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EVALUATION OF FRACTURE RESISTANCE OF 3D-PRINTED IMPLANT RETAINED OVERDENTURE WITH TWO DIFFERENT BUILD ANGLES. (AN IN-VITRO STUDY)

Mona Awajah[*], Nadia Abbas[**] *and* Reham Osman[***]

ABSTRACT

Aim: The aim of this in-vitro study was to evaluate the influence of different build-angles on the fracture resistance of implant-retained 3D- printed overdentures fabricated with100^0 and a 150^0 build-angles.

Methodology: A ready-made resin full edentulous mandibular model was used with two implant inserted in interforaminal region. Optical scanning for the model with implant was done in order to construct standard tessellation language (STL) file and design an implant overdenture. Then, 3D printing was done using digital light processing (DLP) printer with two different build angle(100^0 and 150^0).The fracture resistance was measured; by applying vertical forces at different points (one at anterior region and two at first molar region bilaterally) in the first group with overdentures printed with a 100^0 build angle while in the second group the overdentures which fabricated with a 150^0 build angle using Universal testing machine after being subjected to cycling load for 240000 cycle in chewing simulator machine.

Results: S1 and S2 presented maximum load at failure of 1409 N and 846 N, respectively, and S3 and S4 presented maximum load at failure of 2164 N and 2206 N, respectively. There was no statistically significant difference between fracture resistance values of 100º (S1 and S2) and 150º (S3 and S4) build angles.

Conclusion: Both build-angles proved to have acceptable mechanical properties. Although there was no statistical significance difference between the two groups, the results showed higher values in 150^0 build angle compared to 100^0 build angle group.

KEY WORDS: 3D- printed denture, Build Angle, Dental implant, Fracture Resistance, Implant Overdenture.

* Oral and Maxillofacial Departement, Faculty of Dentistry, Cairo University, Giza, Egypt
** Professor, Prosthodontic Faculty of Dentistry, Cairo University
*** Professor, Proshthodontics Departement, Faculty of Dentistry, Cairo University, Cairo, Egypt

INTRODUCTION

With the arising problems of complete dentures' retention, especially mandibular ones in cases of flat ridges, dental implants can serve as a promising solution for such problems. According to the nature of support, the number of implants and type of implants materials employed to support overdenture, implants can achieve the patient's satisfaction during mastication and speech.

Nowadays, with all of the recent breakthroughs in digital dentistry, it is easy to print dental prosthesis directly with acceptable aesthetics, accuracy, and physical characteristics while also minimizing patient visits. Depending on the material of choice, polymers, metals or ceramics, various printing methods are available. The most common 3D-printing techniques applied in field of prosthodontics include stereolithography(SLA), digital light processing (DLP), fused metal deposition(FMD), and selective laser sintering (SLS) [1, 2].

Different fabrication parameters in the 3D-printing process, affect the physical and mechanical properties of printed object including but not limited to strength, color stability and fracture toughness. The direction of support structure also called the build orientation is one of such manufacturing parameters that influence the overall quality and mechanical properties of printed parts.

However, empirical research on the effect of construction angle on the mechanical qualities of printed complete dentures and overdentures is currently missing. Thus, this in-vitro study evaluated the effect of build-angle at 100^0 and a 150^0 build angle on fracture resistance of 3D-printed implant retained overdentures.

MATERIALS AND METHODS

A ready-made epoxy resin model (Ready-made epoxy resin model SEL models, Barcelona Spain) of completely edentulous mandibular jaw was selected for the purpose of this study. Two epoxy resin models with four printed overdenture; two for each angle (Figure 1A).

For the construction of surgical template, A Complete denture was constructed over the epoxy resin model in a conventional technique:

- A trial denture base was constructed and adjusted on the epoxy resin model till it was completely fitted and accurately placed on the model.
- The cross-linked acrylic teeth of suitable size were set upon the wax (Cosmo MEA, Dentsply-USA). The anterior teeth were placed slightly anterior to the ridge while the premolar was positioned vertical on the ridge and the molar teeth were placed slightly lingual to the crest of the ridge. The occlusal plane was set below the height of the retromolar pad. No modification or grinding of the artificial teeth was performed (Figure 1B).
- The waxed-up denture was processed according to the manufacturer's instructions following the conventional way (Figure 1C).
- Two holes were drilled in position of canine teeth to guide the placement of the two implants (Figure 1D).

Drilling of the implants and Installation of attachment system

After checking the seating of the guide on the model, the guide was used to determine the point of entry of the drill and in turn the site of the implant installation. Drilling was initially performed using drills of diameter size of 2.3 mm (pilot drill), followed by 2.8mm drills and finally 3.4 mm drills for the placement of implants 3.7x10mm in dimension (S-clean tapered dental implant fixtures-direct legacy 4, USA). Then the paralleling pin was inserted in first osteotomy site to ensure parallelism for second implant. The drilling site was then cleaned and the fixture was installed carefully and tightened perfectly using contra angled hand piece and a torque wrench at 30 N force (Figure 1E and 1F).

After placement of the implants in the interforaminal area, the ball attachment (Implant Direct™ Dentistry InterActive Ball Abutment) were screwed over the implants (Figure 1G).

Computer Aided Design(CAD)/Computer Aided Manufacturing (CAM) procedures

Scanning

In order to design and then fabricate a 3D printed implant retained overdenture, the model was scanned using extraoral optical scanner (DOF Swing Dental Scanner, DOF Inc., Korea). The resultant scans were exported as standard tessellation language (STL) files.

Design of the overdenture

The imported standard tessellation language (STL) file into a designing CAD software (DentalCAD 2.3 Matera, exocad GmbH, Darmstadt, Germany) was used to digitally design the overdenture (Figure 2A).

The designed overdenture file was then exported to printer to 3D-print the overdentures. Two different build angles 100°and 150° were selected to orient support structures during the printing of overdentures on build platform (Figure 2B and 2C).

Printing

Overdentures were printed with a desktop digital light processing (DLP) 3D printer (phrozen shuffle XL DLP printer) using light-polymerizing resin material (denture base Nexdent resin material). (Figure 2D and 2E).

The 3D-printed denture was then removed from the build platform, and placed in a plastic container filled with 90% isopropyl alcohol to rinse off the residual uncured resin. For post-processing polymerization, the 3D-printed dentures were then placed in a dental light-polymerizing unit (Enterra VLC Curing Unit; Dentsply Sirona) for 20 minutes to ensure complete polymerization.

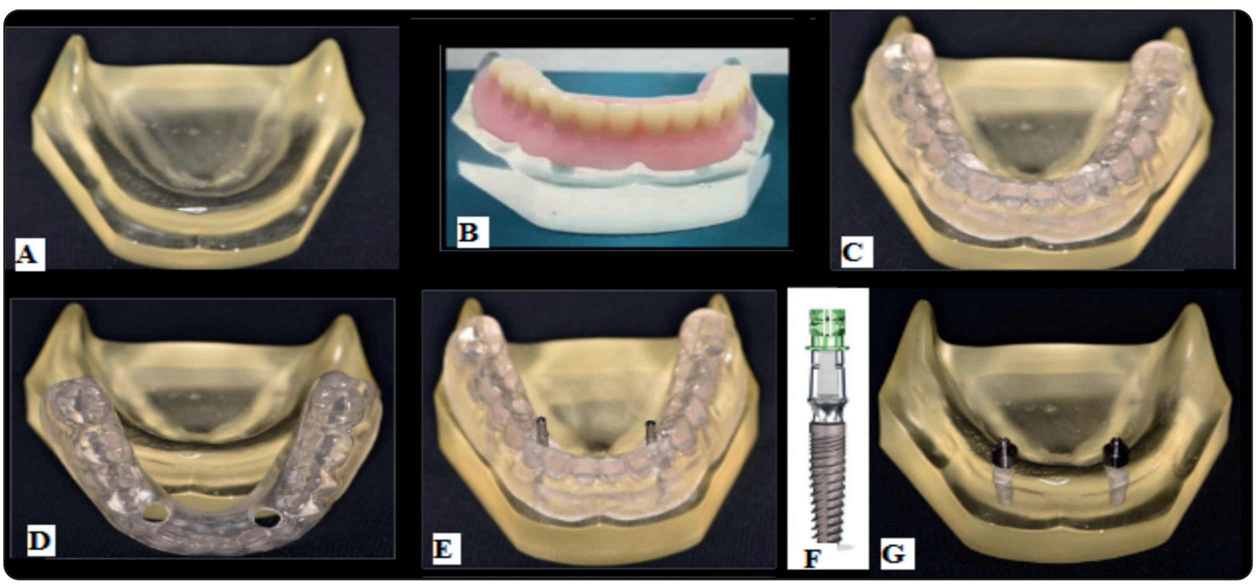

Fig. (1): A: Ready-made epoxy resin model, B: Trial denture base on the model, C: Processed resin denture, D: Holes in the canine area, E: Parallelling pin, F: Dental implant, G: Ball attachment screwed on implants

Afterwards, the supporting structures were removed from the printed dentures with a cutting plier (Cutting tool; Hakko Corp) and finally the dentures were polished with laboratory instruments (Ultra Denture System).

The metal housing was then placed directly over the ball abutments. Block-out rubber sheets were slipped around the ball abutments to block-up undercuts and facilitate the pick-up procedures. The denture base was designed with a recess opposite to the ball attachments to facilitate the pick-up procedure. The denture base was then assured for proper seating as proved by absence of rocking. After that self-cure acrylic resin was mixed according to manufacturer instructions and then placed onto the relived areas of the denture.

The denture was seated over the model cast and held in the place until complete polymerization of the acrylic resin material. Denture base was removed and inspected and the excess relining material was trimmed then the metal housing was picked up with the denture base (Figure 2F).

Then the printed denture bases were ready to be tested in the universal testing machine (Figure 3).

Chewing Simulator and Fracture Test:

Mechanical aging was performed using programmable logic-controlled equipment; the newly developed four stations multimodal ROBOTA chewing simulator operated on servo-motor (ROBOTA chewing simulator, model ACH-09075DC-T, AD-TECH TECNOLOGY CO., LTD., GERMANY) .

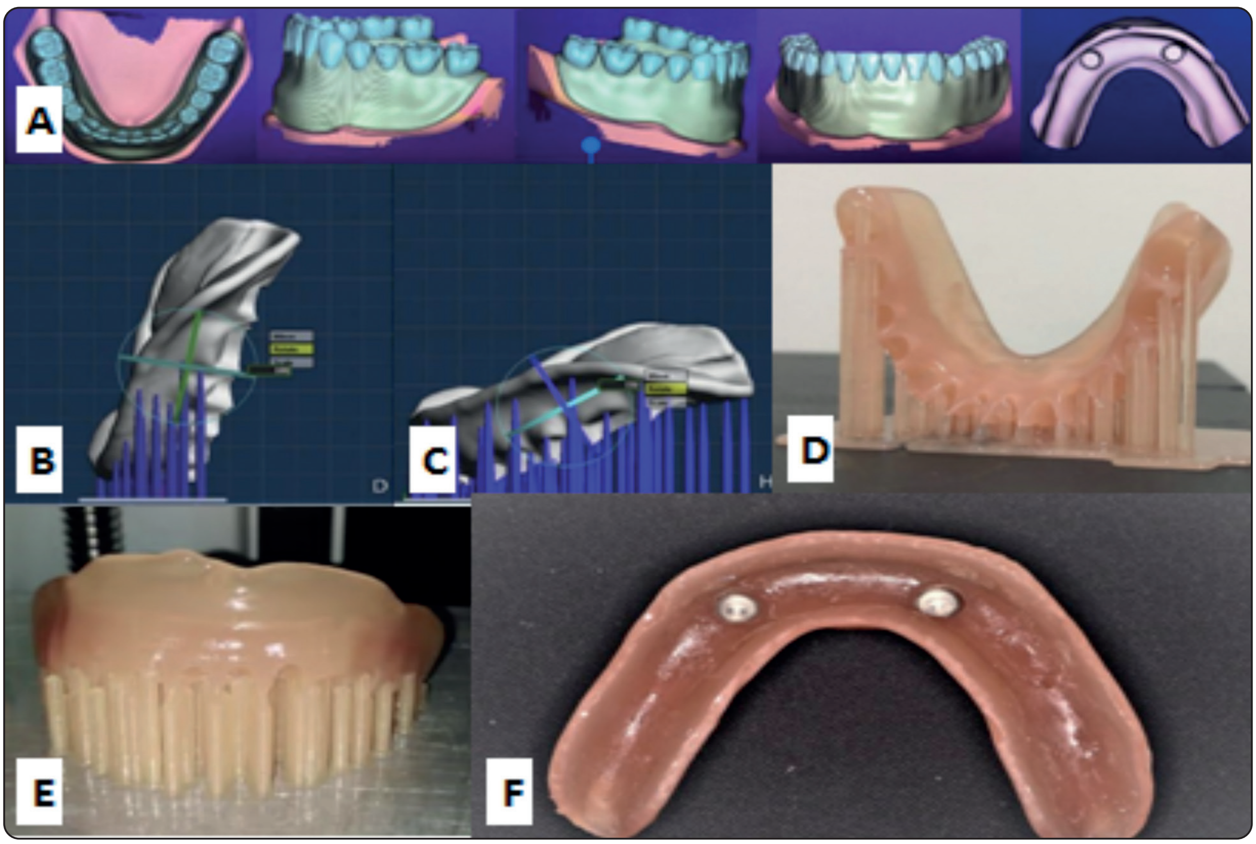

Fig. (2): A: Occlusal, sides, frontal & fitting surface view; B: Build angle 1000; C: Build angle 1500; D: Denture printed with 1000 build angle; E: Denture printed with 1500 build angle; F: Metal housing picked up in the denture base

Fig. (3): Different views of printed denture after curing and polishing

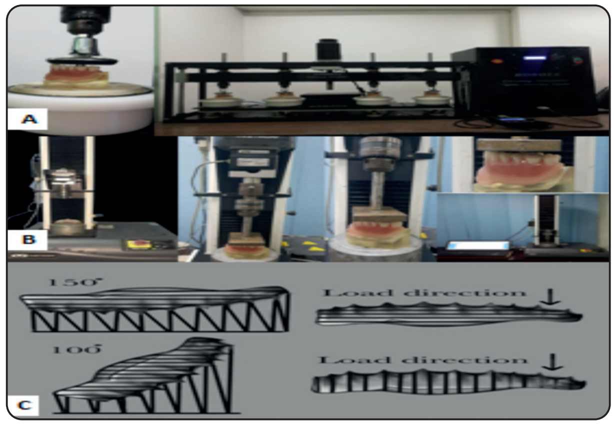

Fig. (4): A: Denture fixed in chewing simulator; B: Load application using universal testing machine and recording of results using machine software; C: Layer orientation during printing process and load application

ROBOTA chewing simulator has four chambers simulating the vertical and horizontal movement simultaneously in thermodynamic condition. Each of the chambers consists of an upper Jackob's chunk as load applicator opposing lower plastic sample holder that can be tightened with screw in which the cast can be fixed to the lower part of simulator (Figure 4A).

A weight of 5 Kg, comparable to 49N of chewing force was exerted. The test was repeated 240000 times to clinically simulate 1 year of intraoral chewing as illustrated in Table 1.

TABLE (1): Chewing simulation test parameter

Vertical movement:3mm	Horizontal movement:1mm
Rising speed:90mm/s	Forward speed:90mm/s
Descending speed:40mm/s	Backward speed:40mm/s
Cycle frequency 1.6Hz	Weight per sample:5kg
Torque:2.4 N.m	

Fracture test was performed using Instron machine. Each cast with its denture was fixed to the lower fixed compartment of Instron machine(model 3345; instron instrument Ltd, USA) and dentures were loaded with a load cell of 5 KN applied on 3-point contact (one at incisors, two at molar area bilaterally) and data were recorded using computer software(Bluehill® lite; Instron instrument) . The samples were statically loaded applying a compressive force using stainless-steel rod ending in a flat plate (40mm*60mm) to ensure 3-point contact. The force applying rod was attached to upper movable compartment of the machine and was moving with a crosshead speed of 5 mm/min. The load required to fracture each sample was recorded in Newton (Figure 4B). Layer orientation of overdenture during printing and load application was illustrated in (Figure 4C).

Statistical analysis:

Data were presented as median, range, mean and standard deviation (SD) values. Non-parametric test was used for comparison between the two build angles. Mann-Whitney U test was used to compare between the two build angles. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.

RESULTS

The fracture load test

Fracture resistance test results revealed that the highest mean value of the fracture load was found in the overdenture printed with 150^0 build angle but

TABLE (2): Descriptive statistics and results of Mann-Whitney U test for comparison between fracture resistances of the two build angles

100º angle				150º angle				*P*-value	*Effect size (d)*
Median	Range	Mean	SD	Median	Range	Mean	SD		
1127.5	846-1409	1127.5	398.1	2185	2164-2206	2185	29.7	0.121	2.449

: Significant at P ≤ 0.05

there was no significant difference between the two groups.

Sample 1 and Sample 2 present overdentures with build angle 100^0 and presented maximum load at failure of 1409N and 846N, respectively, Sample 3 and Sample 4 present overdentures with build angle 150^0 and presented maximum load at failure of 2164 and 2206, respectively.

There was no statistically significant difference between fracture resistance values of 100º and 150º build angles.

The fracture pattern:

The visual assessment of both groups revealed that:

In the overdenture group that was printed with 150^0 build angle the fracture lines were predominant in the anterior and premolar regions (multiple fracture line pattern) (Figure 5A).

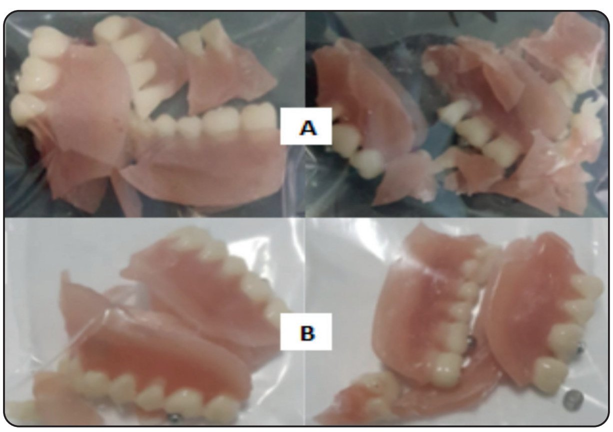

Fig. (5): A: Multiple line fracture of overdenture printed with 1500 build B: Anterior line fracture of overdenture printed with 1000 build

While in overdenture group which was printed with 100^0 build angle the fracture line was mainly located in the anterior area (Figure 5B).

DISCUSSION

The outcome of this study evaluated the fracture load values of the overdenture that was printed with 150^0 build angle versus the overdenture that was printed with 100^0 build angle, which could not be applied intra-orally. The results of a study by **So-Min** indicated that both printing angles could produce a compatible mechanical overdenture with no significant difference between both angles [3].

The principal investigator opted to use a ready-made epoxy resin model, as it had sufficient width and length to accommodate for the placement of the two implants. A model made of epoxy resin was chosen because of good mechanical properties of the material that would prevent mechanical failure of model or implant detachment while applying forces to the assembly [4].

The drilling protocol was performed following sequential drilling as per manufacture's instruction of the implant company. Implant was first installed in the determined site using contra angle piece to secure implant position then manual torque ranch was used. The attachment was fastened to the fixture by torque ranch at 15 Newton.

The acrylic overdenture was constructed from extraoral optical lab scan for epoxy resin cast, where the extraoral scanners demonstrated better precision [5]. The resultant SLT file was then imported to exocad software to design the overdenture and detect the two build angles. In mandibular arch, 100^0 build angle can be recommended for DLP complete denture base to provide favorable tissue surface adaptation [6]. Additive manufacturing decreases patient chair time, enables electronic data archiving, and enables staff to precisely reproduce a denture in a short span of time in case repair or maintenance of an existing prosthesis is required. Furthermore, variability in quality of produced products can be reduced [7]. By using desktop digital light processing (DLP) 3D printer the denture was printed, the fitting surface of the overdentures was designed to receive a ball/socket attachments. Pick-up of the metal housing, finishing and polishing were then performed. This work flow reduces laboratory, clinical costs and require less frequent appointments [8, 9].

In order to test overdentures under conditions that are as close as possible to in vivo conditions and to replicate the actual oral environment, a chewing simulator was used [10]. A weight of 5 Kg, comparable to 49 newton of chewing force was applied to simulate the biting force in patients with opposing complete denture [11]. The test was repeated for 240000 cycles to clinically simulate 1-year of intraoral chewing [12]. Load was applied on 3 points of contact; one anterior and two posterior points using a flat plate load applicator to simulate the characteristics of load application in the patient's mouth [13]. Based on the findings of this study, no statistically significant difference was found in overall fracture resistance of DLP denture bases fabricated with different build angles despite the fact that the recorded mean value of the fracture load was higher in the overdenture group printed with 150^0 build angle when compared to the other group.

The higher mean fracture load value recorded in the overdenture group with 150^0 build angle could be attributed to layer orientation during the printing process. In overdenture group printed with 100^0 build angle, layers were aligned on top of one another along the height of the denture, with the direction of the layers parallel to the direction of load during load application. Thus, under load application layers were easily separated apart from each other. In 150^0 build angle, the layers were stacked along length of denture and were perpendicular to direction of load, which resulted in compression of layers under load application.

A previous study demonstrated that the layer orientation has an effect on the compressive strength of a SLA-printed hybrid composite material. Vertically printed specimens with layers aligned perpendicular to the load direction demonstrated statistically higher strength values than horizontally printed specimens [14]. In overdenture group where the dentures were printed with 150^0 build angle, multiple fracture lines were observed mostly in anterior and premolar regions. This could be explained by the large amount of stored elastic energy (high stress failures) required to fail the material, causing the crack to branch and fragment into several pieces at the fracture point [15].

While in the overdenture group with dentures printed at 100^0 build angle, the fracture lines occurred in the anterior area. This indicates that the material failed through a delamination process between the layers rather than cracking. The layers were separated along their junctions, resulting in the observed plastic deformation and slow crack propagation pattern in this group [15]. However, further studies are required to evaluate the long-term fracture resistance, clinical efficiency and maintenance requirements of the 100^0 and 150^0 build angles.

CONCLUSION

Within the limitations of this study, it could be concluded that:

1) DLP is a promising additive manufacturing

technique in fabrication of implant-retained overdenture with affordable, and acceptable biomechanical properties.

2) Although there was no statistical significance difference between the two groups, the results indicated that 150^0 build angle is better compared to 100^0 build angle group in terms of mechanical properties.

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