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LASER-BASED THREE-DIMENSIONAL PRINTING OF ZIRCONIUM OXIDE HYBRID MATERIALS

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We have recently examined use of an additive manufacturing approach known as two-photon polymerization to create structures out of zirconium oxide hybrid materials for medical device applications. Two photon polymerization involves processing of a structure with sub-microscale features in an additive manner directly from a computer-generated model. In two-photon polymerization, a femtosecond laser beam is focused within a small volume in a near infrared light-transparent photosensitive material; nearly simultaneous absorption of two photons within a small volume in the photosensitive material results in polymerization and hardening of the material. Because of the quadratic dependence of two-photon absorption probability on intensity, photopolymerization occurs in a localized volume. The energy associated with two photon absorption of infrared photons is analogous to the energy associated with a single photon in the ultraviolet light region of the electromagnetic spectrum. The unit volume of material polymerized using two-photon polymerization is known as a voxel (volumetric pixel). The minimum size of the features obtained in a two-photon polymerization-fabricated structure is related to the voxel-voxel distance, the photosensitivity of the material, the numerical aperture of the objective lens, the exposure time, and the laser power. Titanium:sapphire femtosecond lasers are used in two photon polymerization since these lasers produce high energy intensity in the focal volume due to their short pulse width and high peak power.

A medically-relevant structure with an arbitrary geometry may be created using two photon polymerization by polymerizing the material along the laser trace, which is translated in three dimensions via a micropositioning system. Two photon polymerization exhibits advantages over conventional mechanisms for scalable production of small-scale medical devices. Several classes of inexpensive inorganic-organic hybrid materials, polymers, and other photosensitive materials may be fabricated via two photon polymerization. Two photon polymerization can be set up in a conventional environment; no specialized facilities (e.g., cleanroom facilities) are needed. In comparison with conventional multiple-step medical device processing techniques, two photon polymerization is a rapid, straightforward, single-step process. Two photon polymerization was used to create scaffolds for tissue engineering with linear designs in a layer-by-layer manner out of a zirconium oxide hybrid material. Good feature-to-feature uniformity within the scaffolds. In vitro cell studies were used to examine cell-scaffold interactions over time.