*Original Article*

# Accuracy of soy-based resins for dental 3D printing


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**ABSTRACT**

**Objectives:** To verify the accuracy of soy-based resins for dental three-dimensional (3D) printing.

**Materials and Methods:** After conducting a power analysis, models of 10 consecutively treated patients were produced from four different resins using a dental 3D printer. Two of these resins were soy based and therefore biodegradable. These 20 models were measured manually with a caliper as well as digitally by software and compared based on measurement parameters in all three spatial axes.

**Results:** No statistically significant differences were found between the four different resins or between the manual and digital measurements.

**Conclusions:** Soy-based resin seems to be a suitable material for orthodontic 3D printing and is a more environmentally friendly alternative to conventional dental resins. Digital model analysis seems to produce comparable results to manual measurement. (*Angle Orthod*. 2024;94:574–580.)



**KEY WORDS:** Soy-based resin; 3D printing; Accuracy


## INTRODUCTION

Conventional plaster models are still considered the gold standard for orthodontic treatment planning and manufacturing orthodontic appliances.[1] As an alternative, the possibility of working with digital models is becoming increasingly popular in orthodontics.[1,2] Using the data sets generated by an intraoral scan, a digital model can be saved as an STL file. This can then be further processed and evaluated digitally. For communication with the patient and the manufacture of most orthodontic appliances, the production of a physical model is still necessary and useful.[1] However, recently, for example, a material was introduced with which aligners can be made directly using three-dimensional (3D) printing without the need for a model to be manufactured.[3] Also, 3D printing of orthodontic appliances made out of metal or polymeric resin,[4,5] mini-implant retained orthodontic appliances,[6] brackets,[7] auxiliaries,[8] and retainers[9,10] has already been described in the literature.

Manufacturing a physical model from the STL data set is possible using different printing processes. Stereolithography (SLA), digital light processing (DLP), and filament printing are particularly worth mentioning.[1] All three processes are additive printing processes. However, they differ in terms of, among other things, printing time, the accuracy of the printed models, and the materials from which models for dental practice can be made.[1]

Resin is widely used in dentistry for printing models using SLA and DLP processes.[11] The disadvantage, however, is that the resin materials previously used in dental practice cannot be disposed of in household waste, they are not biodegradable, and, according to the manufacturer's instructions, there is a risk of contact allergies for the user. Alternatively, soy-based resin or filament, a biological and sustainable alternative material, is already used in the field of 3D printing.[12]

The use and printing accuracy of soy-based resin in dental or orthodontic practice for the production of models has not yet been thoroughly investigated. Previously, a pilot study was conducted with a small sample size to evaluate the inter- and intraobserver error as well as the feasibility of the materials and methods for different resins.[13] The aims of this study were to determine whether the accuracy of models printed using soy-based resin corresponded to that using resin explicitly developed for dental use and whether soy-based resin could be used as an equivalent and more sustainable material for model production in the future in dental and orthodontic practice. In addition, manual measurements were compared with digital measurements automatically performed by software.


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**Figure 1.** Upper and lower models of the same patient from the four resin materials evaluated in this study (from left to right): Ortho Model Resin OD01 (Shining3D, Hangzhou, China); Plant Based Eco UV Resin (Anycubic, Shenzhen, China); Plant Based Resin+ (Anycubic, Shenzhen, China); Water Washable Resin W1 (Shining3D, Hangzhou, China).

## MATERIALS AND METHODS

### Model Manufacturing

The upper and lower arches of 10 patients (6 female, 4 male) consecutively completing orthodontic treatment in one author's private practice (average age at the end of the retention phase of 15.4 $\pm$ 1.1 years) were digitized using an intraoral scanner (Aoralscan 3, Shining3D, Hangzhou, China). All patients had all 28 teeth present. Prosthetics or craniofacial anomalies were defined as exclusion criteria. There were no dropouts due to these exclusion criteria. Before manufacturing the models, the names of the patients were anonymized.

The scans were aligned, cropped, socketed, and then exported as an STL file using an orthodontic planning and simulation software application (OnyxCeph, Image Instruments, Chemnitz, Germany). A material thickness of 2.5 mm was chosen for all models, and the base was removed digitally.

For the subsequent 3D printing of all 20 arches (10 upper and 10 lower) using a DLP 3D printer specially developed for dental lab purposes (Accufab-L4D, Shining3D, Hangzhou, China), four different resins were used (Figure 1):

- Ortho Model Resin OD01 (Shining3D, Hangzhou, China), specially developed for dental 3D printing and washed using isopropanol after printing.
- Water Washable Resin W1 (Shining3D, Hangzhou, China), required tap water instead of isopropanol for the washing process.
- Plant Based Eco UV Resin (Anycubic, Shenzhen, China), a resin produced from soybean oil that, according to the manufacturer, is biodegradable, does not contain volatile organic compounds, bisphenol A, or harmful chemicals and meets the EN 71-3:2013 standard, which ensured safety precautions defined for toys. When asked, the manufacturing company said that the material should also meet the requirements of the latest version DIN EN 71-3:2021-06. This material was also washed with isopropanol after printing.
- Plant Based Resin+ (Anycubic, Shenzhen, China), similar to Plant Based Eco UV Resin, also made from soybean oil and has a lower hardness than Plant Based Eco UV Resin with greater flexural strength. Isopropanol was also used in the washing process.

The material properties of the four resins can be found in Table 1.

All 80 models were manufactured with a print layer thickness of 0.1 mm and an angle of 90° to the build platform with the parameters specified by the manufacturer for the respective material (Figure 2). All models were printed with the same 3D printer on the same day. No support structures were needed. After printing, the models were further processed according to the manufacturer's instructions for the respective resin. The remaining uncured material was washed off for OD01, Eco UV Resin, and Plant Based Resin+ using 99.9% isopropanol and for Resin W1 using tap water in a special washing unit (Wash & Cure Plus, Anycubic, Shenzhen, China). A light curing unit designed for dental 3D printing (Fabcure, Shining3D, Hangzhou, China) was used afterward.

### Model Measurement and Statistics

Before conducting the study, a power analysis was performed using the software G*Power (version 3.1.9.7, University of Kiel, Germany) with a defining alpha value of 0.05, effect size of 0.60, and achieved power of 0.90. The result indicated a sample size of 20 arches per group/material.

Using an electronic caliper (Brüder Mannesmann, Remscheid, Germany), the individual tooth widths of the maxillary and mandibular central and lateral incisors, as well as the maxillary and mandibular canines in the mesiodistal direction, were measured. In addition, the available space between the mesial of the canine to the mesial of the first molar in all four quadrants, as well as the anterior and posterior arch widths, were measured. For the vertical dimension, measurements of the distance between the incisal edge of the right central incisor and the model base, as well as between the mesiobuccal cusp of each first molar and the model base, were carried out on each of the 80 models. This resulted in 26 measurement parameters

**Table 1.** Properties of the Four Resin Materials Tested in This Study According to the Manufacturer's Information (Left to Right: Ortho Model Resin OD01 [Shining3D, Hangzhou, China]; Plant Based Eco UV Resin [Anycubic, Shenzhen, China]; Plant Based Resin+ [Anycubic, Shenzhen, China]; Water Washable Resin W1 [Shining3D, Hangzhou, China])

| | Ortho Model Resin OD01 | Plant Based Eco UV Resin | Plant Based Resin+ | Water Washable Resin W1 |
|---|---|---|---|---|
| Wavelength, nm | 405 | 355–410 | 365–405 | 405 |
| Viscosity, cps/25° | 322 | 150–300 | 300–500 | 173 |
| Hardness | 86 D | 89 D | 84 D | 85 D |
| Flexural strength, MPa | 108 | 59–70 | 40–60 | 87 |
| Washing medium | Isopropanol | Isopropanol | Isopropanol | Tap water |

per patient (Table 2) and 1040 measured values in total.

To determine the accuracy of the chosen method, a pilot study was conducted[13] in which measurements were taken twice as well as by two researchers analyzing the same resins as performed in this study. In the pilot study, high measurement accuracy was found based on the method error according to Dahlberg[14] (0.07) and the reliability quotient according to Houston[15] (0.99).[13] No statistically significant differences among the multiple measurements as well as between the two researchers were found. Therefore, in the present study, only one person took the measurements.

For the digital measurements, the models were automatically segmented using the software Onyx-Ceph (Image Instruments, Chemnitz, Germany). In rare cases, in which a tooth surface could not be fully detected by the software's algorithm, manual editing was carried out (Figure 3). After that, measurements were automatically generated by the software. These digital steps were carried out twice.

All manually and digitally measured values were entered into an Excel spreadsheet (Microsoft Excel 2019, Microsoft Corp, Redmond, Wash) and evaluated using the statistical software GraphPad Prism 9 (GraphPad Software, Boston, Mass).


**Figure 2.** Models on the build platform of the DLP 3D printer after completion of the printing process.

One-way analysis of variance (ANOVA) was used to determine whether there was a statistically significant difference among the four resin materials. A paired *t*-test was applied to detect possible discrepancies between the two digital measurements. For both statistical tests, the statistical significance was set at $P < .05$. Regarding the digital double measurements, the method error according to Dahlberg[14] and the reliability quotient according to Houston[15] were calculated. In addition, a Bland-Altmann plot was conducted to see if the digital method was comparable with the actual gold standard of manual measurement. Since there were no significant differences among the four resins, the median of all resins was used for the plot.

## RESULTS

The one-way ANOVA resulted in $P = .99$; thus, no statistically significant differences were found among the four resins.

The outcome of the paired *t*-test was $P = .90$, resulting in no statistically significant discrepancies between the two digital measurements. The method error for the digital double measurements according to Dahlberg[14] was calculated as 0.11 and the reliability quotient according to Houston[15] as 0.95.

The Bland-Altmann plot can be seen in Figure 4. The results showed that digital and manual measurements were comparable and very similar. The least accurate measurements appeared to be the anterior and posterior dental arch width. The highest accuracy could be found for the mandibular incisors.

Figure 5 depicts the mean values of the 26 variables for all four resins used as well as for the digital measurements. The greatest agreement was found for the incisors in the upper and lower arches. The largest discrepancies measured were 0.43 mm for the posterior arch width in the mandibular arch and 0.37 mm for the posterior arch width in the maxillary arch.

## DISCUSSION

An intraoral scan eliminates the need to produce an alginate impression and plaster casts, to create bases for the models, as well as trimming and repairing or

**Table 2.** Overview and Definitions of the Measuring Points Used in This Study

| Measurement | Definition |
|---|---|
| Tooth sizes (13–23, 33–43) | Mesiodistal width of the respective tooth |
| Available space at the posterior segment (13–15, 23–25, 33–35, 43–45) | Distance between the distal surfaces of the lateral incisors and the mesial surfaces of the first molars |
| Interpremolar and intermolar widths | Maxilla |
| | Distance between the center of the fissures of the first premolars and distance between the deepest points of the main fissures of the first molars |
| | Mandible |
| | Distance between the contact points of the premolars and distance between the distobuccal cusps of the first molars |
| Vertical | Incisal edge (tooth 11, 41) or mesiobuccal cusp (tooth 16, 26, 36, 46) to the base of the printed model |

embellishing the models. However, in orthodontics, conventional plaster models are still considered the gold standard for treatment planning and the manufacture of orthodontic appliances.[1] Plaster has a high risk of breakage and no long-term dimensional stability.[2] In addition, plaster models require strict archiving and a large amount of space for storage.[2] Digital archiving means that no additional physical storage space is required, as the digital models can be produced again at any time, if necessary.[2,16] In addition, there is no possibility of fracture, as may be experienced when the alginate is being removed from the plaster model. Also, digital models can be automatically measured using software, which represents a significant time saving and an overall increase in efficiency using digital models compared with conventional plaster models.

For the practitioner, the most important requirement for a digital model is its diagnostic accuracy and reliability.[2,16] The accuracy of the models differs depending on the printing process.[1] Models created using SLA and DLP printing have higher accuracy compared with models produced using filament printing.[1] An accuracy of up to 250 μm is considered sufficient for an orthodontic model also usable for the production of aligners.[1,17] This means that all three printing methods can be used for orthodontic purposes. A DLP 3D printer was used in this study because of its high quality and fast printing speed. The accuracy of the models depends on the thickness of the printing layer and the printing angle.[11] Depending on the layer thickness (20, 50, 100 μm) and printing angle (0°, 30°, 60°, 90°), the accuracy of printed models was shown to differ significantly.[11] All models for this study were produced with a layer thickness of 100 μm and an angle of 90° using the same 3D printer. With all the resins and the 3D printer used, a layer thickness of 50 μm would have been possible, but this would have, approximately, doubled the printing time. Previous literature supported that this choice of layer thickness would provide sufficient conditions for orthodontic model analysis and the production of orthodontic appliances.[1,17] The settings were chosen to ensure the best possible comparability and to resemble the clinical application as well as provide the ability to print multiple models in one process. To avoid any external effects possibly affecting the printing process or the material quality, all prints were performed consecutively at an equal temperature on the same day with the same 3D printer.

The accuracy of values measured during model analysis not only depends on the respective material or manufacturing process of the models but also on the examiner. The pilot study revealed high reproducibility and comparability of the manually made (double)

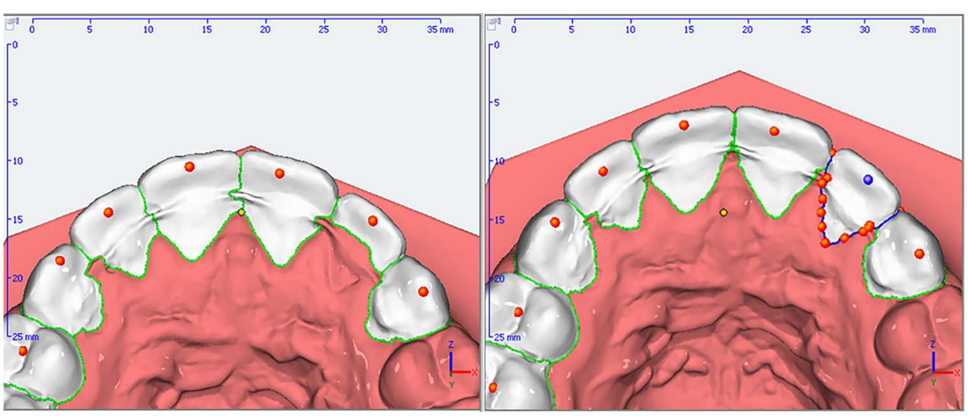

**Figure 3.** Screenshot of the software used (OnyxCeph, Image Instruments, Chemnitz, Germany). The left image shows a rare case for which the software was not able to recognize the complete dental crown automatically, possibly due to the fixed retainer. This had to be corrected manually (right image).

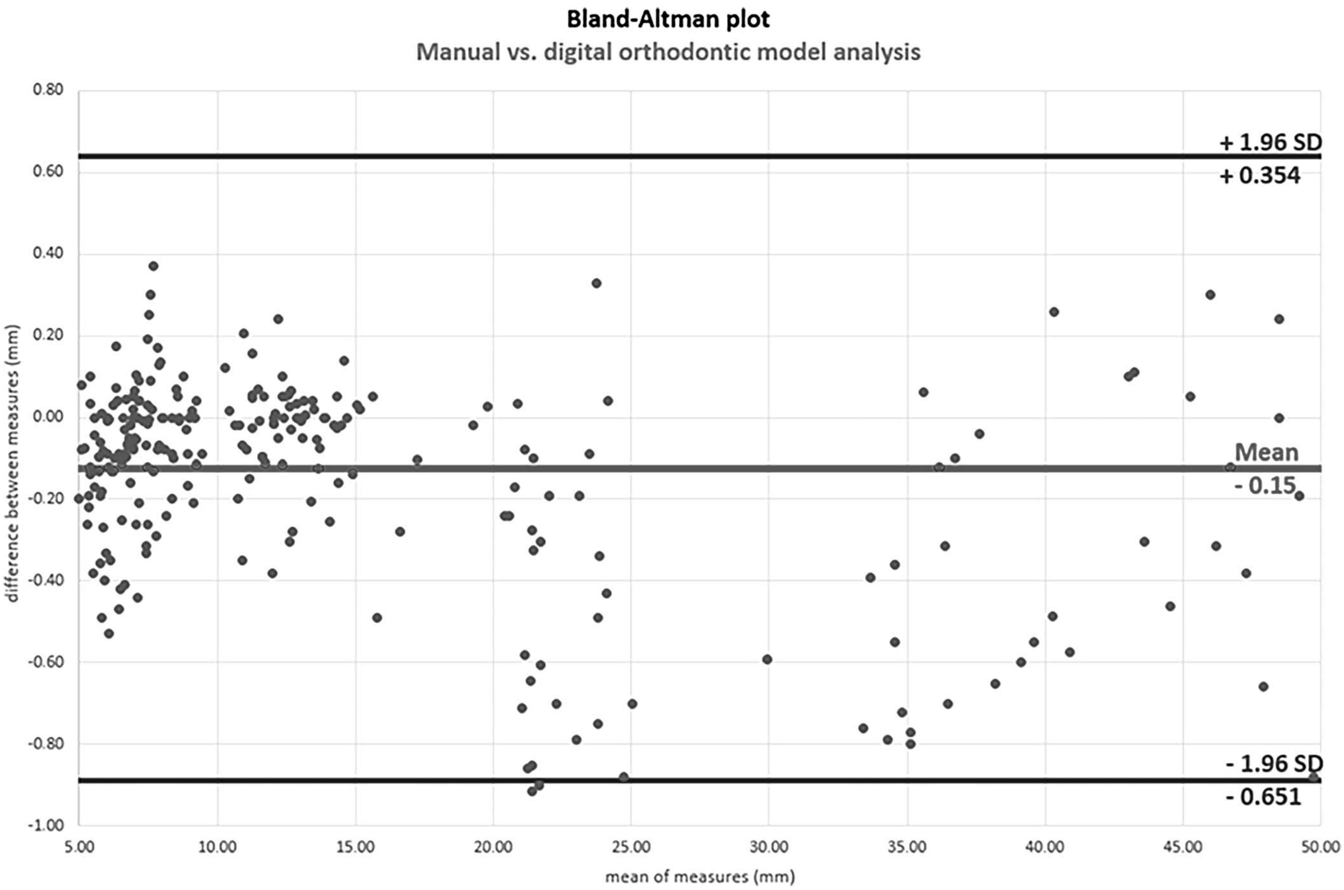


**Figure 4.** Bland-Altmann plot for the values of manual versus digital orthodontic model analysis. Since there were no significant differences among the four resins, the median values were used for the plot. The diagram allows a visual assessment of the relationship between the two plotted variables. Middle line: mean of the difference; upper line: mean of the difference plus 1.96 standard deviation of the difference; lower line: mean of the difference minus 1.96 standard deviation of the difference.

measurements.[13] Thus, the models used in this study were measured by only one examiner as well as by the software digitally. Before conducting the study, the required sample size was determined using power analysis. The various measured values used in this study were deliberately chosen in order to be able to determine the accuracy in all three spatial axes, similar to a prior publication.[18] The statistical tests used did not reveal any significant differences among the four resin materials used. This corresponded to the results of the pilot study.[13] It can therefore be assumed that differences among these resins are negligible when they are used for model printing. The accuracy of the method chosen was previously reported in the pilot study.

Before the software was able to calculate the model measurements, it was necessary to segment the digital models. There are only rare cases in which the dental crowns cannot be fully recognized automatically, for example, with teeth that have not fully erupted, show extensive prosthetics, gingival inflammation, or retainers. Therefore, these possibilities were excluded in the study design as much as possible. When the dental crown was not completely recognized by the software, the outline was corrected manually. In the present study, this never affected the area of measurement. It must be critically noted that any manual interference must be done with great care in order not to distort the measured values. No statistically significant differences were found between the digital double measurements performed in this study. This was in agreement with a previous study in which digital model analysis was reported to show lower variability of repeated measurements.[18] This may be due to the programmed definition of the measurement points using special algorithms. The high accuracy of the double measurements was also reflected in the calculated method error according to Dahlberg[14] and the reliability quotient according to Houston.[15] When collecting the values manually using a caliper, the identification of measuring points and subsequent positioning are one of the most common sources of error.[16,19] The largest discrepancies among the different materials and between those and the digital measurements were found for the posterior arch

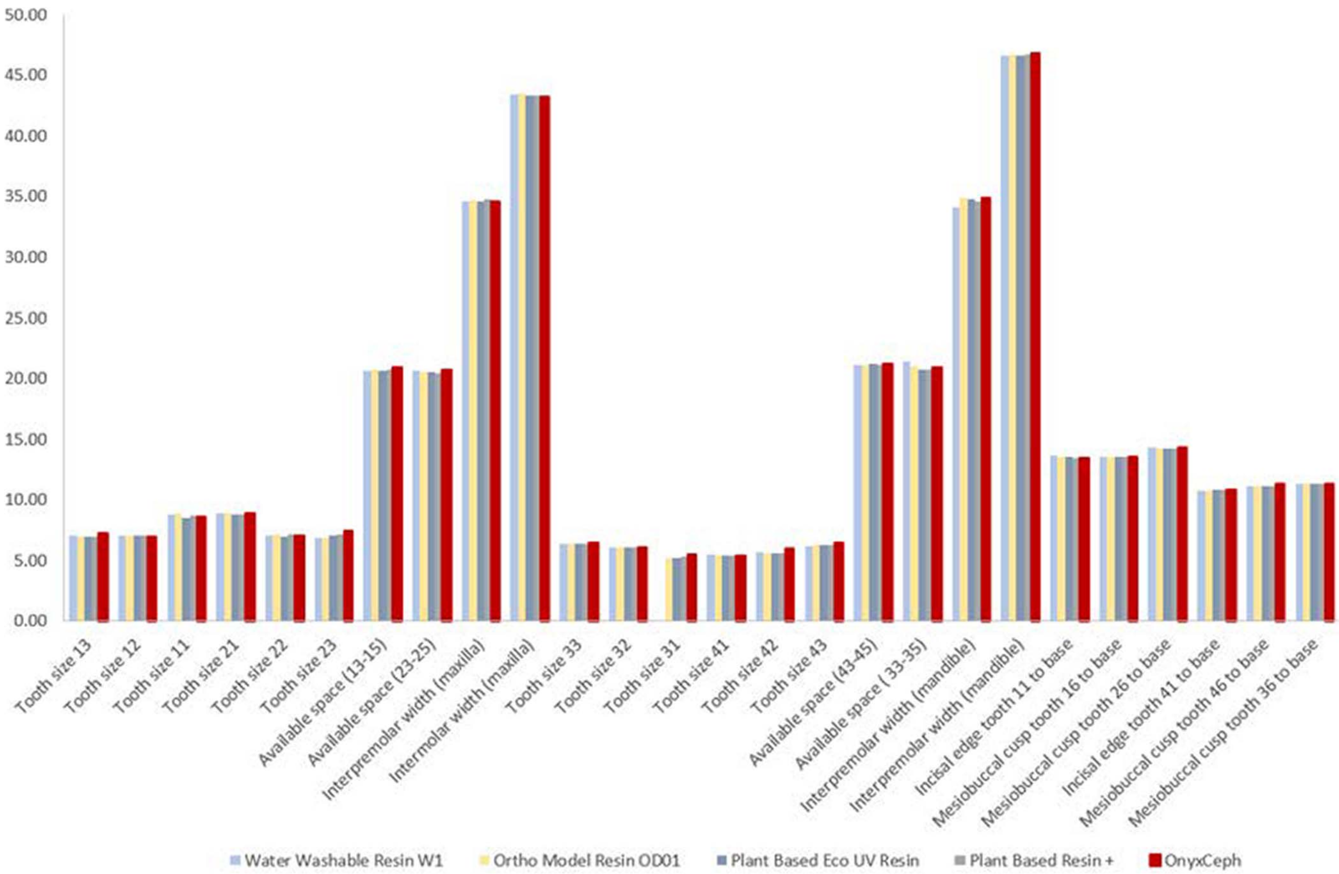


**Figure 5.** Presentation of the average values of all measurements of the four resins as well as of the digital measurements (measured values in millimeters). The explanations for the values examined can be found in Table 2.

widths in the upper and lower arches. This also corresponded to the results of the pilot study.[13] This could have been due to the difficulty in finding the corresponding measurement points compared with other parameters, for the examiner as well as for the software. According to the results of this study, digital measurement could replace manual measurement and is preferable due to significant time savings.

Conventional resins produce a high amount of plastic waste. As an alternative to soy-based resins, the possibility of producing models based on lactic acid nanocomposites has been reported for filament 3D printing.[20] Soy-based resins are biodegradable and recyclable. These models can be disposed of anonymously with household waste. In practice, this not only minimizes the production of plastic waste but also protects the environment. Environmental protection should not play a subordinate role in any practice today. However, it must be noted that isopropanol must be used to clean the models with most resins. Due to its classification, it must not be disposed of in household waste or down the drain. However, this also applies to water-washable resins, which are washed with tap water after printing, as this water also contains unhardened resin. Soy-based resin is reported to be significantly less odorous compared with conventional resins. The soy-based resin used in this study also met the requirements of the safety regulations for toys in accordance with European regulation DIN EN 71-3, according to manufacturer information also in the most current version. Unfortunately, no studies were found on the rate or nature of degradation. Likewise, the manufacturer of the resin could not provide any information regarding this upon request. Therefore, further studies should be carried out on this topic. Provided the configuration is correct, soy-based resins can also be processed with other DLP 3D printers.

## CONCLUSIONS

- Soy-based resin is a biodegradable and therefore sustainable printing material that can be used to produce orthodontic models with accuracy comparable with conventional dental resins and plaster.
- Unlike natural resin, models printed using soy-based resin can be disposed of with household waste. The exception to this is the isopropanol, which is mostly needed to clean the models after printing.

- Digitally measured values for orthodontic model analysis are comparable to those that are obtained manually.

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