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INFLUENCE OF DIODE AND ND:YAG LASER IRRADIATION ON SHEAR BOND STRENGTH BETWEEN SOFT RELINING MATERIAL AND CONVENTIONAL, THERMOPLASTIC, AND CAD/CAM DENTURE RESINS

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ABSTRACT

Purpose: To evaluate the influence of diode and Nd:YAG laser irradiations on the shear bond strength (SBS) between soft liner and different denture base materials.

Materials and Methods: 72 samples (10x10x3mm) were prepared from CAD/CAM milled (IvoCad), 3D-printed (NextDent), polyamide (Flexi Ultra), and PMMA (Acrostone) (n=18 each). Each group was subdivided into 3 groups (n= 6) according to the surface irradiation: no surface irradiation (C), diode laser (L1) and Nd:YAG laser (L2). All specimens were bonded to soft relining material (Acrostone Soft relining). A universal testing machine (UTM) was used to assess SBS. Modes of failure were analyzed using a scanning electron microscope (SEM). Data was analyzed with Shapiro–Wilk, ANOVA, and post hoc Tukey, with a significant level set at 0.05.

Results: PMMA showed the highest significant SBS (0.807 ± 0.038), followed by IvoCad (0.477 ± 0.084), and the least significant SBS were shown with Flexi Ultra (0.326 ± 0.0.094) and NextDent (0.0.326±0.155). Insignificant changes were observed in IvoCad specimens by both L1 and L2 (*p* =1.000, 0.933 respectively). A mixed failure mode dominated all groups, except in PMMA (L1 and L2) subgroups, where a cohesive failure was observed, while adhesive failure was observed in Flexi Ultra and Nextdent (C and L1) subgroups.

Conclusions: Laser irradiation improved the SBS of 3D-printed denture resins, thermoplastic polyamide-nylon, and PMMA, while the milled resin was unaffected.

KEYWORDS: CAD/CAM, Milled, 3D-printed, denture, PMMA, Shear bond strength, Diode, Nd:YAG laser.

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INTRODUCTION

Heat-cured polymethyl methacrylate (PMMA) resin has been a prevalent removable denture base material due to its unique features, including low density that patients prefer, adequate physical and mechanical properties, ease of processing, polishing, and repair, acceptable aesthetics, and cost-effectiveness.[1] However, it's high susceptibility to fracture required reinforcements of PMMA or the development of alternative denture base materials.[2,3]

The introduction of new technologies in dentistry has allowed the development of alternative materials to PMMA, such as injectable thermoplastic polyamide and CAD/CAM resins. The clinical performances of these materials and their bonding characteristics to reline materials are essential and relevant.

Polyamides are thermoplastic nylons formed by condensation of diamine and dibasic acids, providing superior elasticity and molding accuracy than PMMA. [4] Moreover, they have high flexural strength [5], less water sorption [6], and improved denture retention through the engagement of undercuts. [7] Computer-aided design and manufacturing (CAD/CAM) dentures are fabricated using two different technologies: subtractive and additive techniques. The subtractive technique uses a milling bur to cut the prosthesis from large pre-polymerized resin blocks to the digitally planned structure. [8] Milled prosthesis reported good mechanical and surface properties,[3] but it was challenging to reproduce components smaller than the milling bur's size, in addition to the considerable waste of the materials resulting during milling. [9] The additive technology involves assembling the resin material layer by layer, enabling the production of sophisticated designs with minimal waste material. [10] Both CAD/CAM technologies allowed the production of dentures of higher strength and accuracy at a shorter clinical chair time and fewer visits, leading to better clinical outcomes[11,12] and high patient satisfaction.[13,14] Additionally, it permitted digital archiving, making dentures' remanufacturing practicable. [15]

The success of removable dental prosthesis primarily depends on its retention. [9] A removable prosthesis may suffer from deteriorated adaptation over time, influenced by aging and residual ridge resorption. This can reduce patient function and esthetics and lead to dissatisfaction with wearing dentures. [16,17] Relining, rebasing, or denture reconstruction are adequate solutions to improve denture quality in cases of bone resorption.

Denture liners used may be silicone-based[18] or acrylate-based.[19] Acrylic-based denture relining may be hard or soft, auto-polymerized, heat-polymerized, visible light-polymerized, or microwave-polymerized. [20] Research has shown that applying soft denture relining materials can enhance patients' oral comfort and functional abilities, thus improving their overall satisfaction with the denture. This is attributed to the soft relining's viscoelastic cushioning properties. [21]

The chemical composition of the denture base and the relining materials, the addition of bonding agents, the thickness of the denture relining, and the surface topography all affect the SBS. [22,23] A weak bond is correlated with reduced mechanical properties of the denture, bacterial aggregation, staining, or delamination of the reline material. [24]

Acrylic-based auto-polymerized reline materials are mostly PMMA or poly ethyl methacrylate (PEMA) copolymer. These relining materials are chemically similar to the heat-cured PMMA denture base and can successfully bond to it. [25-28] Unlike the thermoplastic polyamide-nylon and the CAD/CAM denture base resins, whose reline bond strength was questionable and may necessitate special surface pre-treatment or unique bonding technique to advance the bonding strength. [19,20,29]

Bond strength could be enhanced by improving the bonding interface. Lasers have been recently used in dentistry in surface characterization of dental materials to enhance bonding to dental structures.[18] Different types of lasers of different laser wavelengths, duration of irradiation, pulse energy, pulse length, device power, and penetration depth were used.[30,31] Lasers may be applied through an active gas, liquid, or semiconductor medium. Solid crystals such as ruby, alexandrite, or neodymium-enriched glasses are the active medium used in neodymium-yttrium-aluminum-garnet (Nd:YAG) laser, while gallium arsenide is a semiconductor active medium, which is mostly used in the gallium-aluminum-argon (Ga-Al-Ar) diode laser. Diode lasers are chiefly addressed due to their economic perspectives of reduced costs compared to other laser strategies. They can be used in a continuous or pulsed mode of operation through contact or noncontact treatment-on-tissues. [32]

Thus, the current study aimed to evaluate the effect of different laser irradiations on the shear bond strength (SBS) of different CAD/CAM, thermoplastic, and conventional denture base materials. Also, the mode of failure was inspected. The null hypothesis states that different tested denture base materials, CAD/CAM, thermoplastic polyamide-nylon, and PMMA denture base materials, as well as the irradiated laser, would not affect the SBS or the failure mode.

MATERIALS AND METHODS

This research has been approved by the Ethics Committee of Alexandria University, Egypt, Faculty of Dentistry (IRB No. 00010556 - IORG 0008839) before any research-related activities.

Sample size estimation

Using SPSS program version 28 (IBM Corp. Released 2021. IBM SPSS Statistics for Windows, Version 28.0. Armonk, NY: IBM Corp), A minimal total sample size of 48 specimens 12 per group with 4 specimens in each subgroup was determined. The number of specimens per subgroup was increased to be 6 per subgroup to avoid specimen damage. [33,34]

Study Design

This in-vitro study included a total of 72 specimens of four denture base materials (n=18 each): milled CAD/CAM resin (IvoCad), and 3D-printed CAD/CAM resin (NextDent), thermoplastic polyamide nylon (Flexi Ultra) and conventional PMMA (Acrostone). All specimens were bonded to chair-side cold-cured soft relining acrylic cross-linked material (Acrostone, Relining material). Table 1 includes the product names, companies, components, and fabrication methods of the materials used in this study.

The fabricated specimens of each denture base material were randomly divided into three subgroups (n = 6 each): control subgroup (C) did not receive any irradiation, (L1) subgroup was irradiated by the Ga-Al-Ar diode laser, (L2) subgroup was irradiated by Nd:YAG laser. Figure 1

Specimens' preparation

All specimens were prepared in dimensions of 10 mm x 10 mm x 3 mm [35], following the ISO standards 29022 (2013). Standardized finishing was done using acrylic stone for two minutes with low speed, then tungsten carbide bur for two minutes, and finally sandpaper (150) grit for one minute. All burs used for the finishing procedure were cylindrical to ensure parallel cutting or grinding of the bur to the sample's surface (to minimize irregularities and equalize the pressure). [36] The surface of the finished specimens remained unpolished to mimic the tissue denture surface as much as possible. All specimens were inspected for flaws or other quality problems and immersed in tap water for 72 hours.[20] Subsequently, they were dried, and their surface was wiped with ethyl alcohol to confirm a clean bonding interface.

TABLE (1) Summary of materials used in present study and fabrication methods:

Materials	Brand name and manufacturer	Composition	Specimens' fabrication method
Conventional heat-cured polymethyl methacrylate	Acrostoneheat-cured denture base (© 2023 Acrostone Dental & Medical Supplies. Egypt)	Powder: Polymer (PMMA), initiator (benzoyl peroxide [BPO]) (0.5%), pigments (salts of cadmium or iron or organic dyes). Liquid: Monomer (MMA), cross-linking agent (Ethylene glycol dimethacrylate (EGDMA) 10%, inhibitor (hydroquinone)	Conventional heat polymerization method. Polymerization cycle: 70°C for one hour and then brought to a boil for half an hour. [35]
Thermoplastic polyamide	Flexi Ultra -flexafil s.a.c.i. leopoldo marechal 1312 – Buenos aires – Argentina "pink 78"	Diamine NH2-(CH2)6-NH2 and a dibasic acid, CO2H-(CH2)4-COOH.	The polyamide cartridge was placed in an electric cartridge furnace (Sabilex BIOSTRONG 400) to liquefy, then injected into the flask after wax elimination, guided by the instructions provided by the manufacturer, under pressure (5-7 Bar) and heat (280° C) for 15 minutes. The flask was allowed to bench cool for 15 to 20 minutes. [56]
CAD/CAM Milled (IvoCad)	IvoCad (Ivoclar Vivadent, Schaan, Liechtenstein)	Prepolymerized PMMA discs 50–100% methyl methacrylate 2.5–10% 1,4-butanediol dimethacrylate	Specimens were sectioned to the required dimensions from the pre-polymerized PMMA blocks using a diamond slicer (IsoMet 5000 Linear Precision Saw, Buehler, USA) in the presence of a water cooler attached to the cutting machine. [35]
3D-printed (NextDent)	NextDent Denture 3D+ (NextDent B.V., Soesterberg, The Netherlands)	Monomer based on acrylic esters: Ethoxylated Bisphenol A > 60% w/w Methacryli oligomer 15–25% Phosphine oxide < 2.5%	Open software (123D design, Autodesk, version 2.2.14, CA, USA). Printer (NextDent® 5100 3D system, NextDent B.V. Centurionbaan 190 3769 AV Soesterberg The Netherlands). The printing layer thickness 50μm/layer. The printing orientation is 90°. The specimens were post-cured in the Post-curing machine: LC-D Print Box with wavelength Blue UV-A, UV-Blue 315-400+400-550 nm for 20 minutes, with total output light UV-A 108 watt, UV-Blue 108 watt. [35]
Acrostone, Relining material	Soft Relining Acrylic Cross Linked - Cold Cure relining material. (© 2023 Acrostone Dental & Medical Supplies. Egypt)	Powder of PMMA and initiator. Liquid of MMA, aromatic ethanol, plasticizer, and tertiary amine. [39]	Powder and liquid are mixed following the manufacturer instructions.

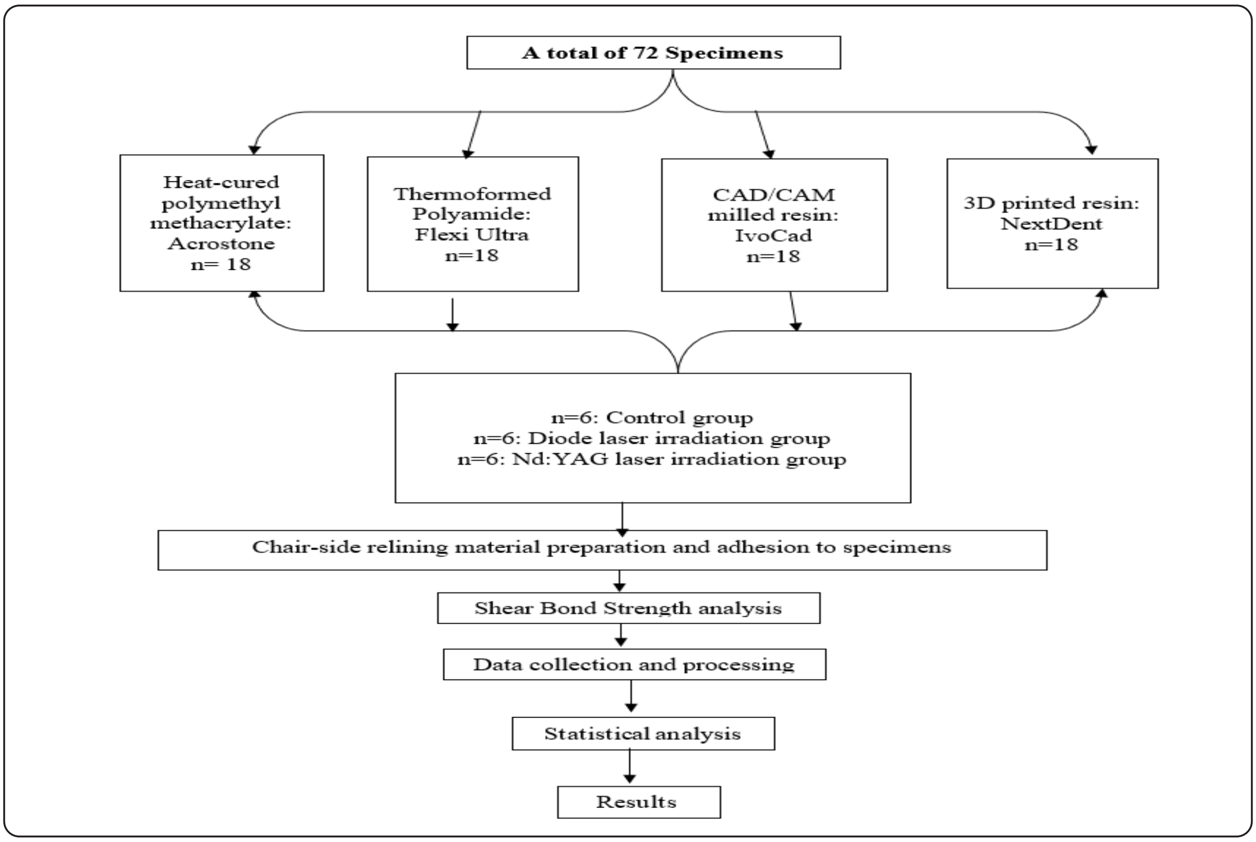

Fig. (1) Study design flow chart

Surface irradiation:

C-subgroup: specimens of each denture base material were left non-irradiated as a control.

L1-subgroup: specimens were irradiated by Ga-Al-Ar Diode laser (Epic 10 Classic Diode Laser, Biolase Inc., Foothill Ranch, California, USA) of 940 nm, 2W power, and energy density of 120 J/cm2 for 60 seconds in a continuous mode at 10 mm distance. [37]

L2-subgroup: specimens were irradiated by Nd:YAG laser with a flat-top handpiece (Light Walker, Fotona, Slovenia) 1064 nm at power 1 W, energy density of 60 J/cm2, frequency of 10 Hz for 60 seconds with a spot diameter of 11 mm in non-contact pulsed mode at 10 mm distance. [38]

Relining procedure:

A brass split mold with a cylindrical inner space of diameter 3 mm and height 6 mm was used to prepare 72 samples of the chair side cold-curing soft relining material. The inner surface of the mold was painted with separating material. The powder and liquid of the relining material were mixed to the appropriate ratio as recommended by the manufacturer [39], placed in the mold, and the two halves closed together and kept under pressure (1 kg) for ten minutes [20,35], till the full setting of the material, Figure 2. [20]

The formed specimens (denture base material bonded to self-cured relining material) were attached to a self-cured PMMA resin block (Acrostone chemical-cured denture base, Acrostone Dental & Medical Supplies. Egypt). [40] Resin blocks were made in silicone molds of dimensions (1.8 cm length and 1.5 cm diameter) to facilitate attaching the specimens tightly to the Universal Testing Machine, Figure 3.

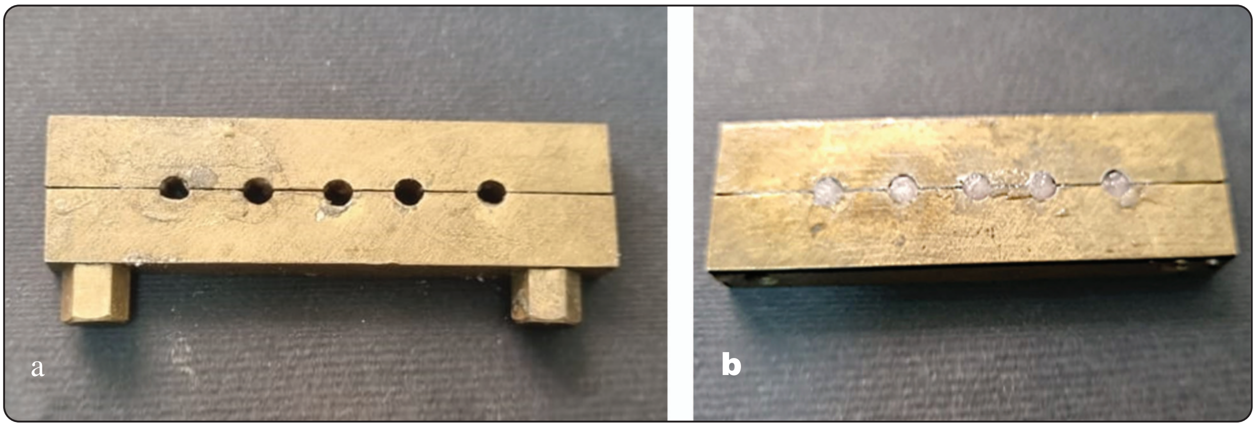

Fig. (2) a- A customized brass mold used for preparing the relining material; b- The mixed auto-polymerized reline resin was packed in the space.

Fig. (3) To facilitate attachment to the Universal testing machine, all specimens were attached to a cylindrical self-cured acrylic resin holder of dimensions 1.8cm length and 1.5cm diameter.

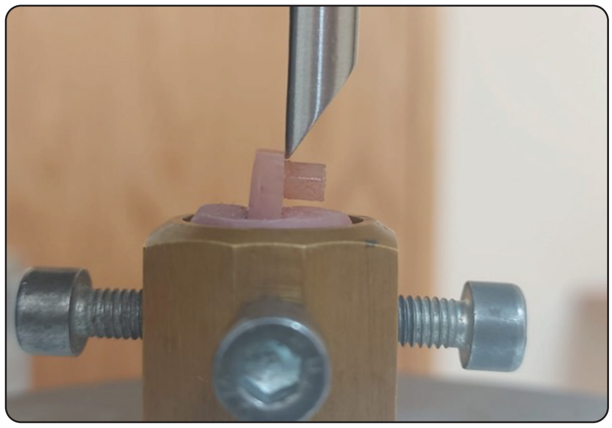

Fig. (4) Universal Testing Machine was used for the shear bond test.

Shear bond strength test (SBS)

The shear bond strength tests were performed using a Universal Testing Machine (5 ST, Tinius Olsen, England). The specimens were mounted in a metal holder, and shear force was applied at a crosshead speed of 1 mm/minute [20,29], until failure of the soft liner bonding to the acrylic plates, Figure 4. The maximum force at the point of failure leading to separation was documented in newtons (N) and calculated into megapascals (MPa) using the subsequent formula: [22]

Shear bond strength (MPa) = N/A

N = maximum load in Newtons (N)

A = Bonding area (mm^2) = 7.07 mm^2

Failure modes evaluation

Scanning electron microscope SEM (JEOL, JSM-5510LV, Peabody, MA, USA) was used to study the failure type at ×50 magnification. Failure mode was categorized as follows: cohesive failure taking place entirely within the denture base or the relining material, adhesive failure at the interface between the denture base and relining material, and mixed failure in which a mixture of the above was observed. [22]

Statistical analysis

Statistical analysis was performed using IBM SPSS statistical software, version 21 (IBM Corp., Armonk, NY, USA). A descriptive analysis of the data using means and standard deviations was calculated. The data's normality was tested using the Shapiro–Wilk tests, and insignificant *p*-values from the test showed that the data were normally distributed. Two-way analysis of variance ANOVA was used to study the effect of denture base materials and surface irradiations on the SBS. One-way ANOVA was used to test the effect of laser irradiation on the SBS of each denture base material. Post hoc Tukey test was applied for all possible pair wise comparisons between groups. All *p*-values less than 0.05 were considered statistically significant.

RESULTS

Results of two-way ANOVA showed that denture base materials and surface irradiation had statistically significant effect on the SBS ($p<0.001$). (Table 2), PMMA showed the highest significant mean SBS (0.807±0.038), followed by IvoCad (0.477±0.084), and the lowest values were reported with Flexi Ultra (0.326±0.0.094) and NextDent (0.0.326±0.155). The overall effect of laser irradiation resulted in a significant increase in mean SBS compared to the control group ($p<0.001$).

Post hoc pairwise comparisons showed no significant differences between Flexi Ultra and NextDent ($p = 1.000$) and no significant differences between the effect of L1 and L2 ($p = 0.186$).

The mean and standard deviation (SD) of the SBS values and *p*-values are recorded in Table 3. Results of one-way ANOVA showed that the variation of the control groups was significant ($p<0.001$), the highest SBS was reported in PMMA (0.498±0.038), and the lowest in Felxi Ultra (0.247±0.044). Pairwise comparisons showed no significant differences between PMMA and IvoCad ($p = 0.079$) or the Flexi Ultra and NextDent ($p = 0.441$). In the groups irradiated by L1 laser, the highest SBS was reported in PMMA (0.952±0.171 MPa) and the lowest in NextDent (0.191±0.021 MPa) with no significant differences between Flexi Ultra and IvoCad ($p = 0.712$). In the L2 groups, PMMA showed the highest SBS (0.971±0.116MPa), and Flexi Ultra the lowest (0.318±0.042 MPa) with no significant differences between Flexi Ultra and IvoCad ($p = 0.10$), Flexi Ultra and NextDent ($p = 0.055$), and IvoCad and NextDent ($p = 0.99$).

Comparisons of the effect of surface irradiation on the material groups are shown in Figure 5. The PMMA showed significantly higher SBS after L1 and L2 irradiation versus (vs.) the control group ($p<0.001$), with no significant differences in mean SBS of L1 and L2 ($p = 0.956$). Flexi Ultra reported significantly higher SBS after L1 vs. control ($p = 0.002$) and no differences of L2 vs. control ($p = 0.192$) and L1 vs L2 ($p = 0.068$). IvoCad showed no differences in SBS in L1 vs. control ($p = 1.000$), L2 vs. control ($p = 0.933$), and L1 vs. L2 ($p = 0.933$). NextDent showed no differences in SBS in L1 vs. control ($p = 0.157$), while significantly higher SBS in L2 versus control ($p = 0.02$) and L2 vs. L1 ($p < 0.001$).

The failure modes of the tested denture base materials under varying surface irradiations are illustrated in Figure 6. In most subgroups, a mixed mode of failure was observed, where remnants of the relining materials were present on the surface of the denture base resin. Cohesive failure, appearing entirely within the denture base or the relining material, was observed only in PMMA-L1 and PMMA-L2 samples. Conversely, adhesive failure at the interface between the denture base and relining material was observed in Flexi Ultra-C, NextDent-C, and NextDent-L1 samples.

TABLE (2) Two-way ANOVA results showing the combined effect of materials and surface irradiation on SBS.

Source	Type III Sum of Squares	df	Mean Square	F-Test	p-value
Material	2.776	3	0.925	98.991	0.000*
Surface irradiation	0.397	2	0.198	21.213	0.000*
Material* Surface irradiation	0.808	6	0.135	14.409	0.000*
Error	0.561	60	0.009		
Total	21.429	72			

***** *Statistically significant at a* $p < 0.05$ *level of significance.***

Table (3): Mean values, SD, and significance of the experiment groups SBS (MPa)

Material groups	Surface irradiation			
	Control Mean ± SD	Diode Laser (L1) Mean ± SD	Nd-YAG laser (L2) Mean ± SD	p -Value
PMMA	0.498±0.038[a]	0.952±0.171[A]	0.971±0.116[A]	< 0.001*
Flexi Ultra	0.247±0.044[b, A,]	0.413±0.099[a, B]	0.318±0.042[a ,A, B]	0.002*
IvoCad	0.483±0.079[a, A]	0.483±0.107[a, A]	0.465±0.078[a, b, A]	0.920
NextDent	0.305±0.089[b, A]	0.191±0.021[A]	0.483±0.148[b,]	0.001*
P-Value	< 0.001*	< 0.001*	< 0.001*	

Abbreviations: MPa, Mega Pascal; SD, standard deviation; *p-value < 0.05 is significant; same small letters vertically in each column indicate a non-significant difference between the pairs, while same capital letters in each row indicate a non-significant difference between the pairs horizontally.

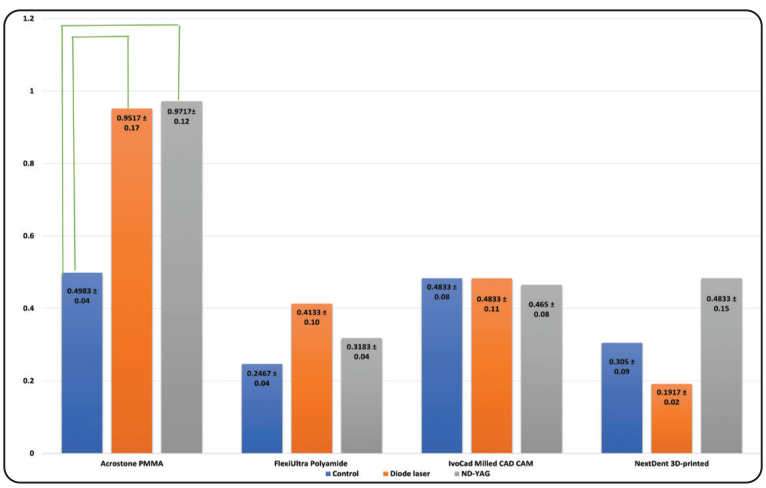

Fig. (5) Comparison of the surface irradiation effect on the shear bond strengths of the studied denture base materials. * Denotes a significant difference between groups (P < 0.05).

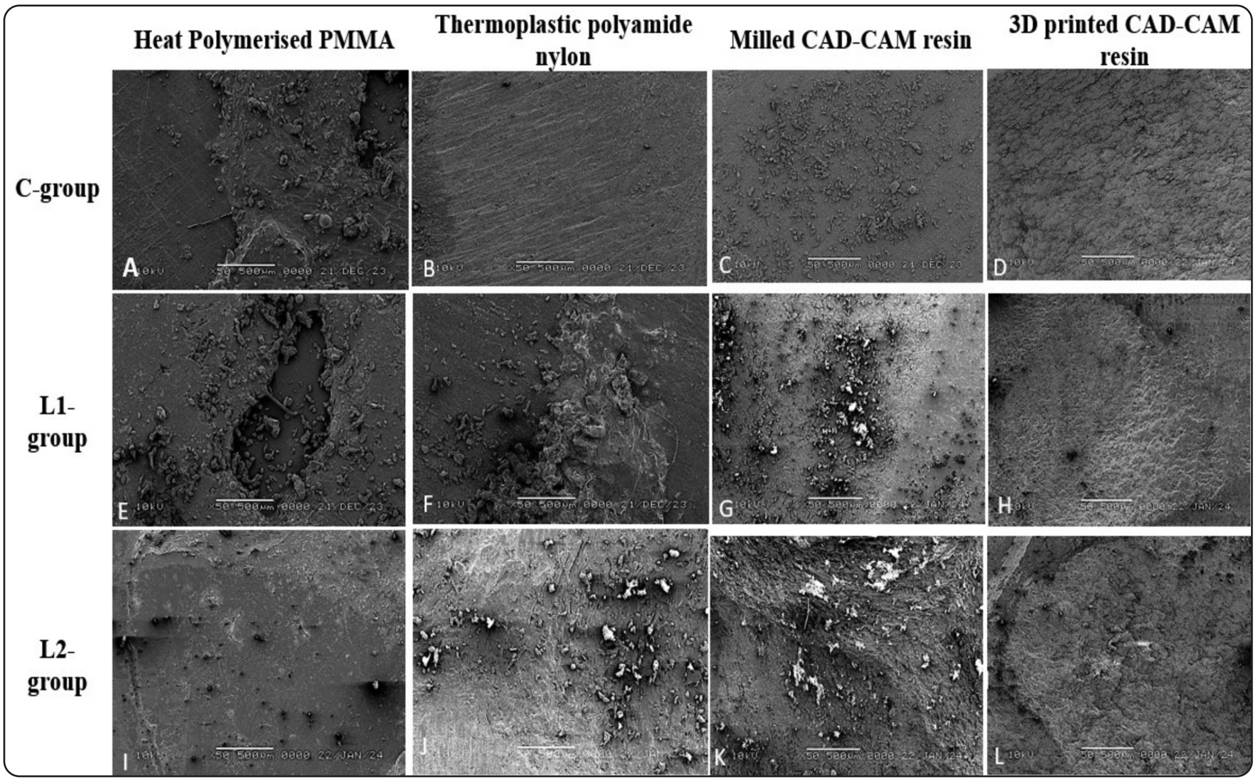

Fig. (6) SEM images (x50 magnification) of sample representative of the denture base materials with different surface irradiations: A; PMMA-C (mixed), B; PMMA-L1 (cohesive), C; PMMA-L2 (cohesive), D; Flexi Ultra-C (adhesive), E; Flexi Ultra-L1 (mixed), F; Flexi Ultra-L2 (mixed), G; IvoCad-C (mixed), H; IvoCad-L1 (mixed), I; IvoCad-L2 (mixed), J; NextDent-C (adhesive), K; NextDent-L1 (adhesive), L; NextDent-L2 (mixed).

DISCUSSION

This in vitro study tested the effect of laser surface irradiations on the SBS of soft liner to conventional, thermoplastic and CAD/CAM manufactured denture base resins. Denture base resin materials and surface irradiation showed significant differences and reported higher SBS than non-irradiated specimens except for the milled CAD/CAM denture resins. Thus, the null hypothesis that the differently manufactured denture base material does not affect the SBS was rejected, while the null hypothesis that laser irradiation does not affect SBS was partially rejected.

Reline bonding characteristics were studied for tensile[27,41], shear[20,42,43], and transverse[27] tests. The shear bond strength was selected for the present study as a reliable test for evaluating the reline-denture base bonding by a vertically applied load directed at the relining-denture base interface. Clinically, the stresses applied to the interface of the two materials, leading to bond failure, are most closely related to shear and tear, and it was believed that the SBS replicates the clinical situations better than tensile force. [20,25]

Bond failure modes were investigated in this study by SEM scanning as an adjunctive qualitative evaluation to the reline-denture base interface. Analyses provided critical information about bonding effectiveness. Mixed and cohesive failures are preferred over adhesive failures because the latter indicates low bond strength. [19,35,43,44]

ISO 10139-2:2016 determined that the minimal clinically accepted reline bond strength for soft long-term denture liners is at least 1.0 MPa.[23]

The relining material used in this study is classified as short-term and should not be used over six months due to the leak out of the plasticizers over time. For the short-term soft liners, the ISO 10139-2:2016 did not indicate the least bond strength requirement, although some authors mentioned 0.44 MPa as an accepted minimum requirement.[19,43,44] In the current study, the non-irradiated PMMA and IvoCad topped the minimum SBS requirements for a short-term relining materials while the Flexi Ultra and NextDent did not. After laser irradiation, the SBS of PMMA was considerably improved and approached that of the long-term soft liners of 1 MPa, while IvoCad remained at the level of the short-term relining (0.44 MPa). The Nd:YAG improved the SBS of the 3D-printed resins to exceed the minimum requirements of 0.44 MPa. The Ga-Al-Ar laser diode irradiation improved the SBS of the thermoplastic polyamide-nylon, but it barely reached the accepted minimum level.

SBS of the conventional heat-cured PMMA before and after irradiation was higher than that of the other tested materials. This was predictable due to the comparable chemical composition of the denture base and the relining material. The acrylic reline monomers are bonded to the persisting functional groups of the denture base, and a covalent bond develops between the newly added reline resin and the current heat-cure denture base material. [25] Nevertheless, it should be emphasized that the laser irradiation nearly doubled the SBS of the PMMA.

On the contrary, the thermoplastic polyamides reported the lowest SBS, possibly due to the considerable chain-chain interaction developed from hydrogen bonds between the neighboring amide groups. Due to their high intensity of crystallinity, the result is a denture base that is intensely resistant to chemical mediators.[24,45] Accordingly, non-irradiated thermoplastic polyamides showed difficulty reacting with the reline resin monomers.[28] This was evidenced by observing adhesive failures between the auto-polymerized reline and polyamide in this study.

Laser irradiation had an insignificant effect on the SBS of the chair-side relined milled CAD/CAM denture base, possibly due to the industrial fabrication of the PMMA blocks. Milled CAD/CAM blocks are pre-polymerized and fabricated under high pressure and temperatures. This results in highly condensed and low-porosity materials with superior chemical and mechanical properties, rendering the material relatively unaffected by the laser irradiation. [46,47]

An important aspect to be considered is that the 3D printing resin in this study is primarily composed of bisphenol-A dimethacrylate. Hence, the conventional cross-linking of methyl methacrylate that occurs between PMMA interfaces may not be occurring in this group. This is an important factor that might have affected the lower SBS of the non-irradiated 3D-printed specimens. These results agree with Mert et al.[29] and Cho and Song.[48] The Nd:YAG laser irradiation improved the SBS of the 3D-printed CAD/CAM resin probably due to the ability of Nd:YAG to deeply penetrate the surface of the resin and produce an etching effect, thus increasing surface roughness[49,50], wettability[51], and surface area needed for adequate bond and micro-mechanical retention. [52]

Different effects of the Ga-Al-Ar diode laser and the Nd:YAG laser on the denture base materials may be due to the different nature of both types of lasers. The Nd:YAG laser is a pulsed laser with a high wavelength of 1064 nm in the near-infrared range of the electromagnetic spectrum and possesses an increased likelihood of dissipating energy and penetrating tissues up to a depth of 4mm.[53] The diode lasers, on the other hand, are in the range of 810 nm/980 nm wavelength and are characterized by low power. [54] So, the lower power and shorter wavelength may be the cause that the Ga-Al-Ar diode laser affected the thermoplastic polyamide but did not produce a significant effect on both CAD/CAM resins (milled and 3D-printed), which are characterized by higher mechanical properties. [8,9,55]

In the literature, it was difficult to find similar studies for comparison. Nevertheless, the results are comparable with Alabady and Khalaf despite testing tensile bond strength and not shear[56], but they reported a nearly doubled tensile bond strength of the Nd:YAG laser-applited injectable thermoplastic resin. On the other hand, the current study's results contradict their failure mode, which was all cohesive, while a mixed failure mode was observed in this study. This difference may be due to the different test used and the higher laser power (15 watts) compared to 1 in the current study.

One of the limitations of the current study was that the effect of thermocycling or cyclic loading on SBS was not investigated. Removable dentures are subjected to temperature changes and occlusal loads in the oral environment, which could affect the mechanical properties of denture base materials. Another limitation was the inability to reproduce the clinical circumstances of the denture base, which might affect the shear bond strength, and only one acrylate-based soft denture liner was used. We propose that future investigations consider soft denture lining materials from various categories, encompassing short-term and long-term options and acrylate-based and silicone-based formulations. Additionally, we suggest that future studies focus on creating specimens that closely mirror the geometric outline of removable dentures and investigate suitable laser protocols to enhance the shear bond strength (SBS) of milled CAD/CAM resins.

CONCLUSIONS

Based on the findings of this study, the composition of denture base material directly affected the SBS. Laser irradiation improved the SBS of 3D-printed denture resins, thermoplastic polyamide-nylon, and PMMA, while the milled resin was unaffected.

The clinical implementation of the current study would suggest that Ga-Al-Ar Diode or Nd:YAG laser surface irradiations are equally recommended to enhance SBS of PMMA denture base, Ga-Al-Ar Diode is recommended for thermoplastic polyamide, and Nd:YAG laser is recommended for 3D-printed resin. Further studies are needed to improve the SBS of the milled CAD/CAM resins.

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