Resin adjustment of three-dimensional printed thermoset occlusal splints: bonding properties – Short communication

Leila Perea-Lowery[1], Pekka K. Vallittu[2]

[1] DDS, Specialist in Prosthetic Dentistry, PhD, MBA
Assistant Professor, Department of Biomaterials Science and Turku Clinical Biomaterials Centre – TCBC
Institute of Dentistry
University of Turku, Finland
Address: Itäinen Pitkäkatu 4 B (2nd floor), Turku, FI-20520, Finland.

[2] DDS, PhD, Specialist in Prosthetic Dentistry
Professor, Department of Biomaterials Science and Director of Turku Clinical Biomaterials Centre – TCBC
Institute of Dentistry
University of Turku and City of Turku Welfare Division, Oral Health Care, Finland
Address: Lemminkäisenkatu 2, Turku, FI-20520, Finland.

Corresponding author:
Leila Perea-Lowery
Phone: +358 404 434 431
Fax: +358 2 333 83 56
Email: leila.perea@utu.fi

Abstract

Objectives: To evaluate the interfacial adhesion of an autopolymerizing acrylic resin to 3D printed thermoset occlusal splints compared to thermoplastic occlusal splints.

Materials and Methods: Cylinders made of an autopolymerizing acrylic resin were adhered to 3D printed thermoset and also to thermoplastic plates. A different surface treatment and three storage conditions were used: dry, 7 days water-storage and 14 days water-storage. Bond strength test (so-called shear-bond strength test) was afterward performed.

Results: ANOVA (R^2=0.764) revealed significant differences in bond strength according to material (p <0.001) and storage (p <0.001) but not for surface treatment (p =0.202).

Conclusions: The bond strength of autopolymerizing acrylic resin to 3D printed thermoset plates is higher when compared to thermoplastic plates. Bonding between acrylic resin and 3D printed splints was high enough for clinical applications.

Clinical relevance: The bond strength values obtained in this study with 3D printed plates were at the level of generally accepted adequate bonding values for prosthetic materials.

Keywords: 3D-printed splint, CAD/CAM, thermoplastic foil, thermoset occlusal splint, bond strength, PMMA

1. Introduction

A significant technological development in digital dentistry in the field of three-dimensional (3D) printing has provided new treatment alternatives and a variety of therapeutic approaches [1]. Some of those approaches are focused on the achievement of a correct occlusal relationship, which is the case of orthognatic surgery [2] and orthodontic treatments [3], in addition to those used for treating temporomandibular disorders that aim also at balancing the masticatory system [4]. In the case of orthognatic surgery, the use of software to plan 3D surgeries and incorporate data from computed tomographic or cone-beam CT scans has given clinicians helpful tools to assist in diagnosis, treatment planning and postoperative control [5][6]. However, a precise method is mandatory to transfer virtual 3D orthognatic planning to surgery and to achieve maxillofacial symmetry in all relations [7][8][9]. The 3D virtual planning of orthognatic surgery includes the production of a virtual skull and dentition and the manufacturing of digital and subsequent physical splints [10], which are expected to lead to more accurate planning and to provide superior results.

In the case of orthodontic treatments, the clear alignment therapy has traditionally involved the use of clear thermoformed plastic aligners for mild to moderate orthodontic tooth movements [11]. However, the need for aligners designed for more complex tooth movements and with improved control of tooth position in all planes of space has paved the way for the incorporation of computerized 3D interactive treatment planning and appliance design [12][13]. These 3D manufactured appliances in conjunction with computerized 3D model manipulation that mimic the different stages of the orthodontic treatment provides increased predictability of treatment outcomes [13].

Occlusal splint therapy is commonly used for treating temporomandibular disorders, as well as for occlusal stabilization and to prevent dental wear [14][15]. Poly(methyl methacrylate) (PMMA) is frequently used for adjusting occlusal splints due to its properties that bring advantages to the final occlusal device. These advantages include low shrinkage, ease to use and resistance to abrasion [16][17]. Thermoformable foils have been used in combination with PMMA-containing self-cured resins to shape occlusal splints. This process can be time consuming, in addition to the unpleasant taste and the potential thermal irritation that can take place in the patient's mouth while adjusting the splint intraorally [18].

An efficient and cost-effective alternative for manufacturing occlusal devices for the treatment of temporomandibular disorders might be the use of 3D printing equipment to obtain detailed 3D occlusal splints. A direct production of a digital and subsequent physical splint leads to more precise planning of the treatment sequence, time saving and more predictable results. However, some studies have evaluated the accuracy of final digital splints compared to conventional manual splints, reporting maximum error of around 0.9-1mm [19][20][21].

Inaccurate 3D printed splints might be a result of deficiencies in the scanning process done intraorally or due to the laboratory scanning of the cast. For instance, it was found that scan pastern has a significant effect on trueness and precision and that certain scan patterns may affect the fit of appliances made with digital models [22]. The scanning device also plays an important role and it should be of a high trueness since this indicates that the scanner delivers a result that is close or equal to the dimensions of the object being scanned [23]. Some authors [24] reported that the precision of intraoral scanners decreased with an increasing distance between the scanbodies, which can also be translated into inaccurate end results. It is also known from the clinical practice that manipulation of mandible to the centric relation, which is the reference position for the mandible, can be challenging and the cause of inaccuracy in bite registration.

A variety of 3D printing methods and devices are currently available, which in some cases might generate differences in accuracy with potential alterations in the end product. The current printing systems may be categorized based on the printing methods as a) extrusion printing, where a material is handed out from a nozzle with computer controlled movement of a 3-axis stage [25][26]; b) inkjet printing, where droplets of an ink are allocated using 3-axis stages [27]; c) laser melting and sintering, where the high temperature of the laser is utilized to sinter specific regions in a powder bed while a platform moves up or down and the material is coupled layer-by-layer generating a 3D structure [28]; and d) lithography printing, which uses photopolymers that are kept in a Z-axis controlled vat, resulting in a 3D printed structure due to the direct exposition of the polymer to light [29].

Nowadays is common to perform computer-assisted craniomaxillofacial surgeries due to the higher possibilities for preoperative planning, surgical transfer and a better control of the process. For orthognatic surgery is it common to create a preoperative model surgery to then manufacture surgical splints for the transfer of the surgical planning [30][31]. There are some reports on the specifications of splints that can be produced by computer-assisted technologies [19], as well as the workflow for the manufacturing process when using 3D printing devices [32].

In the event that a 3D printed occlusal splint is lacking in height to meet the treatment goals, two alternatives could be used to achieve the expected outcomes. First, scanning, planning and printing a new 3D splint, which can be costly, or second, adding small amounts of self-curing resins where the 3D printed occlusal device is insufficient. To the authors' knowledge, no published reports exist on the bond strength of self-cured resins to 3D printed occlusal splints. Therefore, the purpose of this study was to evaluate the bond strength of an autopolymerizing acrylic resin to 3D printed occlusal splints compared to thermoplastic foils dependent on artificial aging.

2. Materials and Methods

2.1 3D CAD design and 3D printing

An open source CAD software (FreeCAD v. 0.15) was used for designing the samples prior to 3D printing. Test rectangular plates were designed with set dimensions of 20mm in length, 10mm in width and 2mm in thickness. Samples were afterwards saved as .STL files and exported into 3D printing software (PreForm Software 2.10.3). A commercially available biocompatible transparent blue Class IIa material developed for digital manufacturing of splints (NextDent Ortho Rigid, Vertex Dental, Netherlands) was used for the 3D printing samples. We set the printing layer thickness to 100μm and used the resin parameter “white” from the ones available in the PreForm Software.

2.2 Design of thermoplastic samples

Transparent thermoformable foils (Erkodur, Erkoden GmbH)) were cut using an electric saw to obtain rectangular plates of 20mm in length, 10mm in width and 1mm in thickness.

2.3 Sample preparation and testing mechanical properties

3D and thermoplasctic samples were divided into two categories. Each category was subdivided into two groups based on the surface treatment that they would receive: a) no treatment and b) monomer liquid of MMA applied during 3 minutes [33]. Next, cylinders made of an autopolymerizing polymethyl(methacrylate) acrylic resin (Palapress; Heraeus Kulzer GmbH) were attached to the plates. Subsequently, each group was subdivided into three subgroups (n=8) based on the storage conditions: 24 hours under ambient laboratory conditions (23 ± 1^{o}C), 7 days water-storage and 14 days water-storage. Bond strength tests (so-called shear-bond strength test) were afterward performed using a universal testing machine (Model LR 30K plus; Lloyd Instruments), and data were recorded with data analysis software (Nexygen; Lloyd Instruments). The specimens were loaded at the interface of the substrate and the autopolymerizing polymethyl(methacrylate) acrylic resin at a 1.0 mm/min crosshead speed until fracture occurred. Bond strengths were calculated in MPa.

2.3 Statistical analyses

The differences in the bond strength according to material, surface treatment and storage were evaluated for statistical significance using a multivariate ANOVA. All analyses were conducted using IBM® SPSS® 19.0 for Windows (Microsoft).

3. Results

ANOVA (R^2=0.784) revealed significant differences in the bond strength according to material (p <0.001) and storage (p <0.001) but not for surface treatment (p =0.202). The 3D printed plates showed significantly higher bond strength values than the thermoplastics. A graphic representation of the results obtained is presented in Figure 1. Figure 2 shows the adhesive-cohesive failure type seen in all thermoplastic plates. The 3D printed specimens showed a cohesive failure (Figure 3).

4. Discussion

Computer-aided design and computer-aided manufacturing (CAD/CAM) has developed rapidly and has spread from industry to medicine [34][35][36][37], enabling the implementation of efficient treatment protocols in a variety of applications. Some of those are for instance the use of 3D scaffolds that operate as templates to hold cells and support tissue ingrowth [38]. In dentistry it has a variety of applications and in the case of occlusal splints, 3D printed appliances are being used as an alternative to address the weaknesses of laboratory-based methods, as well as to provide cost-effective and time-efficient devices.

Recent developments of 3D printers offer new possibilities for the fabrication of more precise devices based on 3D digital models. In order to use 3D printed dental models with a clinical applicability, accuracy of the printed outcome must be guaranteed. Currently, the accuracy of 3D printed devices shows some deficiencies when compared with those produced via computer numeric control processing as a reductive manufacturing process. As a result, in some cases 3D printed products require post processing to secure smooth surfaces [39], which might affect the final fit of the 3D printed devices.

The process of designing and printing a 3D device vary due to multiple parameters that differ from printer to printer, which can interfere with the quality of the printed parts leaning on the material used. In this study, stereolithography (SLA) was the printing method used to manufacture the 3D printed samples. In this method a galvano mirror scanner directs the laser light to raster the surface of a vat of monomers, uncovering voxels to create 3D polymer structures [40].

Some authors have reported deficiencies on the accuracy of 3D printed materials depending on the orientation of the printed part and the area where accuracy was measured [41]. Aspects such as length and thickness of 3D printed appliances showed percentage error in a range of 2% to 20% depending on the angulation used from printing (from 0˚ to 90˚) [41]. They also found a percent error variation greater than 41.5% in sample thickness relying upon which resin color setting was selected for the printing process [41]. Other authors reported differences in accuracy of 30µm of the CAD design when printing provisional crowns using a 3D printer from the same manufacturer as the dental material itself [42]. It has also been found that the mechanical performance of a 3D printed material varies depending on the mechanism by which individual layers in the 3D printed device interact. Printed materials that are anisotropic can be altered by the printing orientation, and also the adhesion between layers is weaker than the adhesion within the same layer [40].

Considering the aspects mentioned above, in the event that a 3D printed occlusal splint is slightly inaccurate, the addition of small amounts of autopolymerizing resin might provide a solution to meet its purpose. The results of this study show that the bond strength between 3D printed thermoset plates and an autopolymerizing polymethyl(methacrylate) acrylic resin was considerably and significantly higher than the bond strength of vacuum mouldable thermoplastic plates and the same acrylic resin. The bond strength values to 3D printed material were at the level of generally accepted adequate bonding values for prosthetic materials. Good bonding properties were expected to be based on free radical polymerization. Low bonding values with thermoplastic plates suggests that dissolving parameters of MMA and thermoplastic polymers do not match and allow interpenetrating polymer network bonding to take place.

5. Conclusions

The bond strength of autopolymerizing acrylic resin to 3D printed thermoset plates is higher when compared to thermoplastic plates and it is adequate for adjusting the splint by adding self cure acrylic resin.

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Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.

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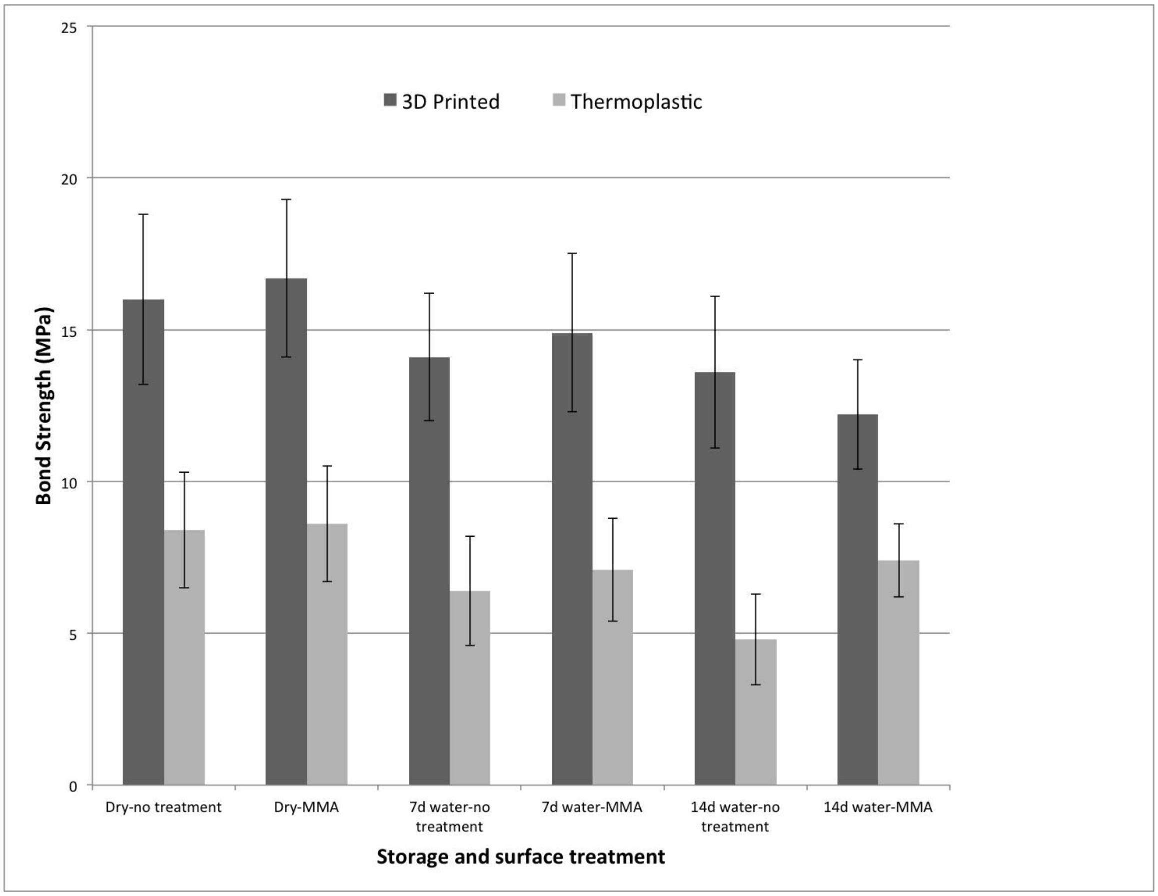

Figure 1. Schematic representation of the bond strength according to storage and surface treatment.

Figure 2. Scanning electron microscopy (SEM) image of the partially adhesive type failure observed in the vacuum mouldable thermoplastic plates after SBS test. Key: arrows show the areas with adhesive failure.

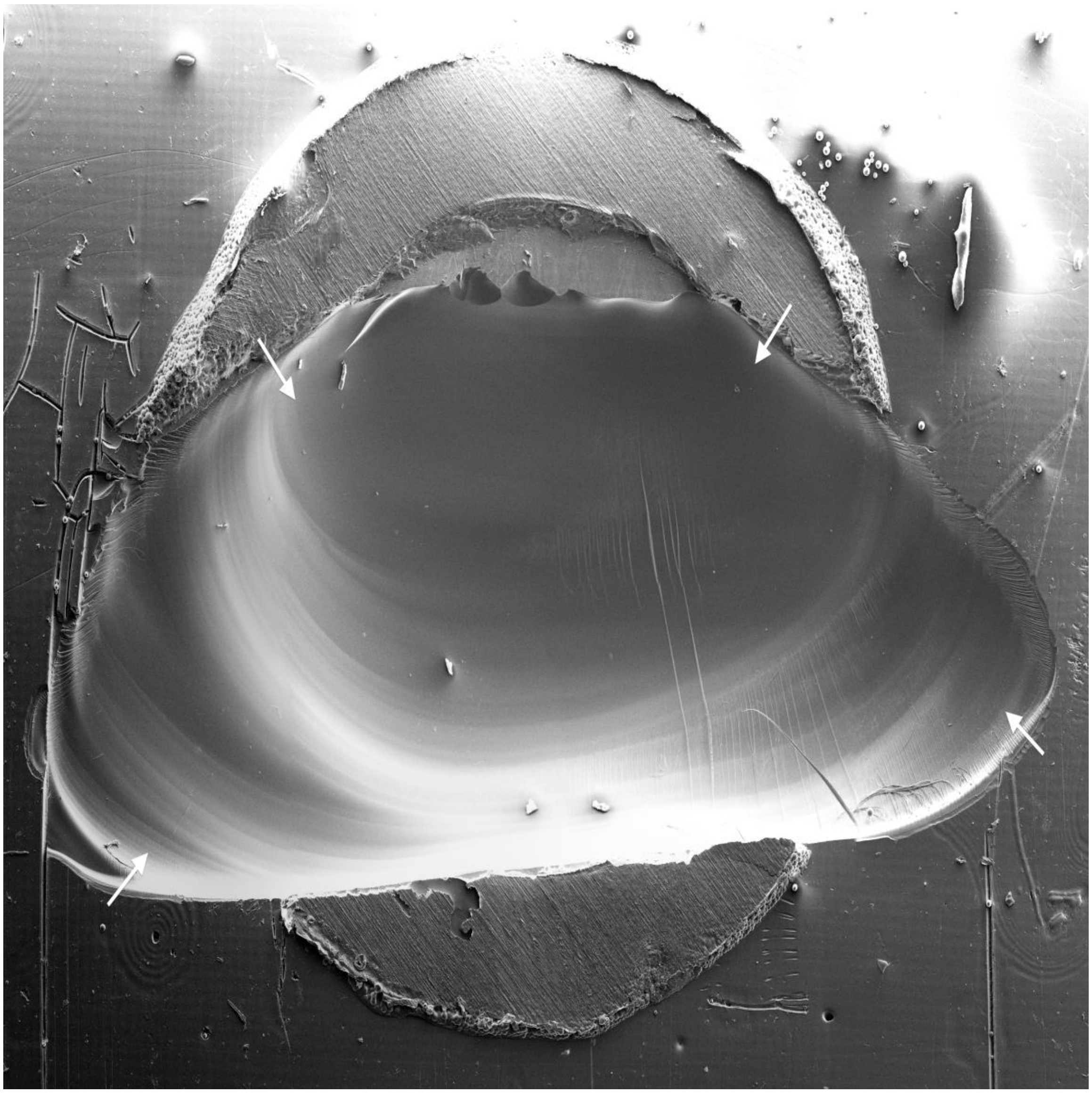

Figure 3. Scanning electron microscopy (SEM) image of the cohesive type of failure observed in the 3D-printed splints after SBS test. Key: arrows show the cohesive failure area.