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COMPARATIVE EVALUATION OF TENSILE BOND STRENGTH OF TWO SOFT LINERS BONDED TO HEAT-CURED AND 3D-PRINTED DENTURE BASE MATERIALS

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ABSTRACT

Purpose: The study was conducted to evaluate the tensile bond strength between acrylic-based and silicon-based denture liners bonded to conventional heat-cured PMMA and 3D-printed denture base materials.

Materials and Methods: A total of forty dumbbell-shaped specimens were fabricated for the test of tensile bond strength with dimensions 75 mm in length, 12mm in diameter at its thickest portion, and 7 mm at its thinnest section. The specimens were divided into two equal groups (n=20) depending on the denture base material (conventional heat-cured PMMA and 3D- printed) and each group was subdivided into two subgroups (n =10) depending on the material of soft liner bonded to it, subgroup A: Acrylic-based soft liner and subgroup B: Silicon-based soft liner.

Results: The silicon-based soft liner bonded to conventional PMMA recorded the highest tensile bond strength while the least value for bond strength mean was recorded by the acrylic-based liner bonded to the 3D-printed denture resin.

Conclusion: The silicon-based soft liner showed greater bond strength to conventional PMMA and 3D-printed denture bases than the acrylic-based soft liner.

KEYWORDS: Silicon-based soft-liners, Acrylic-based soft-liners, 3D-printed denture bases.

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INTRODUCTION

Recently, new digital technologies have gained popularity in several dental applications. Using digital technology for the design and fabrication of removable prostheses has lessened the effort exerted by technicians and dental prosthodontists [(1)].

Digital design and fabrication of the denture base can be a promising approach, which could diminish the amount of error in the collection of data and avoid polymerization shrinkage of the polymers which occurs during conventional processing as the prosthesis fabricated using 3D-printed or milled resin which is already pre-polymerized [(2-4)].

The additive technique of denture construction has become popular recently in the dental field and is suggested to be an alternative to conventional technique which provides many benefits for removable prosthesis constructions[(5-9)]. Among these benefits are: the lower cost of many printers compared to milling equipment, the waste of material is decreased, and unlike milled processes, 3D-printed techniques possess the ability to print complex designs and multiple dentures can be printed at the same time [(5)].

Since this technique reduces the number of sessions to two or three visits, makes it more favorable to both patients and prosthodontists, as well as it allows digital archiving, and research revealed better fit and adaptation of the denture base to denture foundation areas [(10, 11)].

Enhancing denture retention and stability can be accomplished through relining of the denture base; it also can reduce the amount of bone resorptions at denture foundation areas. The chair-side technique can be made directly at the clinic it is a simple technique and proved to be effective [(12)].

Denture soft liners act as a cushion on stress-bearing areas that absorb and redistribute the occlusal load applied over the denture foundation area. However, soft denture liners have some serious drawbacks including plasticizers leaching out of the material, which consequently reduces its softness and its bond to the denture bases materials which affect the durability of the soft liner [(13, 14)].

Soft denture liners can be classified according to their chemical composition into acrylic-based liners which can be either cold-cured or heat-cured, and silicone-based liners which can be either heat-cured or room-temperature-vulcanized [(15)].

The strength of the bond between the denture base and lining material is an indicator of the durability of the soft liner and its rate of failure[(12,16-18)].

The following study was conducted to evaluate the tensile bond strength between different types of soft liners bonded to different denture bases.

MATERIALS AND METHODS

The Ethics Committee of the Faculty of Dental Medicine for Girls, Al-Azhar University, had given a code of approval; (P- PD-23-13).

Specimens' Grouping:

For the tensile bond strength test, a total of forty dumbbell-shaped specimens were used in the current study. Depending on the type of denture base material, the forty specimens were divided into two equal groups (n=20). **Group I**: heat-cured PMMA (Acrostone Manufacturing and Import Co, Egypt) and **Group II**: 3D- printed acrylic resin (Nextdent, 3D denture base, Netherlands). additional division was made depending on the type of the soft liner used, into two subgroups (n =10) **Subgroup A**: Acrylic-based soft-liner Coe-Soft (COE, GC America Inc., USA) and **Subgroup B**: Silicon-based soft liner (Mucopren Soft, Kettenbach Dental, United States).

The specimen's dimensions were designed as follows: the length measured 75 mm, 12mm was the diameter measurement at its thickest part, and the thinnest part measured 7 mm.

Subgroup (IA): 10 specimens of conventional PMMA resin lined with acrylic-based soft liner.

Subgroup (IB): 10 specimens of conventional PMMA resin lined with silicon-based soft liner.

Subgroup (IIA):10 specimens of 3D-printed resin lined with acrylic-based soft liner.

Subgroup (IIB):10 specimens of 3D-printed resin lined with silicon-based soft liner.

Preparation of the 3D-printed specimens

Using computer-aided design software (Chitubox, CBD Technology Co., Ltd, China), twenty specimens were 3D-printed using a 3D printer (Next dent 5100 printers. Netherland) and 3D denture base material (Nextdent, 3d denture base, Netherland) in 45-degree orientation with a 50 µm layer in thickness as follows; The bottle of the denture base material was thoroughly shacked for 5 minutes and thoroughly mixed using the 3D mixer of Nextdent (LC-3D Mixer, NextDent, Vertex Dental B.V., Netherland), as represented in Figure (1).

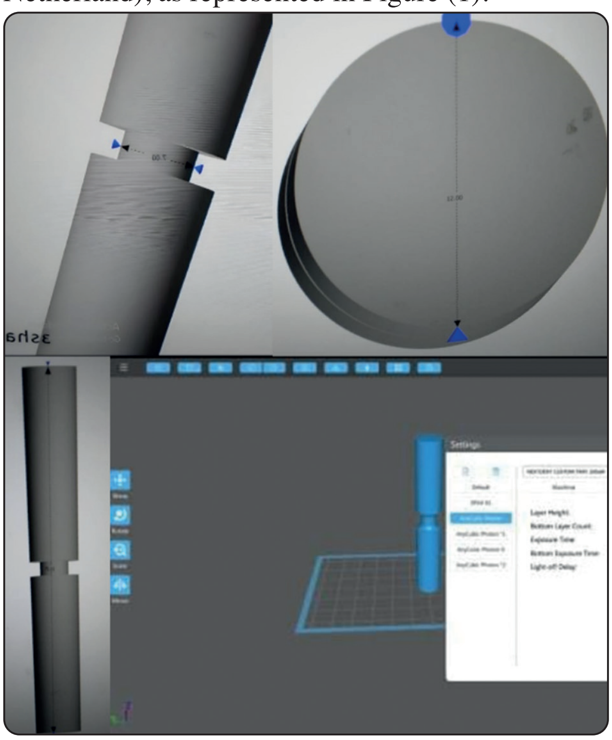

Fig. (1) 3D- printed denture base specimen's design.

The specimens were all submerged in the alcohol bath to get cleaned for 3 min. immediately after printing, and then for additional 2 minutes to remove any excess material. After cleaning the printed section, they were allowed to dry for 10 minutes to make sure that there was no remnant from the alcohol in the printed sections before the post-curing process.

10 min was considered the ideal post-polymerization cure period, after that the specimens were submerged in a bowl of glycerol and exposed in the curing unit to the UV light (LC-D Print Box, Vertex Dental B.V., Netherland) for final polymerization. Post-curing is mandatory to achieve the final material characteristics specified by the manufacturer.

The specimens were numbered and flasked using gypsum material. Flasking of the specimen was done to allow the soft-liner materials' application during the relining procedure and to make sure that lining material thickness was standard to all the specimens at three mm as recommended.

Preparation of the heat-cured acrylic resin specimens

Twenty PMMA specimens were fabricated using the same molds created by the 3D-printed specimens in the dental flask, the conventional PMMA was packed at the dough stage (Acrostone, Heat-cured Manufacturing, and Import Co, Egypt) the flask was reassembled, pressed, and then immersed in a thermally controlled polymerization unit. The specimens were processed for 90 min at 70 degrees, then for 30 min at 100 degrees. The specimens were then cautiously taken out of the flask once they had finished polymerizing, and the specimens were finished using a tungsten carbide bur.

Three mm from the center of the thinnest portion was removed from each specimen of the forty specimens with a low-speed diamond saw under continuous water cooling (DEMCO, Manila, Philippines), then the cutting surfaces were smoothened with 400 grit abrasive paper.

Application of Silicon-based soft-liner:

The material of silicon-based soft-liner was added to twenty specimens, 10 3D-printed and 10 conventional PMMA specimens. The two sections of each specimen were stabilized at a 3mm distance from each other in the dental flask mold. The adhesive was applied to the denture base's adhesive areas (Mucopren Soft, Kettenbach Dental, United States), and it was left to dry for 30 seconds. After applying a second layer, it was given 90 seconds to dry. The dispensing gun was used to apply Mucopren Soft; the flask was reassembled and the material was allowed to set under pressure. The specimens were then immersed in water at fifty degrees for 30 min. After that, removing the excess material and applying a layer of the sealant material was made to the exposed part of the lining material using (Mucopren Soft-Sealant; Kettenbach Dental United States), as seen in Figure (2).

Fig. (2) Application of Silicon-based soft-liner.

Application of Acrylic-based soft-liner:

The acrylic-based soft-liner material was added to twenty specimens, 10 3D-printed and 10 conventional PMMA specimens. The auto-polymerizing reline material Coe-Soft (COE, GC America Inc., Alsip, United States) was applied following the manufacturer's instructions. Between the two parts of each of the twenty specimens, packing of the reline material was carried out and allowed to be set for 15 minutes. An extension of the setting time for one more hour was done.

Prior to the testing procedure, all the specimens were put in the distilled water for twenty-four hours.

Bond strength evaluation

The tensile bond strength of the specimens was evaluated using Model 3345 Universal Testing Machine (Instron Industrial Products, United States) with a five kN load cell. Bluehill Lite software was used to record the data.

The universal testing machine gripped the specimen from its terminals through the upper and lower plates of the machine using adjusting screws. The device was subjected to a gradual increase in the vertical load for 1mm per a min till the two sections of each specimen were totally separated from each other, while Bluehill Lite software program recorded the associated decrease in the load/displacement curve.

The amount of the load required to break the bond was obtained in Newton using Bluehill lite software program. For the tensile bond strength to be obtained in Mega Pascal (MPa), the recorded load was divided by the interfacial area.

$$\mathbf{TBS = F / A}$$

Where F: the recorded load was divided by A: the cross-sectional area of the specimens.

The mode of failure

Evaluation of the mode of failure was made through visual detection of the separated sections of each specimen. Three types of failures were spotted, adhesive failure if there was a complete separation at the interface between the soft-liner and denture base, cohesive failure if there were damage in the soft-liner bulk itself, or mixed failure if both types of adhesive and cohesive failures were detected.

STATISTICAL ANALYSIS

Applying one-way ANOVA and a post hoc test for pairwise comparisons (intra and inter) produced the result of the current study. P-values lower than 0.05 were regarded as statistically significant (95% significance level) P-values below 0.001 were regarded as being highly statistically significant. (99% significance level). Data normality was tested using the Shapiro-Wilk test. Data analysis was made using the statistical software SPSS (version 25, IBM Co. United States).

RESULTS

The highest tensile bond strength mean value was recorded for Group (IB) (1.18 ±0.23 MPa) while Group (IIB) showed a mean value of (0.93±0.21 MPa) and Group (IA) (0.49±0.04 MPa) with a highly significant difference between them. Moreover, Group (IIA) recorded the least tensile bond strength mean value (0.35±0.05 MPa) as depicted in Figure (3) and Table (1).

Mode of failure analysis

The distribution for the mode of failure showed that the test specimens revealed adhesive failure to be the predominant type in the main groups for (90%) and (80%) of (Group I and II) respectively, while mixed failure was (10% and 20%) for (Group I and II) respectively. There was no record of cohesive failure in all groups (0%).

TABLE (1) Values of the Mean and Standard Deviation for the tensile bond strength (MPa) of the tested groups.

Subgroup \ Group	Acrylic soft liner (A)	Silicon-based soft liner (B)	P-Value*
Heat cured PMMA(I)	0.49±0.04	1.18±0.23	0.000^{HS}
3D- Printed (II)	0.35±0.05	0.93±0.21	0.000^{HS}
P- Value**	0.000^{HS}	0.004^{S}	

P value for intra-group comparisons (Acrylic Vs. Silicon), and conceded statistically significant if P ≤05.
***** P-value for intergroup comparison (ANOVA test).***
- ^{S} statistically significant at P ≤ 0.05
- ^{HS} highly significant P-value ≤ 0.001

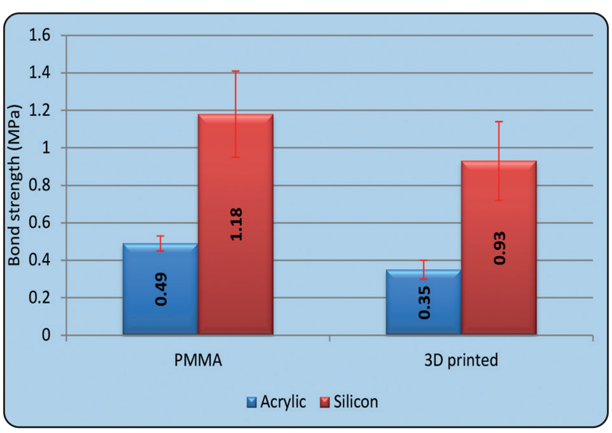

Fig. (3) Bar chart showing the mean values for the tensile bond strength of the tested groups.

DISCUSSION

New technologies have been involved in prosthetic dentistry fabrication, and the use of 3D printing technology (additive technique) for denture fabrication, allows diversity of fresh research in laboratory and clinical fields. However, such techniques provide prosthetic material with chemical, biological, physical, and mechanical behaviors that are still under investigation [1, 19].

The relining of the denture base foundation area is a common clinical procedure that is used to enhance the fitness of the denture base to the denture supporting structures. Usually, it elongates the existing denture's lifetime, since it is a simple and less expensive technique than constructing another denture. It also improves the patient's satisfaction and mastication with the lined prosthesis.

The quality of the bond between the denture lining material and digitally fabricated denture bases, especially rapid prototyping, to is poorly studied [20].

NextDent is a biocompatible denture base material with excellent mechanical characteristics compared to the conventional acrylic resin used for complete denture construction so, it was used in the current study as denture base material. The recommended time for an optimal post-polymerization cure was set to be 10 minutes according to Dimitrova M et al.,[21].

Regarding denture base material, the records of the current study for (**Group I**) revealed higher readings for **(Subgroup IB)** where the conventional PMMA denture base was lined with silicon-based Mucopren Soft (1.18±0.23) MPa, and the readings were decreased for **(Subgroup IA)** where the same denture base material was lined with acrylic-based Coe-Soft (0.49±0.04MPa). According to a study made by Azpiazu-Flores et al.,[17] where the conventional PMMA denture base was lined with silicon-based Mucopren Soft liner and showed a higher reading for adhesive strength (1.78±0.32MPa) compared to the reading for conventional PMMA lined with the acrylic-based liner Perma soft (0.66±0.06 MPa).

Moreover, previous studies by Elias and Henriquez[22], also reported that Mucopren soft-liner had high tensile adhesive strength to conventional PMMA compared to acrylic-based liners used in their study with an average of (1.63±0.48). While Mese et, al. mentioned that the mean value of the bond to conventional PMMA was (0.45) Mega Pascal for acrylic based Coe Soft [23].

Regarding the 3D-printed denture base **(Group II),** the results showed the mean value of tensile bond strength for 3D-printed denture base lined with the COE Soft acrylic-based liner **(Subgroup IIA)** was (0.35± 0.05 MPa) and for the 3D- printed denture base lined with Mucopren **(Subgroup IIB),** the mean value was significantly higher (0.93±0.21 MPa). This was in accordance with another study where a 3D-printed denture base was lined with silicon-based Mucopren Soft recorded (0.68 ±0.20 MPa) and when the same denture base material was lined with Perma soft (acrylic based liner) and the value decreased to (0.32 ±0.04 MPa)[17].

These results were conforming with a previous study made by Choi JE et al.[15] who recorded a decrease in the values of the bond strength values for the printed denture resin with both types of soft liners and attributed that to the cross-linked structure of 3D-printed resin, which restricted the conditioning of the resin surface by ethyl acetate and led to poorer adhesion values of both acrylic based and silicon based liners to printed resin compared to conventional PMMA[17].

Regarding soft liner material, the silicon-based Mucopren showed better adhesion to both the printed denture resin and the heat cured PMMA resin. This result was confirmed by a previous study by Rajaganesh et al.[12] that revealed better adhesion between the silicone based liners bonded to conventional PMMA than with the acrylic based lining materials. Additionally, a study made by Madan et al.[24] stated that, the silicon-based liners had an improved adhesive bonding system despite the dissimilarity in their chemical composition and referred that to the ability of the silicon to penetrate greatly into the increased molecular weight, cross-linked denture resin. In addition to that, the presence of volatile solvents in the chemical composition of the adhesive system of the silicone-based polymer improved the bonding quality of silicone based lining material to denture resin.

Moreover, this study revealed that the result of silicon based lining of two types of denture materials showed higher bonding than the acrylic based liner. This could be a result of applying the adhesive prior to the liner application. This might be explained by the fact that certain types of soft-liner materials do not adhere well to denture base materials, therefore the silicon-based soft-liner material required the application of an adhesive before its application in order to enhance the formed bond [25].

While the acrylic-based Coe-soft showed good bonding to conventional PMMA denture bases and lower bonding to printed denture base. The mean for **(subgroup IIA)** where the bonding strength between the acrylic based (Coe Soft) and printed denture resin showed to be below 0.44 MPa. According to Wright PS, the 0.44 MPa value was regarded as the minimum bonding strength between soft liners and denture bases that was clinically acceptable. [26].

All the values recorded in the present study were greater than that value except for the values of the printed resin lined with Coe-soft compared to that value. Therefore, using acrylic based (Coe-soft) with printed resin must be used only for a brief amount of time this is in compliance with Azpiazu-Flores et, al [17] who stated that the use of acrylic based Perma soft liner with printed resin should be carefully assessed and should only be used for a short-term, as their value is below the clinically acceptable value.

On the other hand; regarding, the acrylic-based soft liner; this study reported that the bonding strength of the acrylic-based liner to PMMA resin was lower than that to silicon-based soft liner despite the chemical similarities between them. Kulkarni et al[27] explained this resulted as the monomer didn't completely penetrate the dense cross-linked resin.

The mode of failure is important for the interpretation of the bonding strength test findings. If adhesive failure occurred it could be concluded that the internal strength of the material is higher than the adhesive interface's strength [28]. Regarding the failure mode of this study, there were (90% and 80%) adhesive failures for (Group I and II) respectively, meaning the bond of liner molecules was greater than the bond between the relining material and denture resin which means a change in failure mode. This result was in accordance with Koseglu M et al.[29] who concluded that the increase in the bond strength was usually associated by a change in the type of failure.

CONCLUSIONS

1- The silicon-based soft liner had greater bond strength to conventional PMMA and printed resin than the acrylic-based soft liner.

2- Conventional PMMA showed higher bond strength to both silicon-based and acrylic-based liners compared to printed denture resin.

3- The tensile bond strength of all tested subgroups was clinically acceptable except for the printed denture resin lined with acrylic based liner which should be carefully used.

Ethics Approval

Ethical approval (P-PD-23-13) was given by the Faculty of Dental Medicine for Girls' Ethics Committee (REC), Al-Azhar University, Cairo.

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REFERENCES

1. Hada T, Kanazawa M, Iwaki M, Arakida T, Soeda Y, Katheng A, et al: Effect of printing direction on the accuracy of 3D-printed dentures using stereo lithography technology Materials. 2020; 13: 3405.
2. Steinmassl O, Dumfahrt H, Grunert I, Steinmassl PA. CAD/CAM produces dentures with improved fit. Clin Oral Invest.2018; 22: 2829-35.
3. Unkovskiy A, Wahl E, Zander AT, Huettig F, Spintzyk S. Intraoral scanning to fabricate complete dentures with functional borders: a proof-of-concept case report. BMC Oral Health. 2019; 19: 46.
4. Janeva N, Kovacevska G, Elencevski S, Panchevska S, Mijoska A,. Advantages of CAD/CAM versus Conventional Complete Dentures-A Review. Maced J Med Sci. 2018; 6: 1498-502.

5. Goodacre B, Goodacre C. Additive Manufacturing for Complete Denture Fabrication: A Narrative Review. Journal of Prosthodontics.2022; 31: 47-51.
6. Nicole Kalberer Albert Mehl, Martin Schimmel, Frauke Müller, Murali Srinivasan. CAD-CAM milled versus rapidly prototyped (3D-printed) complete dentures: An in vitro evaluation of trueness. The journal of prosthetic dentistry. 2019; 121; 637-43.
7. Revilla-Leon M, Ozcan M Additive Manufacturing Technologies Used for Processing Polymers: Current Status and Potential Application in Prosthetic Dentistry. Journal of Prosthodontics. 2019; 28: 146–58.
8. Alhallak K, Nankali A. 3D Printing Technologies for Removable Dentures Manufacturing: A Review of Potentials and Challenges. Eur J ProsthodontRestor Dent. 2022; 30: 14-9.
9. 9-Park C, Kee W, Lim H-P, Park S-W. Combining 3D-printed metal and resin for digitally fabricated dentures: a dental technique. J Prosthet Dent. 2020;123: 389-92.
10. Goodacre C, Garbacea A, Naylor WP, Daher T, Marchack CB,. CAD/CAM fabricated complete dentures: concepts and clinical methods of obtaining required morphological data. J Prosthet Dent 2012; 107: 34-46
11. Goodacre B, Goodacre C, Baba N, Kattadiyil M. Comparison of denture base adaptation between CAD-CAM and conventional fabrication techniques. J Prosthet Dent.2016; 116: 249-56.
12. Rajaganesh N, Sabarinathan S, Azhagarasan NS, Shankar C, Krishnakumar J, Swathi S. Comparative evaluation of shear bond strength of two different chairside soft liners to heat processed acrylic denture base resin: An in vitro study. J Pharm Bioallied Sci. 2016;8:154–9.
13. Kreve S, Dos Reis AC. Denture liners: A systematic review relative to adhesion and mechanical properties. Scientific World Journal 2019; 2019:1-9.
14. Panda S, Reddy N, Manual L, Krishna C, Jagadeesh K, Saidath K, Babaji P. An in vitro evaluation of tensile bond strength of soft liners bonded to different denture base resins. Ann Afr Med. 2021;20:116-20.
15. Choi JE, Ng TE, Leong CKY, Kim H, Li P, Waddell JN, et al. Adhesive evaluation of three types of resilient denture liners bonded to heat-polymerized, autopolymerized, or CAD-CAM acrylic resin denture bases. J Prosthet Dent. 2018; 120: 699-70.
16. Ozdemir, H, Ozdogan, A. Bond strength of resilient lining materials to denture base resin: a systematic review and meta-analysis: bond strength of resilient lining to denture base. J Prosthodont .2018; 27: 828-41.
17. Azpiazu-Flores F, Schricker S, Seghi R, Johnston W, Rio D. Adhesive strength of 3 long-term resilient liners to CAD-CAM denture base polymers and heat-polymerized polymethyl methacrylate with thermocycling. The Journal Of Prosthetic Dentistry.2022;15: 1-6.
18. Pazooki G, Zhang T, Palladino S, Mantovani D, Al Dika G. Bond Strength Between A Hard Chairside Reline and A Printed Denture Base Compared to A Conventional Heat Polymerized Denture Base: An In Vitro Study. Online Journal of Dentistry & Oral Health. 2022; 6:1-8.
19. Neshandar Asli H, Rahimabadi S, Babaee Hemmati Y, Falahchai M. Effect of different surface treatments on surface roughness and flexural strength of repaired 3D-printed denture base: An in vitro study. J Prosthet Dent. 2021;126: 595-8.
20. Vuksic J, Pilipovic A, Pericic T, Kranjcic J Tensile Bond Strength between Different Denture Base Materials and Soft Denture Liners. Materials (Basel). 2023; 16: 4615.
21. Dimitrova M, Corsalini M, Kazakova R, Vlahova A, Chuchulska B, Barile G, Capodiferro S, Kazakov S. Comparison between Conventional PMMA and 3D Printed Resins for Denture Bases: A Narrative Review.J. Compos. Sci. 2022, 6, 87-99.
22. Elias C, Henriques F. Effect of thermocycling on the tensile and shear bond strengths of three soft liners to a denture base resin. J appl Oral Sci 2007; 15:18-23.
23. Mese A, Guzel K, Yusal E. Effect of Storage duration on tensile bond strength of acrylic or silicone-based soft denture liners to a processed denture base polymer. Acta Odontologica Scandinavica, 2005; 63: 31-5.
24. Madan N, Datta K. Evaluation of tensile bond strength of heat cure and autopolymerizing silicone-based resilient denture liners before and after thermocycling. Indian J Dent Res 2012; 23: 64-8.
25. Wemken G, Burkhardt F, Spies BC, et al: Bond strength of conventional, subtractive, and additive manufactured denture bases to soft and hard relining materials. Dent Mater 2021;37: 928-38.
26. Wright PS. Soft lining materials: their status and prospects. J Dent 1976;4: 247-56.
27. Kulkarni RS, Parkhedkar R. The effect of denture base surface pretreatments on bond strengths of two long term resilient liners. J Adv Prosthodont 2011; 3: 16-9.
28. Mccabe JF, Carrick TE, Kamohara H. Adhesive bond strength and compliance for denture soft lining materials. Biomaterials. 2002; 23:1347–52.
29. Koseoglu M, Tugut F, Akin H. Tensile bond strength of soft and hard relining materials to conventional and additively manufactured denture-base materials. Prosthodont. 2022; 1–7.