Purpose: To evaluate root-analog implants (RAIs) fabricated by selective laser melting (SLM). Materials and Methods: Two types of implants (a maxillary right first molar RAI and a screw-cylinder-type molar implant) were designed using CAD software. Both implant types were fabricated with the SLM technique using Ti-6Al-4V powder. The stress distribution and micromotion of the implants were evaluated using finite element analysis, and the mechanical properties of the printed implants (relative density and compression test), surface properties of an SLM-fabricated specimen (morphology, roughness, and contact angle test), and biocompatibility of an SLM-fabricated specimen (osteoblast attachment, metal ion precipitation analysis, cell viability, and osteogenic gene expression) were evaluated. Results: The RAI model exhibited better stress distribution and less micromotion than the screw-cylinder implant model. The screw-cylinder implant was better than the RAI at withstanding pressure, but both implant types could withstand masticatory forces. The densities of both implant types were similar to those of the bulk materials. Block samples made using the same SLM technique as the RAI exhibited good surface properties and excellent biocompatibility. Conclusion: The properties of the molar RAI fabricated with the SLM technique suggest that it may have potential for future clinical use, but this will need to be verified by in vivo studies. Int J Oral Maxillofac Implants 2022;37:1176–1185. doi: 10.11607/jomi.9632

Keywords: biocompatibility, finite element analysis, mechanical properties, root-analog implant, selective laser melting, surface properties

Root-analog implants (RAIs) are custom-made to fit the tooth socket of a patient after tooth extraction. RAIs are suitable for immediate implantation but cannot be used in healed ridges. RAIs have several advantages over traditional screw-type implants, including replication of the natural form of the original tooth, no requirement for drilling/surgery to prepare the implantation socket (which reduces the cost and complexity of the procedure as well as patient discomfort), and maximal preservation of the alveolar bone. Traditional screw-type implants are prone to failure due to the concentration of stress forces in particular regions of the implant, especially the screw thread section. Screw loosening can also occur due to a leverage effect, which arises due to the diameter of the crown being bigger than that of the root. Although this leverage effect can be alleviated by decreasing the diameter of the crown, this tends to reduce masticatory efficiency. By contrast, there is no leverage effect for an RAI because its root shape is the same as that of the natural tooth. Therefore, many dentists consider a molar RAI to be a good option when immediate implantation after tooth extraction is possible.

The rapid development of implant materials and CAD/CAM technology has opened up new approaches to the design and manufacture of RAIs. Previous studies have reported the use of CAD/CAM techniques in the production of RAIs, but conventional manufacturing approaches have low efficiency and lack precision when the tooth structure is complex. 3D printing technology can overcome these limitations and is capable of directly producing almost any desired geometry without the need for expensive molds and tooling. Furthermore, 3D printing by additive manufacturing can save materials and decrease costs. Electron beam melting and selective laser melting (SLM) are promising technologies that have already been applied...
in dentistry. SLM is capable of manufacturing small and complicated structures and is therefore well suited for use in the field of stomatology. Recent investigations have combined the use of basic and clinical research to fabricate RAIs by 3D printing, and these studies were successful in achieving good stability of the primary implant. However, no previous reports have described the physicochemical properties and biocompatibility of RAIs manufactured by the SLM method.

The present study aimed to evaluate the feasibility of fabricating RAIs using the SLM method. A one-piece molar RAI and a screw-cylinder–type molar implant were designed using CAD software and fabricated with the SLM technique. The mechanical properties of the two types of implants were evaluated in simulation analyses and compression tests, and the surface features and biocompatibility of specimen blocks made by SLM were assessed through in vitro experiments.

**MATERIALS AND METHODS**

**Implant Design**

*Design of the personalized molar RAI.* A healthy young female volunteer with complete dentition and good oral hygiene was selected as the experimental study subject. Cranial CBCT (i-CAT system, Imaging Sciences International) was used to obtain data in the Digital Imaging and Communications in Medicine (DICOM) format. The maxillary DICOM data were imported into Mimics 17.0 software (Materialise NV), and the threshold function under the Segmentation directory was applied to analyze the threshold values. The unwanted parts were initially deleted using the Edit Mask and Brush tools in the Segmentation directory, and subsequently, the Brush tool was used to precisely modify the image and construct the tooth roots. The 3D model was generated using the Calculate 3D tool in the Segmentation directory, and the root was separated from the crown. The root was imported into 3ds Max 2015 software (Autodesk), and the abutment was created based on 1 mm of the surface of the root. ProBoolean was used to combine the abutment with the root. The height of the root bifurcation was reduced by 2 mm (Fig 1a).

*Design of the screw-cylinder implant post.* A polygon was generated with Rhino3D 5.0 (Robert McNeel & Associates) using nonuniform rational B-splines (NURBS), and the abutment was extruded using the Solid tool (for mechanical analysis). The cylindrical body was drawn, and the spring line in the Curve tool was used. The Helix tool was used to create the threads, which were fit to the cylinder to create the joint. The Solid tool was subsequently used to create the implant (diameter: 4.5 mm and 10.98 mm; length: 11 mm; Fig 1b).

**Finite Element Analysis**

The models of the two implants and bone block (Standard Template Library format) were imported into SolidWorks software (Dassault Systèmes) and combined to generate two finite element analysis models (A and B). The molar RAI and screw-cylinder implant were embedded into the alveolus according to the 3D localization of the maxillary right first molar. They were assumed to be linearly elastic, homogenous, and isotropic.

Finite element analysis was performed using Ansys Workbench 16 software (Ansys). Adjacent finite elements were connected by nodes. Table 1 provides the model types and numbers of elements and nodes. The root was fixed to the alveolar bone on the near-medial and far-medial surfaces and on the surface close to the root tip without displacement. The mechanical properties used for the simulation are shown in Table 2. To simulate the natural occlusal force, a static load of 100 N was applied to the central fossa perpendicular to the occlusal surface, a horizontal force of 80 N was applied passing through the centroid at the one-third crown, and a horizontal force of 50 N was applied passing through the outer edge of the one-third crown (Figs 2a and 2b).

**Implant Fabrication**

The sizes of the 3D models were compensated, and struts were designed using Magics software (Materialise). The...
molar RAI and screw-cylinder implant were produced via SLM using an M290 printer (EOS; power, 280 W; speed, 1,200 mm/s) and Ti-6Al-4V alloy powder with a particle size of 25 to 45 µm as the basic material. Both types of implants were annealed following production (1,400°C; BLMT furnace, Yuxiang).

**Preparation of Ti-6Al-4V Standard Specimens for In Vitro Studies**

The Ti-6Al-4V specimens were fabricated using SLM (M290 printer, EOS; average particle size, 25 to 45 µm). All specimens and implants were fabricated in the same direction and using the same SLM printing technique as the RAI. The sizes of the wrought samples (forged using conventional methods rather than 3D printing) used for the in vitro experiments were the same as those of the SLM samples. The sizes of the solid specimens were 5 × 5 × 2 mm for the osteoblast attachment and cell viability assays, 10 × 10 × 2 mm for the surface morphology and metal ion precipitation analyses, and 20 × 20 × 2 mm for the surface roughness examinations, contact angle test, and osteogenic gene expression analyses. Three samples per group were used for each experiment. The specimens were polished up to 600 grits with emery papers (Yuli Abrasive Belts Group) and sterilized by autoclaving prior to cell-based experiments to follow ASTM-F86-04 standard practice.

**Relative Density Test**

The densities of the two types of dental implants were measured by the Archimedes principle, and the relative densities were determined by the actual/theoretical equation as follows:

\[ p = m/(V_2 - V_1) \]

where \( p \) is the relative density (g/cm³), \( m \) is the mass, \( V_2 \) is the volume of the liquid plus object, and \( V_1 \) is the volume of the liquid.

**Compression Test**

Implant models (n = 3/group) fabricated by SLM were used for the compression tests (UTM 5105, Kesheng). The compression tests were carried out using a force < 800 N to simulate masticatory force at room temperature under a strain rate of 1 mm/s.

**Surface Properties**

*Observation of surface morphology with scanning electron microscopy (SEM).* A JSM-7001F field-emission scanning electron microscope (Jeol) was used to investigate the surface features of the specimen block. All images were collected at an accelerating voltage of 20 kV and a probe current of approximately 600 nA.

*Surface roughness.* The surface roughness of the SLM specimen block was evaluated using an HL620 roughness measuring machine (Mahr). The surface roughness was determined at three randomly selected areas on each SLM specimen (ASME B46.1-2009).

*Contact angle test.* The contact angle test was performed in accordance with ISO15989:2004. The SLM specimen block was examined with a video optical contact angle measurement instrument (OCA 20 system, DataPhysics Instruments). The contact angle was determined at three randomly selected areas on each SLM specimen.

**Biocompatibility Test**

All experiments were approved by the Institutional Animal Care and Use Committee of General Hospital of the PLA and were conducted following its specific guidelines. All animal experiments were conducted in accordance with the National Institutes of Health Guide for the Care and Use of Laboratory Animals.

*Observation of osteoblast attachment by SEM.* Osteoblasts were obtained from rats provided by Beijing Vital River Laboratory Animal Technology. The cranium was harvested from each rat and cut into bone fragments (1 × 1 mm) that were placed into 75-cm² culture flasks (Costar, Corning) following trypsinization (10% trypsin; Gibco, Thermo Fisher Scientific). Once the bone fragment had adhered to the culture flask, it was cultured in low-glucose Dulbecco’s Modified Eagle Medium (DMEM; Gibco) supplemented with 100 U/mL penicillin (Gibco), 100 µg/mL streptomycin (Gibco), and 10% fetal bovine serum (Gibco) at 37°C in a humidified atmosphere of 5% CO₂ and 95% air.

A TM3000 SEM (Hitachi) was used to observe cell attachment. The osteoblast cells obtained using the above procedure were seeded (4 × 10⁵ cells/specimen) on SLM specimen blocks (polished or unpolished, one piece/group) and cultured for 24 hours in complete culture medium at 37°C in a humidified atmosphere of 5% CO₂ and 95% air. The cells on each specimen were rinsed with phosphate-buffered saline (Gibco).
Fig 2  Rows 1 and 3 correspond to the RAI and rows 2 and 4 correspond to the screw-type implant. (a and b) The finite element model (black arrows indicate the direction of force and bone configuration). (c and d) Stress distribution in both types of implants. (e and f) Micromotions of both types of implants. (g and h) Major principal stress in both types of implants. (i and j) Minimum major stress in both types of implants. (k and l) Maximum shear stress in both types of implants.
to remove the cell culture medium, fixed with 3% glutaraldehyde (Sigma-Aldrich), and dehydrated with a series of ethanol solutions of increasing concentration (50%, 60%, 70%, 80%, 90%, and 100%; 5 minutes in each; Sigma). Subsequently, the specimen was prepared by critical point drying (KBSO critical point dryer; Quorum Technologies) and gold sputtering (SCD 500 device; Baltec).

**Metal ion precipitation analysis.** Cells (5 × 10^5 cells/specimen) were seeded on SLM specimen blocks (polished or unpolished, three pieces/group), and cultured in complete culture medium for 3 days. Then, the metal ion content of the cell culture medium was analyzed by inductively coupled plasma mass spectroscopy (7700 series device; Agilent Technologies).

**Cell viability assay.** Leaching liquor for the Ti-6Al-4V specimens was prepared by immersion of the specimen blocks in 1.25 mL DMEM per cm² sample surface area at 37°C for 24 hours, in accordance with the ISO 10993–12:2002 standard. Osteoblasts (5 × 10^3 cells/well) were seeded in 96-well plates (Corning) and incubated for 24 hours. Subsequently, the medium was removed, and the cells were incubated in 100 µL leaching liquor (five duplicate wells for each experimental group arranged in parallel) for 1, 3, 5, or 7 days. The wrought leaching liquor (obtained from specimens forged using standard techniques) was used as the control. Then, 10 µL Cell Counting Kit-8 (CCK-8; Dojindo Laboratories) was added to each well of the 96-well plate, which was incubated at 37°C for 3 hours. Cell viability was determined by measurement of the absorbance at 490 nm using ultraviolet spectrophotometry (GE Healthcare).

**Quantification of osteogenic gene expression.** Polymerase chain reaction (PCR) was used to evaluate the expressions of osteogenesis-related genes. The primer sequences (Table 3) were designed using Primer Express 3.0 software (Applied Biosystems). Osteoblasts (2 × 10^5) were seeded on the wrought (nonprinted) and SLM-printed specimens for 1, 2, or 3 weeks. The cells were harvested from the specimens (n = 3 per group), and total ribonucleic acid (RNA) was extracted using TRIzol reagent (Invitrogen, Thermo Fisher Scientific). The expressions of two genes related to osteogenic differentiation in dental tissues, namely, those encoding runt-related transcription factor-2 (RUNX2) and osteopontin (OPN), were measured by quantitative PCR (qPCR).

**Statistical Analysis**
The experimental results were analyzed using SAS 8.0 software (SAS Institute). Normally distributed data were presented as mean ± SD and were compared between groups using one-way ANOVA and Tukey multiple-comparison post hoc test. Non--normally distributed data were described as median (range) and were analyzed using Kruskal-Wallis test. A P value <.05 was considered to indicate a statistically significant difference.

**RESULTS**

### 3D Models of the Implants

3D models of the RAI and screw-cylinder--type implant are shown in Figs 1a and 1b, respectively. The height of the root bifurcation in the RAI was decreased by 2 mm to adjust the distance from the bone level to the root bifurcation (Fig 1a).

**Finite Element Analysis**
Stress distribution and micromotion are important factors affecting long-term implant integrity. Therefore, finite element analyses were performed (Figs 2a and 2b) to evaluate stress distribution and micromotion in the RAI and screw-cylinder implant (Fig 2c–I). Stress was calculated to be 16.92 MPa for the RAI (Fig 2c) and 137.62 MPa for the screw-cylinder implant (Fig 2d). The degree of micromotion was determined to be only 3.076 × 10⁻³ mm for the RAI (Fig 2e), which was much smaller than the value of 0.0349 mm for the screw-cylinder implant (Fig 2f). The major principal stress was 10.67 MPa for the RAI (Fig 2g) and 151.60 MPa for the screw-type implant (Fig 2h), while the minimum principal stress was 1.35 MPa for the RAI (Fig 2i) and 46.53 MPa for the screw-type implant (Fig 2j). Maximum shear stress was 9.313 MPa for the RAI (Fig 2k) and 74.09 MPa for the screw-cylinder implant (Fig 2l). Stress was concentrated at the neck of both types of implants, although the stress of the RAI was significantly smaller than that of the screw-cylinder implant (Figs 2c, 2d, 2k, and 2l). Stress was distributed from the neck to the central section of the screw-cylinder implant and from the neck to one-third of the root-apex of the RAI. Moreover, the area of stress was greater for the RAI than for the screw-cylinder implant (Figs 2c, 2d, 2k, and 2l). A possible reason for this finding is that the diameter of the molar RAI was greater than that of the screw-cylinder implant. Overall, the results of the finite element analysis indicate that the RAI exhibited better distribution of stress and less micromotion than the screw-cylinder implant.

### Relative Density

The estimated relative density was comparable between the RAI (99.2%) and screw-cylinder--type implant (99.1%) and similar to that of the bulk material, indicating that the 3D printing process generated specimens of the expected density.

**Compression Test**
Since it is critical that implants are able to withstand masticatory forces, compression tests were carried...
out to characterize the responses of the two types of implants to compressive force. The implant samples prior to and following the compression experiment are shown in Fig 3. The RAI was only slightly deformed by compression (Figs 3a and 3b), and its compressive nominal stress-strain curve is shown in Fig 3c. The screw-cylinder implant was also only minimally deformed by compression (Figs 3d and 3e), and its stress-strain curve is presented in Fig 3f. The results indicate that both implants could withstand masticatory forces and underwent only elastic deformation during compression. However, movement in response to a force of 500 N was significantly greater for the RAI than for the screw-cylinder implant ($P < .01$; Fig 4), indicating that the stiffness of the RAI was lower than that of the screw-cylinder implant. This latter finding is not consistent with the results of the finite element analysis.

Surface Properties
The surface roughness and wettability of an implant are factors known to influence osseointegration. Therefore, the surface features of a specimen block fabricated using the same SLM technology as the RAI were evaluated.

Evaluation of surface morphology by SEM. Some un-fused Ti-6Al-4V particles were observed on the surface of the SLM-fabricated specimen (Fig 5a). The surface topography of the specimen was discontinuous, and the structure was microporous (Figs 5a and 5b). The diameters of the micropores on the surface of the specimen ranged from 2 to 6 μm, and the protuberances ranged from 2 to 10 μm (Fig 5b).

Surface roughness. The mean roughness value for the surface of the SLM-fabricated specimen was estimated to be $11.87 ± 0.364$ μm.

Contact angle test. The right and left contact angles of the SLM-fabricated specimen were $99.86 ± 0.279$ degrees and $100.2 ± 0.336$ degrees, respectively, which indicated that the material was hydrophobic.

Biocompatibility
An implant must have good biocompatibility to ensure that the patient does not experience adverse events. Furthermore, the attachment of osteoblasts to the implant surface and osteogenic differentiation of these cells are critical factors for osseointegration of the implant. Therefore, the biocompatibility of SLM-fabricated specimen blocks was evaluated in vitro.

Evaluation of osteoblast attachment by SEM. The osteoblast protuberances were tightly adhered to the polished specimen, and secreted extracellular matrix was visible (Fig 6a). The cells on the unpolished specimen were more stereoscopic, with the cell bodies embedded in larger micropores and protuberances embedded in smaller micropores (Fig 6b).
Metal ion precipitation analysis. The content of Ti, Al, and V ions in the cell culture medium was very low. Furthermore, metal ion content was comparable between the polished and unpolished specimens (Table 4).

Cell viability. The effects of different Ti-6Al-4V specimens on cell viability were determined using a CCK-8 assay following cell culture in leaching liquor for 1, 3, 5, or 7 days (Fig 7). Wrought specimens of Ti-6Al-4V forged using conventional techniques were used as a control group to establish whether the SLM printing technique detrimentally affected the structure of the specimen surface and hence cell attachment and viability. The optical density (OD) value in each group increased significantly with time (\(P < .05\)), reflecting an increase in cell viability. There were no significant differences in OD value between the SLM group and wrought group (\(P > .05\)), indicating that the use of the SLM technique for specimen fabrication did not exert detrimental effects on the interaction between the specimen and cells. Thus, the SLM Ti-6Al-4V extract did not affect cell viability.

Osteogenic gene expression. The expression levels of two genes related to osteogenesis (RUNX2 and OPN) were investigated using qPCR. RUNX2 expression was observed 1 week following osteoblast adherence to the Ti-6Al-4V samples in both the SLM and wrought groups, and RUNX2 expression peaked at 2 weeks before decreasing slightly at 3 weeks (\(P < .05\); Fig 8). Similar results were obtained for OPN expression (Fig 8). There were no significant differences between the SLM and wrought groups in RUNX2 expression or OPN expression at any time points (\(P > .05\); Fig 8), implying that the SLM method of specimen manufacture did not negatively influence osteogenic differentiation.

DISCUSSION

The development of 3D printing technology has simplified the manufacture of RAlIs. The present study utilized a combination of in vitro approaches to investigate the stress distribution, micromotion, and mechanical properties of a molar RAI
fabricated with the SLM technique as well as the surface features and biocompatibility of standardized samples manufactured using the same SLM printing process. Given its good in vitro properties and ease of manufacture, the SLM-fabricated molar RAI may have potential for use as a dental implant in patients. However, this will need to be evaluated in future clinical studies.

During the finite element analysis, three forces were concomitantly applied to the crown in different directions to simulate the masticatory forces. The analysis revealed that stress was concentrated at the neck of both types of implants. A possible reason for this finding is that the implant lacked a surrounding periementum and had an elastic modulus higher than that of bone. This would be consistent with previous studies. The present study also found that the RAI exhibited better conduction of stress, wider distribution of stress, and less micromotion than the screw-cylinder implant, which raises the possibility that the RAI might be associated with less bone resorption and lower susceptibility to damage and failure than a screw-cylinder implant. It is speculated that a molar RAI might transmit masticatory forces better than a screw-cylinder implant because it would conform to the tooth extraction socket and thereby replicate the position of the original tooth so that the orientation of occlusal force was not altered. However, the molar RAI did not withstand compressive stress as well as the screw-cylinder implant, and the results of the compression test were opposite to those of the finite element analysis. This may have been due to the RAI being less stiff than the screw-cylinder-type implant. Both the molar RAI and the screw-cylinder implant had similar relative densities to those of the bulk material. This indicates that the RAI implant should exhibit sufficient strength to withstand masticatory forces, and the results of the compression test verified this. Overall, the present study data indicate that the molar RAI exhibits less stress concentration and less motion than a screw-cylinder implant.

The methods used to secure the implant body to the abutment include screw retention, friction retention, and screw-friction retention. If the length of the retention is insufficient, the connection between the body of the implant and abutment will be loosened, leading to a piece of the retention breaking off and consequent bone resorption. In addition, bone level declines with age. Therefore, the field of the root bifurcation was adjusted by 2 mm to increase the distance from the bone level to the root bifurcation. Despite this change, the finite element analysis showed that the molar RAI exhibited superior stress conduction and distribution compared to the screw-cylinder implant. Furthermore, this minor change did not alter any other factors and would not be expected to affect the convenience of the surgical operation. Therefore, this method of optimization is feasible. Although the height was altered by 2 mm in the present study, in practice, this adjustment could be made on an individualized basis to optimize primary stability and stress distribution. However, the limit of this height adjustment was not addressed in this study and requires further investigation.

Fig 7 Measurement of OD in each group on days 1, 3, 5, and 7. The OD value increased with time, \( *P < .05 \) vs the corresponding group on day 1. No significant differences were noted between the two groups (\( P > .05 \)).

Fig 8 Expression levels of two osteogenesis-related genes (a, OPN and b, RUNX2) at different times following osteoblast adherence to the Ti-6Al-4V samples. No significant differences (\( P > .05 \)) were noted in the expression levels of the two osteogenesis-related genes between specimens fabricated with the SLM method (S) and wrought specimens forged using standard techniques (W). \( *P < .05 \) vs the corresponding group on day 2 for OPN and RUNX2.
The surface topography and roughness of an implant play important roles in cell attachment and proliferation. Cells adhere more easily to a non-smooth surface than a smooth surface, and this was evident in the present SEM analysis, which showed better adhesion of osteoblasts to an unpolished specimen than a polished specimen (Figs 6a and 6b). However, it was reported that cell attachment and proliferation were optimal for materials that had particles with diameters of 63 to 90 μm on their surface. The SEM observations (Fig 5) revealed that the diameters of the protuberances on the SLM specimen blocks (2 to 10 μm) were < 63 μm. Furthermore, a surface with continuous and regular microlamination is better suited to cell attachment and proliferation than a microporous surface, yet the SLM surface exhibited a discontinuous and microporous structure. In addition, the contact angle test implied that the SLM specimen block had a hydrophobic surface, which would be expected to reduce effective cell adhesion. The above data indicate that the surface of the SLM specimen is not fully optimized for cell attachment and proliferation. It is suggested that surface modification methods could be used to enhance the surface roughness and topography of the molar RAI and thereby improve cell attachment and proliferation. This will need further investigation in a future study.

Based on the results of cell culture medium analysis (Table 3), the amounts of Al and V ions that leached from unpolished SLM specimen blocks were very low and similar to the amounts lost from polished specimens. High concentrations of Al and V ions are thought to cause dysfunction of DNA synthesis, whereas low concentrations of these ions can promote DNA synthesis. The RAI is divided into a rough root part and a smooth neck part. Since polishing had no effect on the amount of metal ions released, which was small for both polished and unpolished specimens, the present findings suggest that the molar RAI would be unlikely to exert any cytotoxic actions on cells due to the release of Al or V ions.

The interaction between the molar RAI and osteoblasts includes cell proliferation and osteogenic differentiation. The results of the CCK-8 assay indicated that osteoblasts were able to proliferate over time on both the wrought Ti-6Al-4V samples (forged using conventional methods) and the Ti-6Al-4V specimen blocks printed using the SLM technique, with no significant differences between the two groups at any time points. These findings indicate that an RAI fabricated with the SLM technique would likely exhibit no toxic effects on osteoblasts.

Osteogenic differentiation of osteoblasts is the basis for osseointegration. RUNX2 is the major transcription factor for osteogenic differentiation in osteoblasts, and it regulates the expression of osteogenesis-related genes, such as those encoding alkaline phosphatase and type-I collagen. OPN is an osteogenic marker expressed in osteoblasts during the mineralization stage of osteogenic differentiation. In the present study, osteoblasts showed expression of both RUNX2 and OPN mRNA, and the expression levels were comparable between the wrought group and SLM group. These observations suggest that a molar RAI fabricated with the SLM method would be unlikely to exert adverse effects on the osteogenic differentiation of osteoblasts and osseointegration.

An important limitation of the present study is that it involved only in vitro experiments and did not include any in vivo experiments. Additionally, the sample sizes for some of the experiments (such as the compression test) were quite small. Further research is required to examine the effects of in vivo implantation of molar RAIs fabricated with the SLM technique.

CONCLUSIONS

This study evaluated the characteristics of a molar RAI fabricated with the SLM technique. Finite element analysis revealed that the RAI exhibited better stress distribution and less micromotion than the screw-cylinder implant model. Although the screw-cylinder implant was better than the RAI at withstanding compressive pressure, both implant types were able to withstand masticatory forces. Block samples printed using the same SLM technique as the RAI exhibited good surface properties, although the hydrophobicity, small-diameter protuberances, and microporosity of the surface may make it suboptimal for cell attachment. The surface also exhibited good biocompatibility, and printing with the SLM method did not adversely influence cell proliferation or osteogenesis (compared with forging using standard techniques). It is suggested that molar RAIs fabricated with the SLM technique may have potential for use as dental implants in patients. However, this will need to be evaluated in future in vivo studies in animals and patients. In addition, it will be important to determine whether surface modification techniques would improve the properties of RAIs made by the SLM method.

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