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Research paper

3D printed twin block: A feasibility study

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A B S T R A C T

Aims: Twin blocks are appliances used for Class II skeletal discrepancies, where the lower jaw is positioned more posteriorly compared to the upper. The conventional method of fabrication of this appliance is tedious and labour-intensive; hence this study intends to explore the feasibility of a digital workflow to three-dimensionally (3D) print them.
Methods: Three sets of twin blocks, identical except for amount of offset (0.0 mm, 0.1 mm and 0.2 mm), were designed and 3D printed for 5 anonymized scans of patients with Class II skeletal discrepancies. The intaglio surfaces of the 0.0 mm offset twin blocks were scanned and superimposed onto their original computer-aided-design files. The resultant colour maps, root mean square (RMS) deviations, and percentage in-tolerance values at thresholds of 0.1 mm and 0.2 mm were assessed. The fit and retention of all twin blocks were assessed on their 3D printed models via a fit and retention score (FRS).
Results: The median RMS deviation was 0.10 mm; percentage in-tolerance values at thresholds of 0.1 mm and 0.2 mm were 79.90%, and 94.51%. Printing deviations occurred most often at labial and incisal edges anteriorly, and buccal and occlusal surfaces posteriorly. There was no significant difference between the total FRS for the three groups ($p = 0.076$). However, the frequency of satisfactory scores for upper fit ($p = 0.049$), lower fit ($p = 0.018$), upper retention ($p = 0.038$) and lower retention ($p = 0.015$) differed significantly between the three groups.
Conclusion: This study demonstrated the viability of a digital workflow to 3D print twin blocks. Print accuracy was satisfactory, with 0.1 mm offset providing the best fit and retention.

Introduction

A Class II skeletal relationship (Fig. 1) refers to one in which the lower jaw is positioned more posteriorly compared to the upper jaw. Management of such skeletal discrepancies often depends on its severity and the skeletal maturity of the patient. Severe skeletal discrepancies presenting after growth cessation may require both orthodontics and orthognathic surgery to resolve [1]. Unfortunately, orthognathic surgery is not without risks: such as neurosensory deficits and intra-operative bleeding [2]. Considering the potential complications, growth modification is an alternative that helps harmonize the skeletal discrepancy in growing patients with a Class II skeletal relationship. One example is the twin block, a functional appliance which changes the mandibular posture, stretches muscles and soft tissues and transmits pressures to underlying dental and skeletal structures, thereby moving teeth and modifying skeletal growth [3]. The twin blocks comprise of two separate upper and lower components with interlocking occlusal bite blocks. Inclined planes guide the mandible to a protruded position, changing the distribution of occlusal forces, encouraging mandibular growth to correct the malocclusion [4]. The conventional method of fabrication described in Fig. 2 is tedious and requires a skilled technician.

With the advent of intraoral scanners and CAD-CAM systems, comes the opportunity to streamline the fabrication process, bringing potential advantages, such as, improved aesthetics (with a lack of metal clasps), a smaller appliance profile – possibly making it more comfortable, time and cost savings, and improved quality control in manufacturing. There have been some case reports in the literature regarding this novel topic. Cousley described a method that combines conventional thermoplastic bases with digitally designed and manufactured acrylic blocks [5], and Graf et al. virtually articulated digital models from an intraoral scan into the desired protrusive relationship for the direct design and printing of the twin blocks [6].

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At the point of writing, there are no studies to support the design parameters used in the design and manufacture of 3D printed twin blocks. In order to further test the practicality of a digital workflow for twin block fabrication and elucidate the ideal parameters to be used for digitally designed and printed twin blocks, this study aims to determine the print accuracy of the intaglio surfaces of 3D printed twin blocks, and to compare the fit, retention and bilateral intercuspation of 3D printed twin blocks fabricated with different levels of offsets to determine the most appropriate amount of offset to use. Offset refers to the amount of relief between the digitally designed shell and tooth surface. Because of the natural undercut present on tooth surfaces, the amount of offset will affect the fit and retention of the appliances, and is hence an important design parameter to consider.

Methods

Intra-oral scans that met the following inclusion criteria were obtained from an archive of patients treated in the NDCS Orthodontic residency clinic: a Class II, division 1 malocclusion; Class II skeletal base (ANB angle >/ = 4°), overjet >/= 6 mm; all permanent incisors and first molars erupted; and cervical Vertebral Maturation Stage 1 (CVMS1) to Cervical vertebral maturation stage 3 (CVMS3). Patients with craniofacial syndromes were excluded. Ethical approval for this study was obtained from the SingHealth Institutional Review Board (CIRB Ref: 2019/2974), with waiver of patient consent granted as scans were anonymized.

Digital workflow

The first five consecutive cases from the NDCS Orthodontic Residency clinic case archive from 1st August 2018 that fit the inclusion criteria were identified, and their upper and lower intra-oral scans were exported, anonymized, and uploaded to OrthoAnalyzer, a software for manipulating 3D models.

Upper and lower models were first 3D printed with a *Form2* printer in *Dental Model Resin* (Formlabs). Thereafter, softened sheet wax was used to create a ‘protrusive bite registration’ securing the upper and lower models into a Class I canine relationship with 5−6 mm inter-occlusal clearance at the premolars [7]. Using this wax bite, the models were mounted onto a semi-adjustable articulator, serving as the ‘patient’ in this study. Then the wax bite was trimmed to remove the indentations from the buccal cusps, exposing the buccal surfaces of the models. Finally, a *TRIOS 3* (3Shape Dental Systems, Copenhagen, Denmark) scanner was used to scan the models individually and in occlusion with the trimmed wax bite in place, simulating the scanning of the occlusion intra-orally with the mandible in a protruded position. The digital bite-registration process is summarized in Fig. 3.

Fig. 1. Silhouette of a patient with a Class II Skeletal relationship.

Twin block design and fabrication

3Shape Appliance designer (3Shape Dental Systems, Copenhagen, Denmark) was then used for appliance design (Fig. 4). The inclined planes of the twin block were angled at 70° to the occlusal plane, with 5−6 mm inter-occlusal clearance in the premolar region [7].

The detailed steps taken to design and print the twin block on 3 Shape Appliance Designer are illustrated in **Appendix A**. A summary of the important parameters can be found in the Table 1, and Fig. 5 shows an example of the 3D printed twin block.

The resin used for the 3D printed twin blocks, *Dental LT Clear*, is a biocompatible photopolymer resin, designed for the fabrication of 3D printed parts for use as dental splints, retainers, and similar applications for permanent use (more than 30 days) [8]. Several articles have since been published utilizing Dental LT Clear for the manufacture of 3D printed dental appliances [9−11]. In orthodontics, there seems to be emerging evidence to support the use of Dental LT Clear in aligner fabrication due to better geometric accuracy and higher load resistance versus thermoformed aligners [9] and comparable stress distribution when exposed to compressive forces equivalent to normal human occlusal forces (up to 600 N) [12]. These characteristics also make it suitable for the fabrication of the 3D printed twin block which should ideally be worn full time.

Three sets of twin blocks were fabricated for each case, varying only in the amount of offset at the intaglio surfaces of the shells (offset levels: 0.0 mm, 0.1 mm, and 0.2 mm), for a total of 15 twin blocks. The offset levels of 0.0 mm, 0.1 mm and 0.2 mm were chosen to assess if the manufacturer recommendation of 0.1 mm offset [13] for occlusal splints is also applicable for a 3D printed twin block, or if a different level of offset would be required.

Assessment of print accuracy

The twin blocks printed at 0.0 mm offset (n = 10 [5 upper twin blocks and 5 lower twin blocks]) were used to assess the accuracy of printing and ascertain the magnitude of print deviations at the intaglio surface, to help decide and rationalize the most appropriate amount of offset to use for printing of the twin blocks.

First, the intaglio surfaces of the twin blocks were sprayed with a thin layer of contrast spray (Occlu® Spray Plus, Hager & Werken) by Co-investigator (E.C., an Orthodontics registrar at National Dental Centre) from a distance of 5 cm via short 1 second bursts until the entire intaglio surface was covered. and then scanned with the *TRIOS 3* intraoral scanner. The .stl files were then exported to *Convince* (3Shape Dental Systems, Copenhagen, Denmark), which utilizes a best-fit-surface-mapping-algorithm to align and superimpose the scans of the intaglio surfaces to the original computer-aided design (CAD) file of each corresponding twin block.

The root mean square (RMS) deviation and percentage in-tolerance values at thresholds of 0.1 mm and 0.2 mm were calculated.

RMS was chosen over the mean of the simple arithmetic difference as the latter may masque any existing actual differences. This is because a deviation may have a positive or a negative value, which when added together (as is done when calculating the mean of the simple arithmetic difference), would result in the underestimation of the actual amount of deviation. On the other hand, as RMS is calculated by the square root of averaged squared values, it overcomes the problem, and provides a quantification of the absolute geometric difference between 2 samples.

Percentage in-tolerance threshold levels of 0.1 mm and 0.2 mm were chosen to correspond with the offset levels of the printed twin blocks (0.1 mm offset and 0.2 mm offset) to shed light on the possible reasons for any observed difference between the fit and retention of twin blocks printed with this level of offset.

A colour map (Fig. 6) was also generated for each superimposition, delineating the regions and magnitude of the deviations, and also if

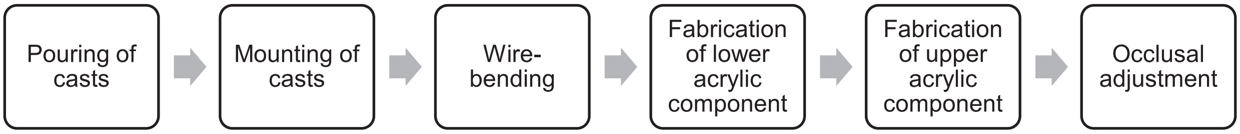

Fig. 2. Conventional fabrication method for twin blocks.

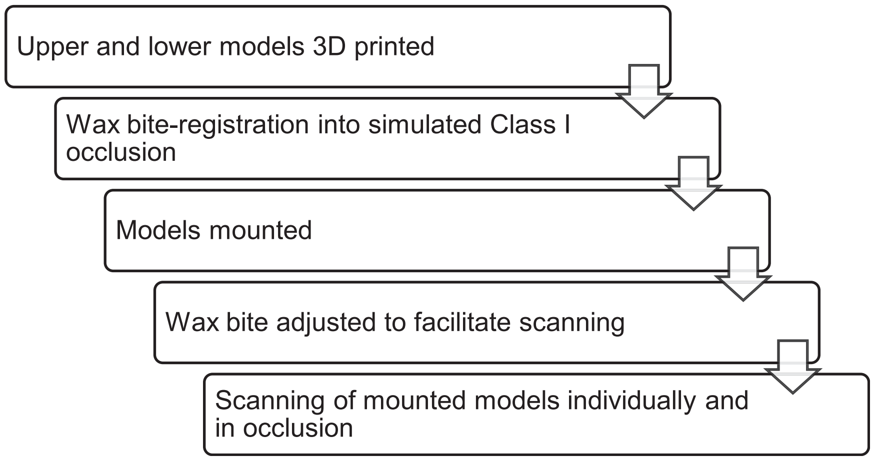

Fig. 3. Obtaining the digital bite-registration.

Fig. 4. Designing the twin block.

Table 1
Basic parameters for printing of 3D printed twin block.

3D printer	Form 2 Printer (Formlabs)
Material	Dental model resin (Formlabs)
Print settings	- **Insertion direction**: was selected to be parallel to the inclination of the incisors, so that undercut would be limited to buccal and lingual/palatal of the posterior teeth (which in our population of young patients with no gingival recession was minimal, as the height of contour of the exposed crown was close to the gingival margins) - **Shell thickness**: 1 mm (based on manufacturer's recommendations of minimum shell thickness for dental splints) [13] - **Shell extensions**: gingival margins of covered teeth
Post-processing protocol	1) Wash in isopropyl alcohol for 15 minutes using Form Wash (Formlabs) 2) Air Dry for 30 minutes 3) Dry with compressed air 4) Post-cure with Form Cure (Formlabs) for 20 minutes at 80 °C

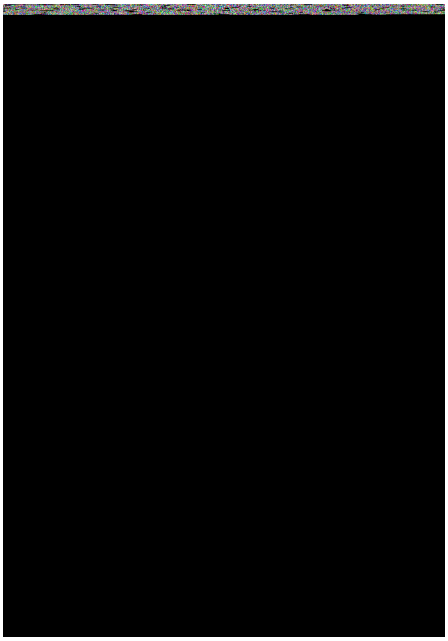

Fig. 5. Image showing of a 3D printed twin block fabricated for this study.

the deviations were positive or negative compared to the original CAD file.

Assessment of fit and retention

Assessment of fit and retention of the twin blocks was carried out on their respective mounted models by Co-investigator (E.C.) once. A fit and retention score (FRS) (developed for this particular study) was calculated based on 5 components, with each scored with either a '1′ ('acceptable') or '0′ ('unacceptable') to obtain a maximum score of 5. The criteria for each component of the FRS required to obtain a score of '1′ is shown in Table 2.

Statistical analyses

To determine the print accuracy of the intaglio surfaces, the median and interquartile ranges (IQR) for the RMS deviations and percentage in-tolerance values at thresholds of 0.1 mm and 0.2 mm were calculated for all upper and lower twin blocks printed at 0.0 mm offset ($n = 10$).

To compare the fit, retention and bilateral intercuspation of the printed twin blocks, the fit and retention score (FRS) of twin blocks printed with different levels of offset were analysed. A Friedman test was carried out to determine if there was any significant difference between the FRS of the different groups.

The individual components of the FRS were analysed with Cochran's Q test to determine if the proportion of a successful outcome was significantly different between the twin blocks printed with different levels of offset.

Results & discussion

Printing accuracy

Quantitative assessment

In this study, the median RMS deviation was 0.10 mm. Given that existing literature recommends acceptable deviations to range from 100 μm (with regards to diagnostic value of dental models) [14] to 250 μm (for dental models used to fabricate appliances) [15], it would appear that print accuracy of the intaglio surfaces of 3D printed twin blocks using a *Form2* printer with *Dental LT Clear*, is adequate for clinical use.

When the tolerance level was set at a threshold of 0.1 mm, the median percentage in-tolerance for twin blocks printed at 0.0 mm offset was 79.90% (with an interquartile range of 5.01%), indicating that 79.9% of the intaglio surface was within 0.1 mm from the actual design file. At a threshold of 0.2 mm, the median percentage in-tolerance was 94.51% (with an interquartile range of 2.12%) (Table 3). The raw data of RMS and percentage in-tolerance values are provided in **Appendix B**.

Median percentage in-tolerance levels at a threshold of 0.1 mm and 0.2 mm did not reach 100%, hence one may postulate that twin blocks fabricated with an offset of 0.1 mm may not seat satisfactorily, since some print deviations exceeded 0.1 mm. However, this was not the case, based on the satisfactory 'upper fit' and 'lower fit' scores for all the twin blocks fabricated with 0.1 mm offset. In fact, twin blocks printed at 0.1 mm offset had the highest median FRS of 5 (out of a maximum of 5), as seen in Table 4. This could be attributed to flexural properties of Dental LT clear (flexural modulus ≥1300Mpa [16]), allowing the twin block to flex and still seat satisfactorily, despite printing discrepancies that exceeded the amount of offset used during fabrication.

One may postulate that degree of dental crowding may have an effect the print accuracy of the 3D printed twin block. However, although prior studies have found crowding to have a statistically significant effect on the accuracy of 3D printed digital models, this difference was deemed by the authors to be clinically insignificant [17], and hence was not included into our analysis.

Qualitative assessment

The colour maps revealed that discrepancies occurred most often at the labial surfaces and incisal edges of anterior teeth, and buccal and occlusal surfaces of posterior teeth. Also, positive discrepancies (warmer colour temperature) were more common than negative discrepancies (cooler colour temperature). Examples of some colour maps obtained are shown in Fig. 6. The location of the deviations

Table 2
Components of the fit and retention score (FRS).

Criteria 1	**Fit of upper twin block to maxillary model**	0 or 1	Clinically acceptable **fit** was defined as minimal 'rocking' of the appliance when inserted completely, without major adjustments, for a score of '1′, otherwise the score will be '0′.
Criteria 2	**Fit of lower twin block to mandibular model**	0 or 1	
Criteria 3	**Retention of upper twin block**	0 or 1	Clinically acceptable **retention** was defined as resistance to dislodgement for a score of '1′, otherwise the score will be '0′.
Criteria 4	**Retention of lower twin block**	0 or 1	0 or 1
Criteria 5	**Bilateral 'intercuspation' of upper and lower twin block at inclined planes***	0 or 1	Inclined planes had to be contacting bilaterally without major adjustments for a score of '1′. If inclined planes were only contacting on one side or not at all, the score will be '0′.
Total possible score:		**0–5**	

Table 3
RMS values and percentage in-tolerance values for twin blocks fabricated at 0.0 mm offset.

	Median (IQR)	
RMS	0.10	(0.01)
In tolerance 0.1 (%)	79.90	(5.01)
In tolerance 0.2 (%)	94.51	(2.12)

Table 4
Summary statistics for FRS classified by offset.

	Offset = 0 Median (IQR)		Offset = 0.1 Median (IQR)		Offset = 0.2 Median (IQR)		P-value[a]
Total FRS Score	**3**	**(1)**	**5**	**(0)**	**3**	**(0)**	0.076

[a] p-value was obtained by Friedman test.

corresponds to those from another study, and it was rationalized that steeply angled surfaces may require more scans from various perspectives [18].

The observed distribution of deviations could also be attributed to the use of anti-reflection powder sprayed on the intaglio surfaces, which tends to collect at the deepest points of incisal edges and occlusal surfaces. A recent study found that contrast spray added an additional 0.035 mm and 0.040 mm of material [11], but this is small relative to our analysed in-threshold values of 0.1 mm and 0.2 mm. Moreover, attempts to scan the intaglio surface without spray were unsuccessful in our study, especially at the incisor region.

Fit and retention score (FRS)

The twin blocks printed at 0.0 mm and 0.2 mm offset had a median total FRS of 3, whilst the twin blocks printed at 0.1 mm offset had a median total FRS of 5. There was no statistically significant difference in the median total FRS for the 3 groups (Table 4). However, there appeared to be a trend for better fit and retention for appliances fabricated at 0.1 mm offset, with 4 out of 5 cases having the twin blocks printed at 0.1 mm offset achieving the highest possible FRS of 5 (Fig. 7).

A significant difference in the frequency of a 'satisfactory' outcome (score of '1′) was found for 'upper fit', 'lower fit', 'upper retention' and 'lower retention' between twin blocks fabricated at 0.0 mm offset, 0.1 mm offset and 0.2 mm offset, with P-values <0.05. No significant difference was found for the component of 'bilateral intercuspation'. This is illustrated in Table 5. Raw data for all fit and retention scores are provided in **Appendix C**.

Fit

The fit of all upper and lower twin blocks printed at 0.1 mm offset and 0.2 mm offset received a satisfactory score ('1′); whereas 4 of 5 lower and 3 of 5 upper twin blocks manufactured at 0.0 mm offset scored an unsatisfactory score ('0′). This resulted in a significant difference in median 'upper fit' scores and 'lower fit' scores between twin blocks manufactured at different offsets (Table 5). This is likely because 0.0 mm offset would offer no allowance for any printing error. However, 3 of 10 twin blocks with 0.0 mm offset were still able to fit, possibly due to the flexural properties of *Dental LT Clear*, or a variation in the frequency or magnitude of print deviations between the different printed twin blocks.

Retention

With regards to '**upper retention**' and '**lower retention**', specimens manufactured at 0.2 mm offset seemed to fare the worst, with 80% of upper and 100% of lower twin blocks fabricated with 0.2 mm offset having unsatisfactory retention (Table 5). This is likely because 0.2 mm offset resulted in a lack of sufficient contact between the appliances and the models, leading to insufficient friction and lack of resistance to dislodging forces. Even though percentage in-tolerance values at 0.2 mm threshold did not reach 100%, indicating that some areas deviated by more than 0.2 mm from the original CAD file, these areas comprised only 5.49% of the intaglio surface, and were likely insufficient to provide adequate contact with the models for satisfactory retention.

Bilateral intercuspation

Bilateral intercuspation on the other hand, seemed unaffected by amount of offset, with 13 of 15 specimens displaying satisfactory intercuspation. This implied that the digital bite registration process is sufficiently accurate to produce twin blocks with satisfactory bilateral intercuspation.

Combined FRS

Despite the significant effect on the individual components of the FRS, amount of offset had no significant effect on the combined FRS. This is because a lesser offset (0.0 mm) was associated with poor fit, but adequate retention; whereas a greater offset (0.2 mm) was associated with acceptable fit but inadequate retention. This resulted in twin blocks fabricated with 0.0 mm and 0.2 mm offset both having median fit and retention scores of 3, albeit their deficiencies in different categories.

Fig. 6. Colour maps for superimposition of scans of the intaglio surface onto the original CAD file for Case 1 upper appliance printed with 0 mm offset set at a threshold of **(a)** 0.1 mm, **(b)** 0.2 mm.

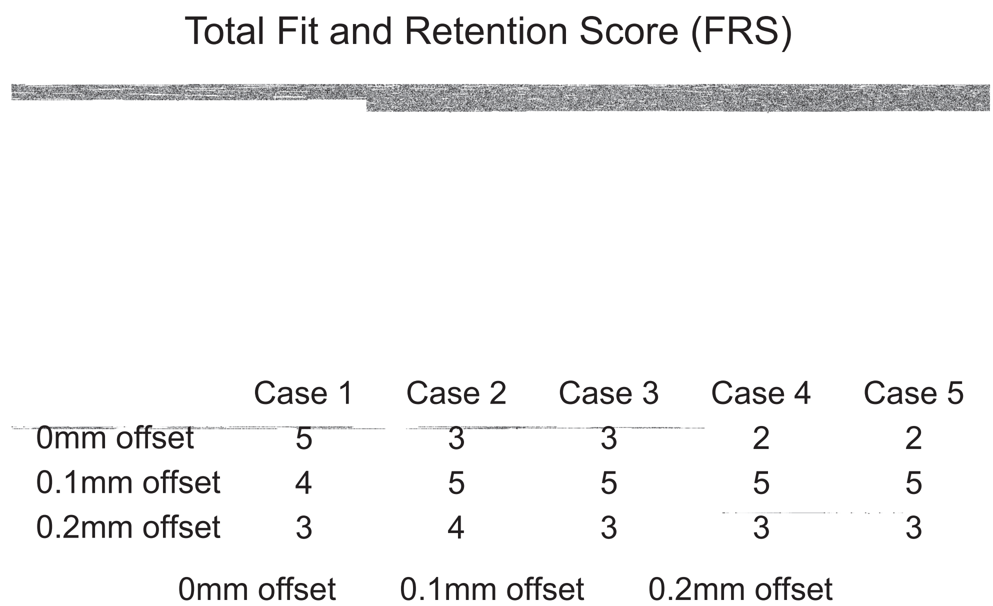

Fig. 7. Bar chart depicting total fit and retention scores (FRS) for all 5 cases.

Table 5
Summary statistics for the individual components of the fit and retention score classified by offset.

		Offset = 0 n (%)		Offset = 0.1 n (%)		Offset = 0.2 n (%)		P-value [b]
Upper fit score	*'0'*	3	(60%)	0	(0%)	0	(0%)	**0.049***
	'1'	2	(40%)	5	(100%)	5	(100%)	
Lower fit score	*'0'*	4	(80%)	0	(0%)	0	(0%)	**0.018***
	'1'	1	(20%)	5	(100%)	5	(100%)	
Upper retention score	*'0'*	1	(20%)	0	(0%)	4	(80%)	**0.038***
	'1'	4	(80%)	5	(100%)	1	(20%)	
Lower retention score	*'0'*	0	(0%)	1	(20%)	5	(100%)	**0.015***
	'1'	5	(100%)	4	(80%)	0	(0%)	
Bilateral intercuspation score	*'0'*	2	(40%)	0	(0%)	0	(0%)	0.135
	'1'	3	(60%)	5	(100%)	5	(100%)	

[b] p-value was obtained by Cochran's Q test.
* p-value <0.05.

An offset of 0.1 mm is most likely to yield adequate fit and retention as compared to 0.0 mm offset and 0.2 mm offset. This is somewhat in agreement with manufacturer's recommendations for the fabrication of dental splints using Dental LT Clear resin, in which they advised for the level of offset to be set at greater than or equal to 0.1 mm [13,19].

Limitations

The authors acknowledge that this is only a pilot study with limited sample size. Results may also not be directly clinically applicable, as intra-oral scanning of the dentition of a live patient understandably differs from scanning a model extra-orally. Also, the fit and retention of an appliance on a model may differ from that clinically due to the periodontal ligament and elasticity of alveolar bone, which allows for individual teeth to be displaced within the bone when a force is applied [3,20]. Because only one printer was used, conclusions may also not be representative of the wide range of printers and materials.

Areas of future study

Further laboratory studies can be done with the use of different printers and materials to identify if the type of printer or material has any effect on the fit and retention of the 3D printed twin blocks.

Additionally, the clinical fit and patient-perceived comfort of 3D printed twin blocks can be compared with conventional twin blocks. Clinically, the bite registration need not rely on printed models and an articulator but may be obtained directly via intra-oral scanning. Fit and retention can be assessed with the same FRS, and patient-perceived comfort can be gauged via a questionnaire or survey.

Subsequently if a significant difference in patient-perceived comfort is observed, the efficacy of the 3D printed twin block can be compared to that of conventional twin blocks, to ascertain if this difference in comfort leads to improved compliance and possibly better clinical results via comparison of cephalometric analysis.

Conclusion

This study has demonstrated the feasibility of a digital workflow for 3D printing twin blocks. It appears that a *Form2* printer and *Dental LT Clear* resin provided sufficient print accuracy for 3D printed twin blocks. Furthermore, an offset of 0.1 mm seems most likely to yield adequate fit and retention for 3D printed twin blocks. Knowledge of areas prone to deviations derived from this study can help guide operators to take more care in scanning these areas, and also apprise them to the potential locations of interferences requiring adjustments while issuing 3D printed appliances. Further research with different printers and materials will be helpful to determine if other variables have any effect on the fit and retention of 3D printed twin blocks. Additionally, future studies applying this digital workflow in a clinical setting could provide valuable insight into other possible advantages of a digitally designed manufactured twin block appliance.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.stlm.2023.100118.

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