those with a no-offset dental model. A 0.1-mm offset is the best choice of parameter for generating the splint.

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