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Polishability and wear resistance of splint material for oral appliances produced with conventional, subtractive, and additive manufacturing

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ABSTRACT

Occlusal splints to treat bruxism are commonly made from polymethylmethacrylate (PMMA) in a manual workflow (powder-liquid technique). Today digitalization allows a machine-based manufacturing in subtractive (milling) and additive (printing) means using industrial-made PMMA or comparable resins. An in-vitro study should assess the surface finish and screen the wear resistance of conventional and industrial materials. Therefore, a total of 30 specimens made from conventionally PMMA (group C; powder-liquid, Palapress), polycarbonate ingots (group S; innoBlanc splint plus), and light-curing resin (group A; VarseoWax splint) were polished to examine the surface roughness (Ra) by profilometry and further analyzed by SEM. The specimens were loaded with a steatite ball moving 5000 times along 1 cm with 5 N of surface pressure under constant wetting (artificial saliva). The total height of profile (Pt) was calculated by further profilometry of the specimens. All specimen showed initially comparable Ra values ranging between 0.06 and 0.05 µm (SD = 0.01) after polishing. SEM investigations revealed no visual cues for scratches or irregularities in any group. After abrasion test, the comparison of the wear depths, revealed mean Pt values of 111.4 µm (SD = 18.5) in C, 85.7 µm (SD = 21.5) in S, and 99.1 µm (SD = 21.5) in A, whereas the mean of S was statistically different from C ($p = 0.025$). No signs of abrasion were found on the steatite balls. All materials showed comparable polished surfaces and a similar scale of wear. It remains questionable if the detected statistical differences are of clinical relevance, but indicates the need for tests of novel materials, especially in additive manufacturing.

1. Introduction

The rise of digitalization enables the fabrication of prostheses, epitheses, and oral appliances by computer assisted manufacturing (CAD/CAM) addressing subtractive and additive approaches (Abduo et al., 2014; Fasbinder, 2013). These two approaches of manufacturing include either milling and grinding for subtractive manufacturing, or stereolithography, selective laser sintering, photo-curing print, fused deposition modelling for additive manufacturing. This implies a demand for adaptations or development of materials which follow the necessities of the particular technology and the specific indication (Stansbury and Idacavage, 2016).

Occlusal appliances are mostly indicated for the treatment of temporomandibular disorders (TMD) (List and Axelsson, 2010). Such occlusal splints are conventionally fabricated in an analog workflow from a refractory cast utilizing vacuum thermomolding of polyethylene (PVAc-PE) individualized occlusally with polymethylmethacrylate (PMMA). Nowadays these appliances can be fabricated by the use of a (complete) digital workflow, applying subtractive as well as additive CAD/CAM methods (Dedem and Turp, 2016; Lauren and McIntyre, 2008; Salmi et al., 2013).

In the first line, such innovations touch upon practical feasibility as well as fit, biocompatibility, and dimensional stability compared towards the conventional gold standard (Dedem and Turp, 2016; Lauren and McIntyre, 2008; Salmi et al., 2013). However, novel or adapted materials for splints made from digital workflow must also show a comparable surface finish and wear behavior (Xu et al., 2017). Both properties are of clinical relevance: Inferior surfaces (e.g. micro porosities as a possible consequence of additive layering/sintering) may lead to bacterial adhesion, fungal infestation or facilitate biofilm formation as well as discoloration (Wu et al., 2013). Inferior wear resistance may lead to a reduced stabilization of occlusal contacts by early formation of wear facets or even a reduced longevity of the appliance (Casey et al., 2003).

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Table 1
Investigated materials, manufacturers, and characterization.

Group (abbreviation)	Material brand name, LOT#	Manufacturer, City, Country	Material composition acc. to manufacturer
conventional (C)	Palapress, R010031/R010028	Heraeus Kulzer, Hanau, Germany	*monomer liquid: methylmethacrylate (> 90%); tetramethylene dimethacrylate (0–5%);* 2-(2H-Benzotriazol-2-yl)-4-methylphenol (< 1%), N,N-dimethyl-p-toluidin (< 1%) *polymer powder:* polymethylmethacrylate (> 95%); Bis(p-Chlorbenzoyl)peroxid (0–5%)
subtractive (S)	innoBlanc splint plus, 1160010515	innoBlanc GmbH, Engelsbrand, Germany	polycarbonate (100%)
additive (A)	VarseoWax Splint, 506534 × 00615	BEGO Comp., Bremen, Germany	Poly(oxy-1,2-ethandiyl), alpha, alpha´-[(1-methylethyliden)di-4 1-phenylen]bis[omega-[(2-methyl-1-oxo-2-propenyl)oxy]- (50–70%); Methacrylacid monoester with propan-1,2-diol (5–10%); 2-Hydroxyethylmethacrylate (5–10%); Diphenyl(2,4,6-trimethylbenzoyl)phosphine oxide (2,5–10%)

Thus, an in-vitro study should compare the surface finish and screen the wear behavior of three commercially available materials for manual, subtractive and additive manufacturing, respectively.

2. Materials and methods

2.1. Preparation of specimens

Ten cylindric specimens (diameter 19.5 mm, height = 3.7 mm) were prepared from each material and accordingly assigned to a group "conventional" (C), "subtractive" (S), and "additive" (A) (see Table 1).

The specimens of the "subtractive group" were designed with OpenSCAD Version 2 (open source software) and milled with CAD/CAM system (Teamziereis, Engelsbrand, Germany).

The specimens of the "conventional group" were fabricated using a silicon mold (Elite Double 32 Fast, Zhermack, Marl am Dümmer, Germany). The monomer and polymer of the PMMA was mixed according to manufactures instructions. For polymerization, the filled molds were set into a pressure curing unit covered by water, applying 2 bar of pressure for 8 min. The specimens of the "additive group" were printed with digital light processing (DLP) using the Varseo 3D-Printer (BEGO, Bremen, Germany) and addressing the above-mentioned CAD dataset. Manufacturing direction followed the circular arc of the cylindrical specimen (see Fig. 1). In consequence, the top surface contained a cross section of all processed layers (50 µm thickness). These specimens were light cured to final hardness with 4 cycles of 5 min, utilizing a curing unit (Heraflash/HiLite, Heraeus Kulzer, Hanau, Germany). The specimens of all groups were finalized with a stepwise polishing using Metaserv Motopol 12 (Buehler, Coventry, Great Britain): First, the top surfaces were polished with a disc (grain 2500) which rotated 150 rpm under continuous wetting for 1 min. Thereafter the disc was changed to grain 4000 and the specimen rotated 90° clockwise for another cycle of 1 min. Final polishing was applied with a buffing wheel at 3000 rpm using universal polishing paste (Ivoclar-Vivadent, Schaan, Principality of Lichtenstein).

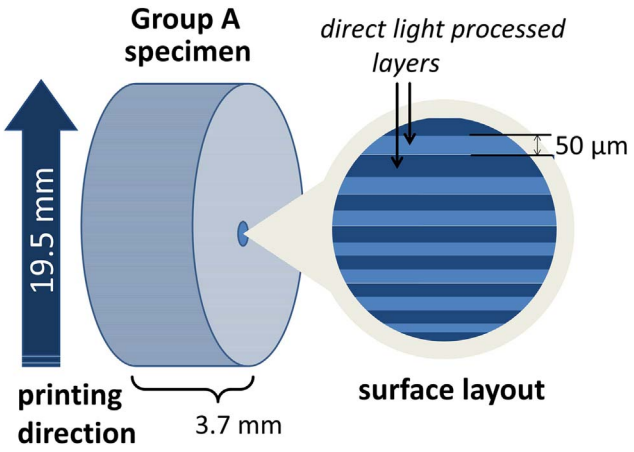

Fig. 1. Manufacturing approach of printed specimens in group A. The specimens were printed along the circle arc resulting in a test surface containing all layers. This is comparable to splint fabrication with AM.

Finally, the specimens were shortly cleaned with a steam jet before washing in an ultrasonic bath (Sonorex RKS2H, Bandelin, Berlin, Germany) with Omnisept IMP (Omnident, Rodgau, Germany) at room temperature for 10 min.

2.2. Quantification of surface roughness after polishing

The surface roughness of the polished specimens was measured with a tactile method (Perthometer S6P, Mahr GmbH, Göttingen, Germany) evaluating 121 single profiles in a quadrat of 9 mm^2 located in the center the of the specimen. Gaussian filter was set to 0.6 mm (1/5 of sampling length) and the surface roughness (Ra values) were calculated as an average of the 121 derived Ra values by use of MountainsMap Software (Version 7.2, DigitalSurf, Besancon, France) according to ISO 4287 (ISO, 2009). Additionally, one randomly selected specimen out of each group was further analyzed via SEM in 170x, 2500x and 5000x magnification to identify surface alterations, porosities or exposed fillers.

2.3. The attrition simulation and device

The specimens were fixed in the abrasion testing device (Abrex, Innowep, Würzburg, Germany) and stressed with 5000 cycles. The ball shaped indenter made from steatite (magnesium silicate,

CeramTec, Plochingen, Germany) and 6 mm in diameter functioned as antagonist which applied 5 N during a movement of 1 cm (Fig. 1). There was no alignment of the abrasion trace towards the layer direction in group A (random orientation). Every 50 cycles artificial saliva (pH = 7, 37 °C, see Table 2) wetted the specimen (Gal et al., 2001; Kontos et al., 2013). A new indenter was used for each specimen.

Table 2
Composition of the artificial saliva according to (Hara et al., 2008).

component	amount (g/l)	manufacturer	LOT-number
Mucin Type III	2.2	Sigma-Aldrich Corp., St. Louis, MO, USA	104H7176
Na_2HPO_4*$2H_2O$	0.961	Merck AG, Darmstadt, Germany	409 K3554280
$CaCl_2$*$2H_2O$	0.213	Merck AG	TA572483 642