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ORIGINAL RESEARCH

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Evaluation of the tensile properties of polished and unpolished 3D SLA- and DLP-Printed specimens used for surgical guides fabrication.

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Abstract

Introduction: The fundamental mechanical properties of 3D printed surgical guides used in orthodontics represent an important indicator for the accuracy of the insertion of skeletal anchorage devices. The tensile strength of devices printed by stereolithography (SLA) and digital light processing (DLP) methods, respectively, is influenced by factors such as finishing process.

Aim of the study: This study illustrates a comparison of the tensile strength in two different types of 3D printed devices (SLA, DLP respectively) undergoing or not a standard process of polishing.

Material and methods: Twenty-four specimens obtained according to ASTM D638-14 (Standard Test Method for Tensile Properties of Plastics) were used for the evaluation of tensile strength. Four groups of 6 samples from each category were created: SLA polished, SLA unpolished, DLP polished and DLP unpolished. After removing the support, finishing was performed to obtain smooth surfaces, according to the manufacturer's recommendation. Type V specimen was used to perform tensile tests in accordance with the standard procedures ASTM D638-14 which recommends at least five specimens to be tested for each sample.

One-way analysis of variance (ANOVA) and t-test showed statistically significant results at $p < 0.05$. SPSSv17 software was used for statistical analysis of the numerical variables, and also descriptive statistics were performed.

Results: The measurements included: tensile strength (maximum load), tensile stress at maximum load and tensile strain at maximum load. The maximum load (tensile strength) of the polished specimens was lower, both for the SLA and DLP, with no statistical significance results.

Conclusions: The conclusions indicated differences between maximum load and tensile stress at maximum load between polished and unpolished specimens, in both SLA and DLP groups. Althought the polishing process reduces the tensile strenght, the data analysis did not present statistically significant results.

Keywords: 3D printing; surgical guide; tensile testing; tensile strength.

Introduction

Additive manufacturing (AM), has been intensively used in several fields of dentistry for obtaining three-dimensional (3D) printed devices [1,2]. In orthodontics, printed surgical guides are used to aid miniimplant placement in the palatum. Numerous studies have shown that the use of printed surgical guides for mini-implants have increased their placement precision in the anterior region of the palate, thus increasing the predictibility of the treatment with temporary anchorage devices (TADs) [1,3,4-9].

Regarding the different printing technologies, extrusion, resin curing and powder fusion are most frequently used [2,3-9]. The stereolithography and digital light processing are resin curing techniques, caractherised by exposure of photosensitive monomers to controlled high energy or ultraviolet light in order to obtain layers of cured materials [8,10-19]. The advantages of the stereolithography (SLA) and digital light processing (DLP) techniques are high resolutions and extra-finishing of the printed specimens in comparison with the extrusion or powder fusion methods [20].

The evaluation of the mechanical properties of the printed components is a valuable indicator on the clinical behaviour of the above mentioned materials. Several studies investigated the effects of the aging process, building orientation of the layers and pre-conditioning [10,21-30]. Furthermore the resin producer provided information about basic mechanical properties as well [20-23].

Tensile test represents a testing method that provides information about the tensile strength which enables performance prediction during clinical use of a resin material. Tensile properties rely on several factors regarding the orientation of the layers and printing methods. However, few studies referred to the modifications of the tensile properties due to polishing and processing techniques [8,20-21,24-27].

The main purpose of the present study is to measure the tensile strength in two different types of 3D printed devices (SLA, DLP respectively) undergoing a standard polishing process or not.

Material and methods

Twenty-four standard specimens were manufactured in accordance with ASTM D638-14 (Standard Test Method for Tensile Properties of Plastics) to examine the tensile properties of the polished and unpolished mass materials and were used for the two different kind of printing methods. Using the recommended mass of materials for the manufacturing of surgical guides (DentaGuide, Asiga and Dental SG Resin, Formlab, respectively) were obtained twelve samples by digital light processing procedure (Asiga Max UV, Asiga, Sidney, Australia), and other 12 samples were obtained by stereolitography technique (Form 2, Formlabs, Boston, MA, USA. The specimens obtained using each printing method were distributed into two sub-groups: polished and unpolished. The post-processing sequence of the SLA printed specimens consisted of a 5 min rinsing cycle in 99% isopropanol solution, drying process by air exposure, and light curing (λ = 405 nm) at 60 °C for thirty minutes. Finally, after removing the supports and evening the surface, finishing was performed. The polishing treatment was done according to the manufacturers recommendation: high grit sandpaper was used to even out and smooth support marks, then a pumice and a rag wheel were used to obtain a perfectly smooth surface.

Type V specimen was used to perform tensile tests in accordance with the standard procedures ASTM D638-14. When a thickness of 7 mm or less is available the type I specimen shall be used as an optimal option.

This test method can be used to generate data referring to tensile properties for the specification and control of plastics. This information is additionally helpful for the study of quality features, also sustaining the research and development domains.

The testing machine is made of a testing device of the constant-rate-of-crosshead-movement type that consists primarily of the following:

- Fixed member- grip-carrying member that is fixed or virtually stationary.

-A second moveable grip-carrying component is also described in the instruction manual. The grips used to hold the test specimen between the testing machine's fixed and movable members can either be fixed or self-aligning. The testing device's fixed and movable parts are rigidly connected to the fixed grips.

When using this type of fixture, special care must be taken to insert and clamp the specimen so that the direction of pull through the center line of the grip assembly perfectly coincides with the long axis of the test specimen. The self aligning grips are joined to the immovable and movable parts of the testing machine so that they align freely when a force is applied (the longitudinal axis of the specimen coalignes with the centreline of the grip assembly. The specimens should be completely aligned with the direction of pull to prevent any rotating motion that could cause slippage in the grips. The amount of misalignment that self-aligning grips can tolerate has a precise limit. In order to prevent slippage related to the grips as much as possible, the test specimen must be held.

-A drive mechanism that imparts a constant, controlled velocity to the moving element in relation to the stationary element. The control of this pace shall be in accordance with all the provided indications. A reliable load indicator that displays the total tensile load the specimen is carrying while being held by the grips is called a load indicator.

Standard procedures for tensile properties recommends at least five specimens for each sample where isotropic materials or molded specimens are used [28]. For each specimen the process consisted in being loaded at a speed of 1 mm/min during the test and the tensile properties of the material were measured as follows: tensile strength (tensile stress at maximum load), tensile strain at maximum load, and tensile modulus of elasticity (figure 2).

To get the tensile strength divide the greatest load that the specimen could withstand in newtons (pounds-force) by the specimen's average original cross-sectional area in square meters (square inches) in the gage length segment. Tensile strength at yield or tensile strength at break, depending on which phrase is appropriate, should be reported and referenced to three significant figures and expressed in Pascals (pounds force per square inch).

When consistent deformation occurs along the specimen gage length, elongation values are accurate and can be recorded. For engineering design, elongation values are quantitatively significant and appropriate. Nominal strain values are reported when non-uniform deformation (such as necking) takes place within the specimen gage length. Nominal strain values are only useful in terms of quality. The percentage change in grip separation related to the starting grip separation represents nominal strain.

The modulus of elasticity, or the ratio of stress (nominal) to corresponding strain below a material's proportional limit, is calculated by extending the initial linear portion of the load-extension curve and dividing the difference in stress corresponding to any segment of section on this straight line by the corresponding difference in strain.

Tensile strength at yield is the measurement made at the point where the maximum stress occurs. Tensile strength at break is defined as the tensile load per unit area of minimal original cross section, borne by the test specimen at any given moment, within the gage boundaries, when the maximum stress occurs at break.

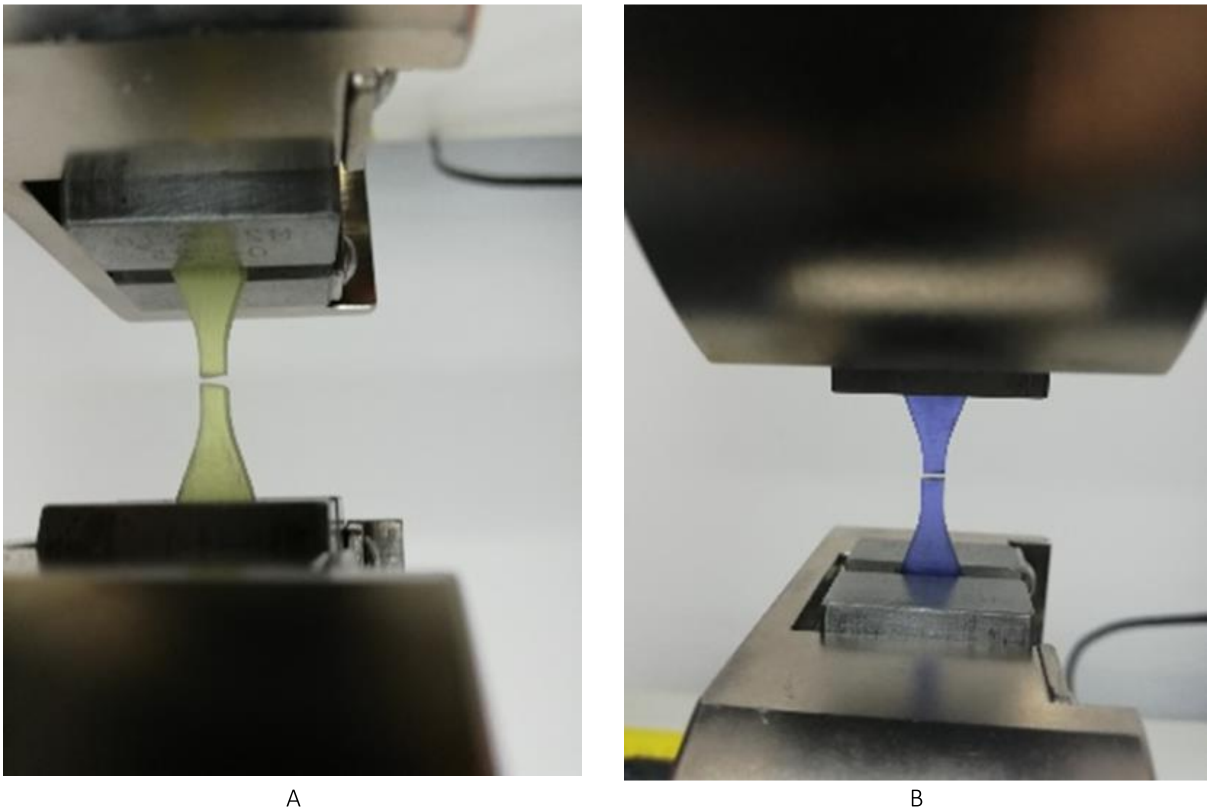
A B

Figure 1. Standard tensile test ASTM D638-14: A - SLA printed specimen, B - DLP printed specimen

The data were analyzed using SPSSv17 software for statistics. For the interpretation of the numerical variables registered, descriptive statistics were performed. Statistical analysis was performed using one-way analysis of variance (ANOVA) and t-test. The results were considered significant at $p < 0.05$.

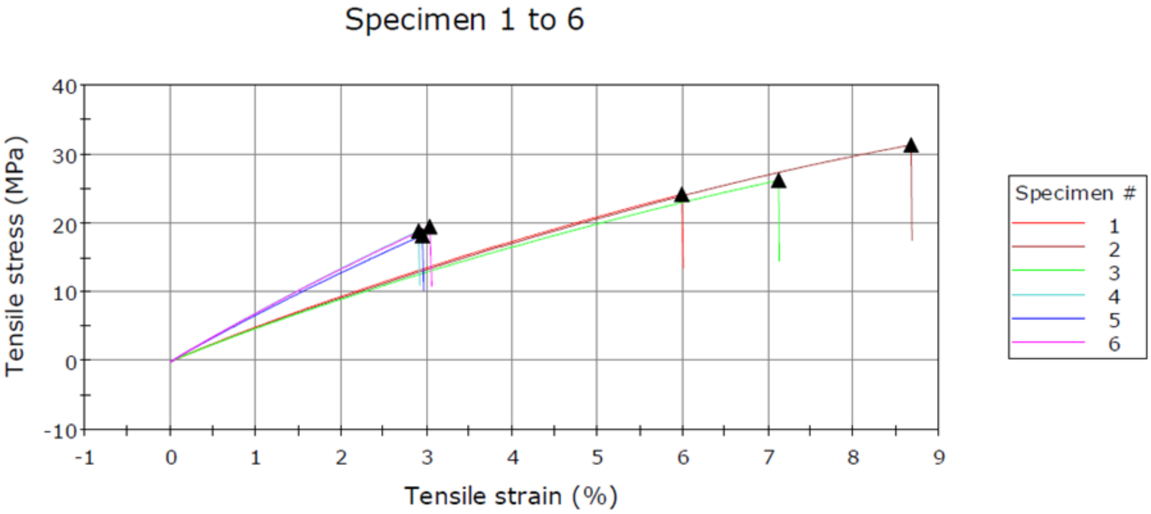

Figure 2. Stress-strain curves of the tensile test: SLA unpolished specimen

Maximum load, tensile stress at maximum load and tensile strain at maximum load were measured for DLP and SLA 3D printed polished and unpolished guides. All data obtained after the evaluation the specimens are represented in table 1.

Table 1. Mean and standard deviations of the measured parameters for the specimens during the tensile test. p value of the ANOVA test

Tensile property	SLA Polished Mean± SD	SLA Unpolished Mean± SD	DLP Polished Mean± SD	DLP Unpolished Mean± SD	*p* Value ^{c}
Maximum Load (N)	239.51 55.89	428.34 43.54	331.00 30.53	456.83 106.02	**0.003372**
Tensile stress at Maximum Load (MPa)	23.03 5.12	51.08 4.66	32.70 2.97	43.69 10.20	**0.02**
Tensile strain at Maximum Load (%)	**5.11** **2.50**	**8.53** **1.36**	**9.15** **3.35**	**12.45** **1.98**	**0.36**

The values for the maximum load (tensile strength) of the tested specimens were significantly different when all the four groups were compared (p=0.003372). The tensile stress at maximum load was also statistically different. Regarding the tensile stress, the same decrease was observed in this parameter for the SLA and DLP polished printed specimens, compared to the unpolished ones. The maximum load (tensile strength) of the polished specimens was decresed, both for the SLA and DLP printed specimens, however there was no statistical significance present.

Table 2. p values of the t test: is-insignificant, s- significant

	Polished-Unpolished		SLA-DLP	
	SLA (p)	DLP (p)	Polished (p)	Unpolished (p)
Maximum Load (N)	0.08^{is}	0.21^{is}	0.2^{is}	0.44 ^{is}
Tensile stress at Maximum Load (MPa)	0.03^{s}	0.01^{s}	0.25 ^{is}	0.15 ^{is}
Tensile strain at Maximum Load (%)	0.43 ^{is}	0.07 ^{is}	0.2 ^{is}	0.3 ^{is}

Discussions

The aim of this present study is to measure the tensile properties of the materials that 3D printed surgical guides are made of, for orthodontic mini-implant positioning. Regarding the printing methods, SLA and DLP were considered. Both SLA and DLP printing methods work by exposing a resin in liquid form to a light source, UV (ultraviolet) laser beam (for SLA) and stationary UV light (for DLP) [11,12-22, 25]. Evaluation of the tensile properties of a certain material is recommended, especially when in vitro studies of their clinical behaviour are limited [27-30]. According to Chantarapanich, additively printed materials have mechanical properties that can be affected by both the unprinted material properties and the manufacturing method. The tensile strenght of epoxy resin materials increased after a 24 days cycle of ageing because the material has become stiffer but more brittle [30,31]. The same author studied the influence of post-processing treatment of the epoxy materials on their mechanical properties. His study concluded that increasing UV exposure time, increased the strength of the samples [30].

Polishing is recommended after the post processing sequence of the printed guides [31-35]. Our study shows a decreased tensile strenght for both the SLA and DLP printed specimens after polishing, being in agreement with the principles cited in some recent articles [36, 37]. Our study is also in accordance with the findings of Kazemi and Rahimi [38]. They studied the influence exerted by the presence of the supports on the tensile strength of the samples printed by stereolitography. Their study demonstrated that the tensile strenght is influenced by the increasing roughness of the external surface of the specimens. In the meantime, it is well known that the strength of the appliance with symmetrically support was lower than in the same appliance, but unsymmetrically supported [39].

When comparing the stereolitography printed specimen with the digital light processing-printed, neither the maximum tensile load and tensile stress were not significantly different (not for the polished and also not for the unpolished ones). There are several studies that investigated the fundamental tensile strenght and elasticity modulus of the elements printed by SLA technology. [27,40,41]. The results indicated that there are differences between the tensile modulus of 3D prints and their mass materials. Regarding specimens with edge build orientation the tensile properties are slightly different compared to the specimens with flat orientation [42, 43, 44, 45].

When it comes to the interpretation of the measurement results of our study concerning the usual prototypes, the standard samples underlined the mechanical effects on the material's behaviour during polishing procedure.

The main disadvantage of the present research is represented by the in vitro design. Observing and testing how the surgical splints clinically behave could help in obtaining more accurate data. Amplfying the number of the samples and widening the testing methods to include flexurale and bending properties would also introduce significant data for further studies.

Conclusions

The conclusions of our study are as follows:

1. When comparing the polished and unpolished specimens, for both the SLA and DLP printed materials, there were differences between maximum load and tensile stress at maximum load.
2. Polishing reduces the tensile strenght of the specimens, however the values were not statistically significant.

Conflict of interest: None to declare.

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