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Production tolerance of additive manufactured polymeric objects for clinical applications

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ABSTRACT

Objectives. To determine the production tolerance of four commercially available additive manufacturing systems.

Methods. By reverse engineering annex A and B from the ISO_12836;2012, two geometrical figures relevant to dentistry was obtained. Object A specifies the measurement of an inlay-shaped object and B a multi-unit specimen to simulate a four-unit bridge model. The objects were divided into x, y and z measurements, object A was divided into a total of 16 parameters and object B was tested for 12 parameters. The objects were designed digitally and manufactured by professionals in four different additive manufacturing systems; each system produced 10 samples of each objects.

Results. For object A, three manufacturers presented an accuracy of <100 μm and one system showed an accuracy of <20 μm. For object B, all systems presented an accuracy of <100 μm, and most parameters were <40 μm. The standard deviation for most parameters were <40 μm.

Significance. The growing interest and use of intra-oral digitizing systems stresses the use of computer aided manufacturing of working models. The additive manufacturing techniques has the potential to help us in the digital workflow. Thus, it is important to have knowledge about production accuracy and tolerances. This study presents a method to test additive manufacturing units for accuracy and repeatability.

1. Introduction

The application of computer aided design (CAD) and computer aided manufacturing (CAM) in dentistry has evolved over the last two decades. Today, what was originally inspired by the industry has changed the treatment modalities in many clinical situations. The methodology for dental applications starts from the dental technicians scanning conventional plaster models to obtain virtual models or, more recently, the clinicians digitizing the oral cavity with an intra-oral scanner. By using computer software, the technicians have the capability to virtually design crowns and bridges on the virtual models. In this way, it has been suggested that the human errors that could occur during the laboratory procedures can be reduced, therefore leading to a passive fitness of the prosthetic construction [1]. Until recently, the majority of these prosthodontic constructions have been manufactured using subtractive computer numerically controlled (CNC) techniques, better known as milling techniques possible for a wide variety of materials.

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Subtractive manufacturing is a process in which a piece of material is cut into its final geometry by removing the unnecessary bulk material [2]. From an ecological viewpoint, it can be suggested that the method is rather wasteful since more material is removed than used in the final product. Moreover, the subtractive technique also has a limitation in the amount of objects it can produce per milling procedure, the inability to manufacture complex geometries and the fact that these machines use drills and burrs that wear.

An alternative way of manufacturing the CAD-based construction is the so-called additive manufacturing process [3]. The basic concept of all additive production methods is to apply sequentially thin layers of material (layering), which are then solidified through computer control layers. A plethora of additive manufacturing (AM) methods is available on the market, which in a collective term can be called rapid prototyping/manufacturing (RP/RM) [4]. In contrast to the subtractive manufacturing, it can be suggested that the AM methods generate less material waste since unnecessary structures will not be created unless so designed. There is no use of drills and burrs that wear, and the systems have a superior capability to produce complex geometries, which makes the production technique a suitable solution for the dental field. For instance, additive manufacturing process has the possibility to be utilized for model production, fixed/removable prosthodontics, diagnostic and treatment planning for oral and maxillofacial surgery, as well as for orthodontics [5,6]. With regards to the production of polymeric products, there exist mainly two AM systems that are actively utilized in dentistry, namely stereolithography (SLA), and the selective laser melting/sintering (SLM/SLS).

Stereolithography is a method, which involves a computer aided design (CAD) model communicating through a Standard Tesselation Language (STL) file extension with a manufacturing machine (CAM) that produces the intended object [7]. The SLA method could be utilized with the platform covered by liquid resin that is cured according to computer-controlled layers with UV light or laser while the platform is moving in the z-direction (vertically). The SLA in dentistry is used during the prosthodontic laboratory procedure replacing wax models with lost wax investment casting capable photopolymers. Moreover, the method is used for manufacturing intra-oral provisional restorations, laboratory models replacing dental stone models, and for diagnostic models (made from computer tomography) in the fields of orthodontics and oral and maxillofacial surgery.

Selective laser melting (SLM) is a fabrication method that communicates with the CAD using the same file system STL. The method uses a powder as layering material that is sintered/melted with a laser according to computer-controlled layers onto a platform [8].

There exist numerous studies with regards to the accuracy and precision of the SLA systems, mostly focusing on biomodels for treatment planning and diagnostics in the fields of oral and maxillofacial surgery and orthodontics [6,9–12]. The drawback of these different studies is that the methods and objects to determine the accuracy and precision of SLA products are unique for each study, which makes it difficult to compare and to reproduce data. Lamentably, at present there is no industry standard for assessing the accuracy and precision of objects made from additive CAD/CAM systems in dentistry. It must be noted here that in 2012, an ISO standard for assessing accuracy of digitizing devises was published, however, this ISO (12836;2012) is mainly focused on testing intra-oral and laboratory digital scanners. Therefore, it is of utmost importance to obtain information with regards to the production tolerance (accuracy and precision) of the products generated from different AM systems, which could provide information necessary for a universal calibration of them.

Thus, the aim of this current study was to determine the production tolerance of four commercially available AM systems by reverse engineering annex A and B from the ISO_12836;2012.

2. Materials and methods

2.1. *ISO reference*

The ISO 12836 “Dentistry – Digitizing devices for CAD/CAM systems for indirect dental restorations – Test methods for assessing accuracy”. The ISO describes three geometrical figures, described as Annex A, B and C the present study has utilized Annex A and B as reference, the former specifying the measurement of an inlay-shaped object and the latter a multi-unit specimen to simulate a four-unit bridge model. Annex A and from the ISO was the reference for the design of object A and B in the present study (Figs. 1 and 2). The CAD was designed as solids using 3D modeling software (Solidworks educational edition 2013) with an edge radius of 0.01 mm. Both CAD models were exported as standard tessellation language files (STL) and delivered together with production information to the manufacturers.

2.2. *CAM*

A total of four additive manufacturing units were tested EOS (Formiga P110) 3D Systems (Projet MP 3510), Stratasys (Objet 30) and Stratasys (Objet Eden) (Table 1). Authorized personnel from each company manufactured all objects. All producers manufactured 10 sets for object A and 10 sets for object B on separate build plates. The geometries of both object A and B have no undercuts, thus there was no need for support structures, allowing the objects to be manufactured directly onto the build plate. The person responsible for each production unit decided material and software settings to achieve accurate samples. All manufacturers had seen the protocol ahead of initiating the present study. It was clear that all objects would be tested for geometrical accuracy. The manufacturers decided the best parameters for their specific machine, price was not an evaluated parameter (Table 1). The material of choice was then specified together with information about the print resolution, specification of the production unit, software, and the manufacturing time (Table 1). The test samples went through the same process as for clinical dental products, regarding both production and shipment.

2.3. *Measurements*

The measurements for the inlay shaped geometry of object A was divided in *x*, *y* and *z*-axis. The geometrical measurements