Abstract

Research on dental 3D printing materials

using epoxidized soybean oil

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[Introduction]

In recent years, the integration of digital technology within dentistry, particularly in orthodontics, has seen rapid advancement. The use of intraoral scanners for optical impression and cone-beam CT for three-dimensional evaluation are revolutionizing diagnosis and treatment planning in orthodontics. Aligner-type orthodontic appliances, designed and manufactured based on digital data acquired through these scanners, are increasingly popular.

Currently, many 3D printed models are used in the production of aligner-type orthodontic appliances, but most dental 3D printing resin materials used currently derive from petroleum resources. With the growing digitalization in dentistry, the consumption of these materials is expected to increase, highlighting the need for more sustainable alternatives. Although the broader manufacturing industry has seen the development of materials from renewable resources as substitutes for those derived from fossil resources, such applications in dentistry remain limited. This study investigates the use of epoxidized soybean oil-based 3D printing materials as an alternative in the dental field and compares their properties with commercially available materials.

[Materials and Methods]

1. Material composition

Resins based on epoxidized soybean oil acrylate or methacrylate were prepared. Diluents such as tetrahydro furfuryl methacrylate (THFMA) or isobornyl methacrylate (IBOMA) or 2-isopropyl-2-methacryloyl oxyadamantane (PADMA) were used, along with phenylbis-2,4,6-trimethylbenzoylphosphine oxide (BAPO) as photoinitiator. The mixture of Epoxidized soybean oil acrylate or methacrylate with diluent and photoinitiator was homogenized at 50 ° C for 1 hour. Two commercially available dental 3D printed model materials were selected for comparison.

Each material was cast into a mold with an inner diameter of 4 mm and depth of 3 mm, and cured with 405 nm LED light for 1 hour.

2. 3D printing process

Designed using 3D modeling software (Thinkercad, Autodesk), the specimens were printed with a DLP 3D printer (Pro 95, SprintRay), at a layer thickness of 50 µm. Post-printing procedures, as recommended by the manufacturer, included washing with isopropyl alcohol using a washing/drying machine (Pro Wash/Dry, SprintRay), dried, and then removed from the platform for post-curing (Pro Core, SprintRay).

3. Fourier transform infrared spectroscopy (FTIR)

The resin samples, both pre and post-curing, were analyzed using an infrared spectrophotometer (FTIR-6600 JASCO) in attenuated total reflection (ATR) mode between 4000 and 800 cm^{-1}.

4. Evaluation of Mechanical Properties of Cast Samples

The hardness and elastic modulus of each sample created by casting and 3D printing were evaluated using a nanoindentation test (ENT-1100A, Elionix). The indentation load was set at 10 mN.

5. Thermal analysis

The thermogravimetric analyzer (TGA-50, SHIMADZU), differential scanning calorimeter (TA-DSC2500, TA Instruments), and thermomechanical analyzer (TMA Q400, TA Instruments) were employed to evaluate the thermal properties of the 3D printed samples.

6. Evaluation of Mechanical Properties of 3D Printed Samples

The hardness and elastic modulus of each 3D printed sample were evaluated using a nanoindentation test (ENT-1100A, Elionix). The indentation load was set at 10 mN.

Three-point bending tests on the 3D printed bars (2 × 2 × 25 mm) were conducted using a small tabletop testing machine (EZ Test, Shimadzu) with a 500 N load cell at a crosshead speed of 2.0 mm/min and 7.0 mm of stroke.

7. Surface properties observation

Gold deposition was applied on each sample (casting and 3D printing), and their surface properties were examined using a scanning electron microscope (SEM) (JMS-7800F, JEOL). Surface roughness measurements for 3D printed samples were taken using a stylus-type surface profilometer (DektakXT, Bruker).

8. Accuracy assessment on dental models

Dental models were designed using an orthodontic imaging system (Maestro 3D Dental Studio, AGE Solutions) and 3D printed with each resin, to then being scanned using a dental laboratory desktop scanner to obtain the digital data. The accuracy was evaluated by superimposing the 3d printed model data with reference data using a three-dimensional analysis software (Geomagic Control X 2022, 3D systems).

9. Statistical Analysis

Statistical analysis was conducted using statistical analysis software (SPSS Statics 26, IBM).

[Results and Discussion]

The FTIR spectrum of epoxidized soybean oil-based resin, both before and after curing, was compared to that of commercial materials, showing a similar decrease in the peak corresponding to the carbon double bond. Among the three diluents, resins with IBOMA showed superior hardness and elastic modulus, attributed to IBOMA´s inherent stiffness. A comparison between acrylate and methacrylate-based resins revealed that methacrylate resins exhibited a trend toward higher physical properties. This is likely due to acrylates rapid curing leading to a heterogeneous polymer network, which tends to be brittle and exhibit low toughness, while methacrylate´s lower reactivity and their incorporation into light-curing resins contribute to improving their mechanical properties. Resins composed of epoxidized soybean oil methacrylate and IBOMA displayed similar hardness and a higher glass transition temperature upon thermal analysis compared to commercial materials.

SEM observations revealed that the epoxidized soybean oil-based resin showed stripe patterns with intervals matching the lamination width, and similar to those of the commercial material. Epoxidized soybean oil methacrylate-based resin showed a trend toward lower surface roughness.

The accuracy assessment on dental models indicated high modeling precision comparable to commercial material

[Conclusion.]

The findings suggest that epoxidized soybean oil-based resins are a viable alternative to conventional dental 3D printing materials. They demonstrate comparable mechanical, thermal, and surface properties, along with high accuracy in dental model production, paving the way for more sustainable practices in dental material science.