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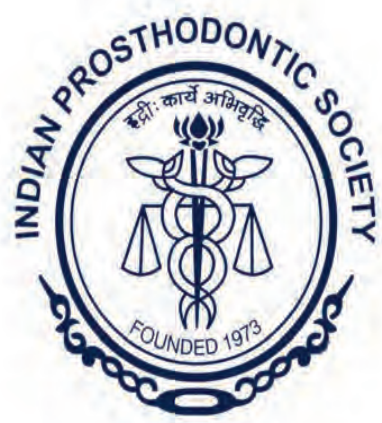

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To serve as a medium for continued prosthodontics education and quantitative scientific publications on clinical trials, basic science related to the biological aspects of prosthodontics, basic science related to prosthodontics techniques as well as orofacial pain that will ultimately improve the prosthodontics research and patient's health and psychological comfort.

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Addresses

Editorial Office
Prof. (Dr). V. Anand Kumar
Editor-in-Chief, The Journal of Indian Prosthodontic Society
Dept. of Prosthodontics, Sri Ramachandra Dental College
Sri Ramachandra Institute of Higher Education and Research (SRIHER)
Porur, Chennai – 600116, India
E-mail: editorjips2021@gmail.com, anandkumar.v@sriramachandra.edu.in
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BRIEF COMMUNICATION

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Significance of hypothesis and *P* value

The hypothesis is the critical part of scientific exploration that represents researcher's expectation from the study. The *P* value denotes the probability of occurrence of statistical significance in measuring the outcome of research and is based on the proposed hypothesis.[1] Researchers often misinterpret the *P* value and provide false conclusions not related to the outcome of research. Hence, the hypothesis should be stated before the initiation of research and should ideally be the last statement in the manuscript's "Introduction." Hypothesis is the relationship that exists between the cause (proposed mechanism) and the effect (observation).[2] It is often contradictory to the existing science and not required to be present in the real world. It evaluates the significance of an observed effect in the sample population that could be applied to a target population.

A research question should have an *null* and *alternate hypotheses*. Since we cannot skew toward a conclusion until a scientific methodology is conducted; we must state a "*Null Hypothesis*" that there is no difference between a cause and an effect. "Smoking cigars does not have any effect on implant failure" is a null hypothesis statement to link between smoking cigar and implant failure. However, there is no mention on the number of cigars smoked per day to identify the precise effect on implant failure. Hence, the appropriate way of stating the null hypothesis would be "Smoking two cigars per day does not have any effect on implant failure," which constitutes a threshold that can be compared to a control population.

An "Alternative Hypothesis" states that a difference exists between a cause and an effect and is the inverse of a null hypothesis. "Smoking two cigars per day has an effect on implant failure" is a nonspecific alternative hypothesis that does not state the direction of the effect; whether positive or negative. Specifying the direction of effect provides clarity in a hypothesis and its fundamental effect on the *P* value. The alternative hypothesis can be modified as "Smoking two cigars per day increases implant failure" or "Smoking two cigars per day decreases implant failure." For the same data and analyses, an insignificant $P = 0.08$ for a nonspecific alternative hypothesis would change to a significant $P = 0.04$ by restating to a specific alternative hypothesis.[1] The statistically significant value considered for dental research is $P < 0.05$ with a 95% confidence interval, indicating most of the study population mean lies within this range. The threshold value for determining statistical significance is also known as the alpha value (α) or level of significance and is always kept to a minimum of 0.05 or less (<5%).[3] The significance level is the threshold beyond which there is very unlikely nonoccurrence of an event in the sample population; hence, the alternate hypothesis will be accepted when $P < 0.05$. However, we will never state that an alternate hypothesis is accepted, but we state either null hypothesis is accepted or rejected in the manuscript's "Discussion."

As stated earlier, to reject a null hypothesis, the observed effect of the data should be significant (<0.05) to indicate that the effect is real and not obtained by chance. However, there is a 5% probability that the observed difference claimed in the research could not have occurred in reality in the sample population; all the included implants may not be affected due to smoking cigars and there will be a minimal sample (probability of 5%) to which the smoking had no effect.[2] An alpha error (type I) would occur if this population becomes the entire population. To bolster the outcome of a research to the general population, it is preferable to lower the *P* value so that the population or the entire data have a strong evidence against the null hypothesis. Hence, the significance level < 1% is considered to be better in the medical field and 5% for research and business.[2] When a smaller sample size is used in the study design, the risk of rejecting the null hypothesis increases, when it is actually true. In addition, the type of statistical test and the number of independent variables also play a vital role in generating the *P* value for the stated hypothesis. Hence, it is highly essential to work with the statistician from the beginning of the research so that each outcome

can be scientifically interpreted and translated to the general public.

Anand Kumar Vaidyanathan

Department of Prosthodontics, Sri Ramachandra Dental College, Sri Ramachandra Institute of Higher Education and Research, Chennai, Tamil Nadu, India

Address for correspondence: Prof. Anand Kumar Vaidyanathan, Department of Prosthodontics, Sri Ramachandra Dental College, Sri Ramachandra Institute of Higher Education and Research, Chennai, Tamil Nadu, India.
E-mail: anand_anandhi@hotmail.com

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Systematic Review

Accuracy of single-unit ceramic crown fabrication after digital versus conventional impressions: A systematic review and meta-analysis

Jimmy Manisha, Gunjan Srivastava, Sitansu Sekhar Das, Naghma Tabarak, Gopal Krishna Choudhury

Department of Prosthodontics, Institute of Dental Sciences, Siksha 'O' Anusandhan, Deemed to be University, Bhubaneswar, Odisha, India

Abstract

In the present era when interest in digital dentistry is increasing, the published literature is still confusing about whether digital impression provides similar accuracy as provided by a conventional impression for the fabrication of a single-unit ceramic crown. The aim of the study was to systematically review the *in vivo* studies comparing marginal, axial, and occlusal fit of single-unit ceramic crowns fabricated after digital impressions with the ones fabricated after conventional impressions. The PubMed, Scopus, and Cochrane online databases were searched for studies comparing the digital impression technique with the conventional technique for single-unit ceramic crowns. Data extraction was done for the year of publication, type of study, country, number of patients, impression system (intraoral scanner [IOS] or conventional impression), marginal fit, axial fit, and occlusal fit. Ten studies were included for meta-analysis regarding the discrepancy in marginal fit, axial fit, and occlusal fit. The digital impression proved to be better than the conventional impression. The mean difference for marginal fit was 6.54 μm (heterogeneity $P < 0.00001$, $I^2 = 93\%$), for axial fit 24.69 μm (heterogeneity $P = 0.34$, $I^2 = 11\%$), and for occlusal fit 6.99 μm (heterogeneity $P = 0.03$, $I^2 = 59\%$). The results of meta-analyses suggest that there is no significant difference between the impression systems (marginally favoring digital impression). The digital impression technique provided better marginal and internal fit of single-unit ceramic crowns than the conventional impression technique. The digital workflow using IOS provided a clinically acceptable marginal fit for single-unit crowns.

Keywords: Conventional impression, digital impression, intraoral scanner

Address for correspondence: Dr. Gunjan Srivastava, Department of Prosthodontics, Institute of Dental Sciences, Siksha 'O' Anusandhan, Deemed to be University, Bhubaneswar - 751 003, Odisha, India.
E-mail: gunjansrivastava@soa.ac.in

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INTRODUCTION

An impression is the negative replica of the oral tissue. It is standard to record the oral tissues for various dental treatments, especially for indirect restorations. Hence, the accuracy of the impression is a significant determinant of the success and longevity of the restoration. The longstanding success of restoration is subject to marginal fit between restoration and prepared abutment tooth; any discrepancy may result in the development of secondary caries or pulpitis, plaque retention, and periodontal problems.[1,2]

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The documented factors which impact the marginal fit of dental restoration are the design of preparation, location of the marginal finish line (supra- or subgingival), restoration type, impression material, and technique.[3,4]

Conventional impression techniques involving elastomeric impression materials such as polyvinyl siloxane (PVS) and polyether are predominant. PVS impression materials are the best in this regard.[5] The digital impression technique came into the scene in the early 1980s, and digital scanners are predominantly used for three-dimensional capturing of the prepared tooth for a complete digital workflow for the fabrication of ceramic restoration. Intraoral scanners work on different principles, including active triangulation, parallel confocal imaging, active wavefront sampling, and stereophotogrammetry.[6]

The digital impression method has improved with time. It has improved patient acceptance, real-time impression display, reduced gag reflex, reduced chair time, lesser distortion compared to conventional counterpart, cost-effectiveness, minimal invasiveness, and easy communication with laboratories and patients due to the transfer of digital data and no need for any storage.[7] The studies usually mention the mean value of the marginal discrepancy.[8] The mean value of marginal discrepancy for ceramic crowns with the conventional impression technique was between 70 and 154 μm, whereas the same was between 49 and 149 μm with the digital impression technique in the included studies.[9-13] Mclean and von Fraunhofer,[14] however, concluded that the maximum tolerable marginal opening is 120 μm and this value has been accepted by most of the authors.[11,15,16]

The accuracy of digital impressions has been previously assessed mainly through *in vitro* studies.[17-20] There is a measurable discrepancy between the values provided by different studies with different restorations. Some studies indicate the advantage of the conventional impression method and others display that the complete digital workflow provides a better marginal fit. The lowest values of marginal discrepancy quoted by different studies need to be substantiated as to whether the digital impression technique provides similar results to the already established conventional impression technique.

A systematic review evaluated the marginal fit of the single-unit ceramic restoration considering both the *in vitro* and *in vivo* studies.[21] The present systematic review aims to compare the accuracy of the single-unit ceramic crowns fabricated with digital and conventional impression techniques considering only the *in vivo* studies and to assess whether the digital method provides an acceptable level of accuracy as provided by the conventional method.

METHODS

This study was designed as a systematic review of *in vivo* publications and a meta-analysis of the results. The study was registered in the PROSPERO database with registration number CRD42022297047. The search strategy was based on the PICO format considering the Population, Intervention, Comparison, and Outcome. An electronic search was conducted till August 2022 in PubMed, Scopus, and Cochrane databases [Figure 1]. The following terms were used in the search (Single unit crown OR fixed dental prostheses) AND (optical scanner OR intraoral scanner OR digital impression) AND (conventional impression OR silicone impression OR polyvinylsiloxane impression) AND (marginal fit OR marginal accuracy OR internal fit OR internal accuracy). References of the selected articles were also searched for inclusion. In addition, a hand search was performed in the following dental journals: *The Journal of Prosthetic Dentistry*, *The Journal of Indian Prosthodontic Society*, and *Clinical Oral Investigations*.

Criteria for study selection

The following inclusion criteria were applied. Only *in vivo* studies, randomized controlled trials (RCTs), and prospective studies were included. Studies examining tooth-supported single-unit crowns were taken into consideration. Only those articles were included which compared both conventional and digital impression techniques in the same study. The details of the impression material and method used for conventional impression techniques and the system used for digital impressions had to be mentioned in the study. Publications only in the English language were included. *In vitro* studies comparing the digital and conventional impression techniques were excluded, and similarly, studies including implant-supported and multiunit fixed dental prostheses were excluded.

Two independent reviewers (JM and GS) screened the titles and abstracts as per the inclusion criteria mentioned earlier. The full text of those articles was retrieved which were selected after abstract screening. Through independent screening, the full text of all included articles for this systematic review was scrutinized by both reviewers for final selection, and any disagreement was resolved with the third reviewer SSD.

A reviewer (JM) extracted the data from the final included articles in the following manner: year of publication, type of study, country, number of patients, impression system (intraoral scanner [IOS] or conventional

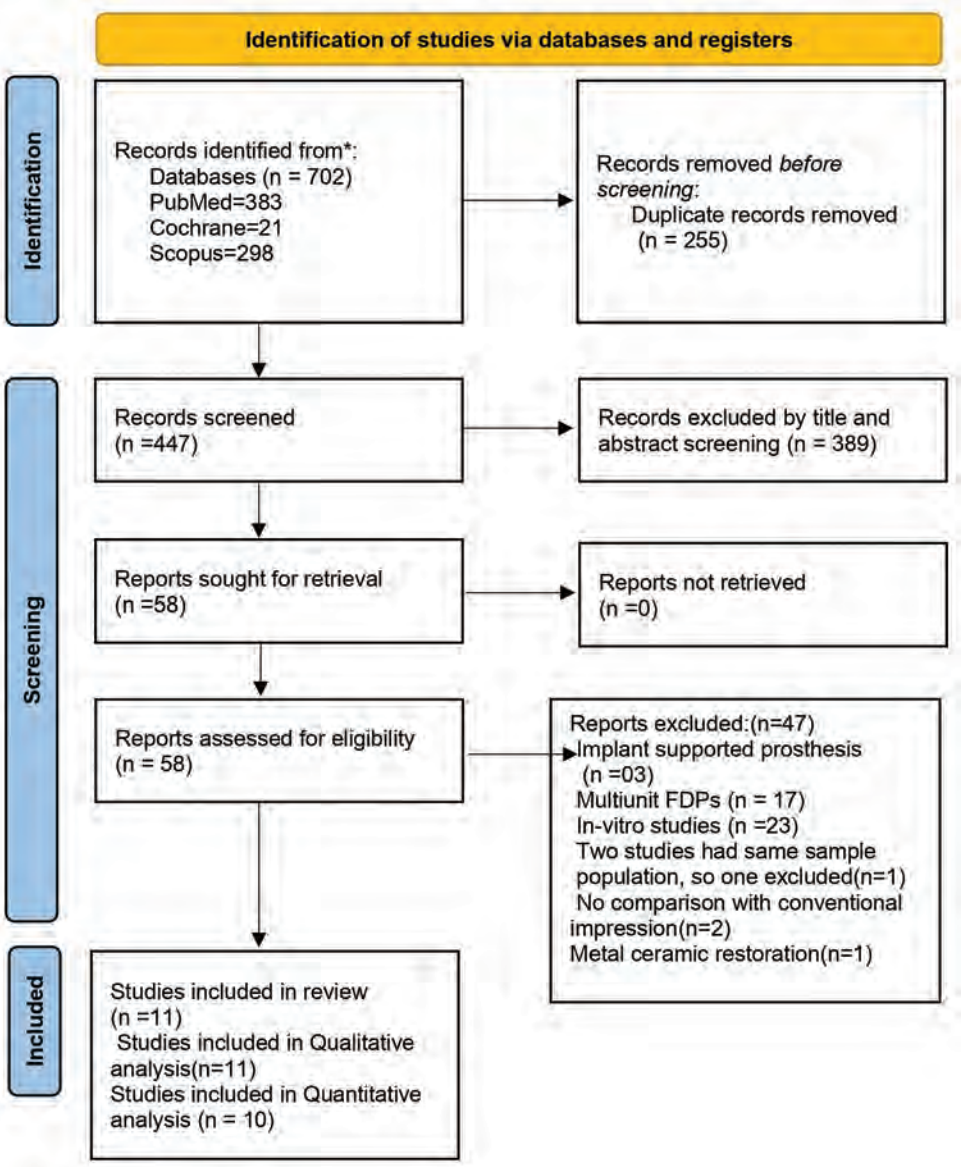

Figure 1: PRISMA flowchart for literature search

impression), marginal fit, axial fit, and occlusal fit. In the impression system, the type of IOS used and the type of conventional impression used were also noted. All these data were reevaluated by another reviewer (GS) independently.

Risk of bias assessment

Two independent reviewers (JM and GS) conducted the quality assessment of the included studies. Cochrane collaboration tool for risk of bias with Review Manager 5.4 was used to assess the risk of bias in all included studies [Figures 2 and 3]. All the studies had a low-to-moderate risk of bias. Randomization was present in all the studies except for two.[10,22] Participant and personnel blinding was mentioned in two studies[11,23] whereas it was unclear in all other studies. Outcome blinding was done in five studies.[9,11,16,23,24] No attrition was there in the included studies except for two studies.[10,15] In one of the studies[15] out of 34 patients, one dropped out of the study as it developed irreversible pulpitis after tooth preparation. In another study,[10] 31 patients with 64 teeth were initially scanned, out of which 7 patients with 17 teeth did not turn up for the final analysis, hence resulting in attrition, and finally, 24 patients with 49 teeth were included in the final analysis. Reporting bias was present in one of the studies[10] and unclear bias was in another study.[9]

RESULTS

A total of 702 articles were identified from an electronic search (Cochrane n = 21, PubMed n = 383, and Scopus n = 298 articles). Two hundred and fifty-five articles were

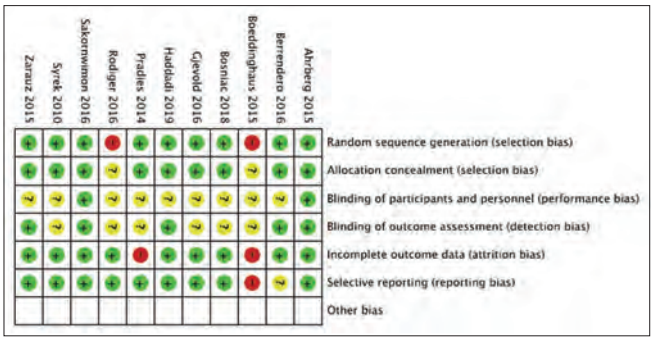

Figure 2: Risk of bias assessment of included studies using the Cochrane collaboration tool for risk of bias

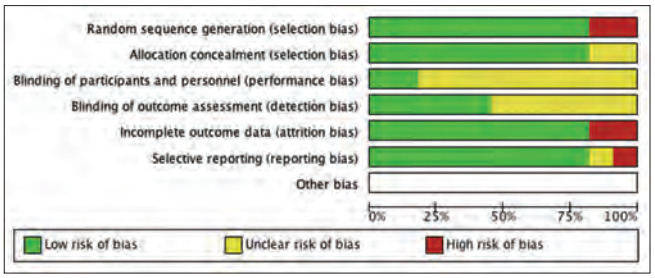

Figure 3: Risk of bias graph

removed as duplicates. Three hundred and eighty-nine were excluded based on title and abstract screening. After examination of the full text of 58 articles, 3 of them were excluded as they described implant-supported fixed prostheses, 17 of them described multiunit fixed dental prostheses, and 23 were excluded as they were *in vitro* studies. Two studies had the same sample, so one was excluded.[25] Two studies Brawek *et al*.[26] and Scotti *et al*.[27] compared two different intraoral scanners rather than comparing with any conventional impression technique and hence were excluded. Likewise, another study[28] evaluated metal-ceramic crowns and hence was excluded. One of the studies[23] compared only patient preferences using intraoral scanners and conventional impressions. This study was included in the qualitative analysis but not in the quantitative analysis. Finally, 11 studies were included in our systematic review [Figure 1].

Eight of the included studies were RCTs[9,11-13,15,16,23,24] and the rest were *in vivo* studies.[10,22,29] Ten studies were included for the meta-analysis of discrepancy in marginal fit,[9-13,15,16,22,24,29] four studies each for the discrepancy in axial fit,[9,11,16,24] and occlusal fit.[11,12,22,24] The forest plot was obtained using Review Manager 5.4.

A summary of the characteristic of included studies is presented in Table 1. Six studies used the TRIOS intraoral scanner,[9,10,12,22,24,29] and four used the LAVA COS system.[10,11,13,15] One study used the ITERO system,[16] and two studies the CEREC OMNICAM system.[10,29] One study[23] did not mention the system's name; they only discussed that it was a powdered system. Likewise, different conventional impression materials were also used in different studies. Most of the studies used vinyl poly siloxane (VPS), while two studies used polyether,[11,12] and one used vinyl polyether silicone.[10]

A confidence interval of 95% was used for all three meta-analyses. The inverse variance statistical method was used. The analysis model was fixed type. The mean difference between the studies was compared. While comparing the discrepancy in the marginal fit, the total number of cases was 439 for digital impressions and 440 for conventional ones. Similarly, for the axial fit, the total number of samples was 92 for both groups, and for the occlusal fit, the sample size was 68 for digital impression and 69 for conventional impression.

In the obtained forest plot, the mean difference for marginal fit was 6.54 μm [heterogeneity $P < 0.00001$, $I^2 = 93\%$, Figure 4], and for axial fit 24.69 μm [heterogeneity $P = 0.34$, $I^2 = 11\%$, Figure 5], and for occlusal fit 6.99 μm [heterogeneity $P = 0.03$, $I^2 = 59\%$, Figure 6]. Both digital and conventional impressions showed similar results. This suggests no significant difference between both impression systems (marginally favoring digital impression).

DISCUSSION

The results of this systematic review prefer the digital impression technique over the conventional technique, though marginally when considering single-unit ceramic crown fabrication. From the meta-analysis, it was evident that marginal fit values are better with digital impression-making. The mean values of marginal fit were below the 120 μm threshold value of clinical acceptability for all the studies except for Rödiger *et al*.[22] for which it was 147 μm, and for Boeddinghaus *et al*.,[10] it was 149 μm. There are several techniques to quantity the marginal or internal fit of the crown for *in vitro* studies like the triple scan protocol used by Anadioti *et al*.[3] Another method used by Abdel-Azim *et al*.[20] measured the marginal gap at four different points of each specimen under ×45 magnification with a stereomicroscope. Measurement of the marginal or internal fit under *in vivo* conditions is not possible. Hence, assessment of the clinical fit of the crowns is done by silicone replica technique; wherein the fabricated crown was cemented on its corresponding prepared tooth applying ultra-light body silicone, thereafter crown was embedded in light-polymerizing resin to stabilize the recorded interface. All the specimens were then sectioned

Table 1: Characteristics of included studies

Author, year	Type of study	Country	Number of patients	Impression system	Marginal fit	Axial fit	Occlusal fit
Haddadi *et al.*, 2019[24]	RCT (split-mouth design)	Germany	19 19	CI=VPS IOS=Trios 3	CI=125±39 IOS=104±50	CI=115±95.81 IOS=95±76.38	CI=182±147.4 IOS=156±132.66
Bosniac *et al.*, 2019[29]	*In vivo* study	Germany	63 63	CI=VPS IOS 1=Cerec AC Omnicam IOS 2=Cara Trios	CI=143.29±100.71 IOS 1=86.09±64.46 IOS 2=88.95±54.46	NR	NR
Berrendero *et al.*, 2016[9]	RCT	Germany	30 30	CI=VPS IOS=Trios	CI=119.9±59.9 IOS=106.6±69.6	CI=105.2±49.8 IOS=82.8±40.3	NR
Rödiger *et al.*, 2017[22]	*In vivo* study	Germany	20 20	CI=VPS IOS=Cara Trios	CI=117.94±74.21 IOS=147.88±63.88	NR	CI=164.22±73.17 IOS=207.60±69.99
Sakornwimon and Leevailoj, 2017[23]	RCT	Thailand	8 8	CI=VPS IOS=NR	NR	NR	NR
Ahrberg *et al.*, 2016[11]	RCT	Germany	17 17	CI=Polyether IOS=Lava COS	CI=70.40±28.87 IOS=61.08±24.77	CI=92.13±49.87 IOS=88.27±41.49	CI=171.51±60.98 IOS=155.57±49.85
Zarauz *et al.*, 2016[16]	RCT	Germany	26 26	CI=VPS IOS=Cadent iTero	CI=133.51±48.78 IOS=80.29±26.24	CI=120.93±53.22 IOS=81.62±26.91	NR
Boeddinghaus *et al.*, 2015[10]	*In vivo* study	Germany	49 49 (patient 24)	CI=Vinyl polyether silicone IOS1=Cerec Omnicam IOS2=Trios IOS3=3M Lava	CI=113±19 IOS1=149±26 IOS2=112±13.75 IOS3=88±17	NR	NR
Pradíes *et al.*, 2015[15]	RCT	Spain	33 33	CI=silicon IOS=Lava COS	CI=91.46±72.17 IOS=76.33±65.32	NR	NR
Gjelvold *et al.*, 2016[12]	RCT	Sweden	13 12	CI=polyether IOS=Trios	CI=154±66 IOS=125±53	NR	CI=158±65 IOS=121±41
Syrek *et al.*, 2010[13]	RCT	Germany	9 9	CI=VPS IOS=Lava COS	CI=71±26 IOS=49±18	NR	NR

RCT: Randomized controlled trial, CI: Conventional impression, IOS: Intraoral scanner, VPS: Vinyl poly siloxane, NR: Not reported

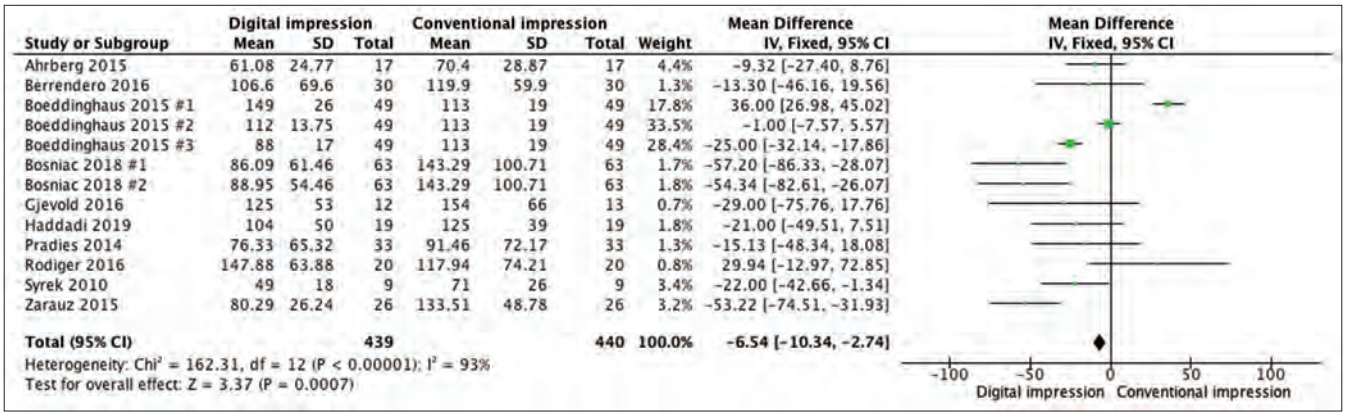

Figure 4: Forest plot of comparison of studies evaluating discrepancy in marginal fit. CI: Confidence interval, IV: Inverse variance, SD: Standard deviation

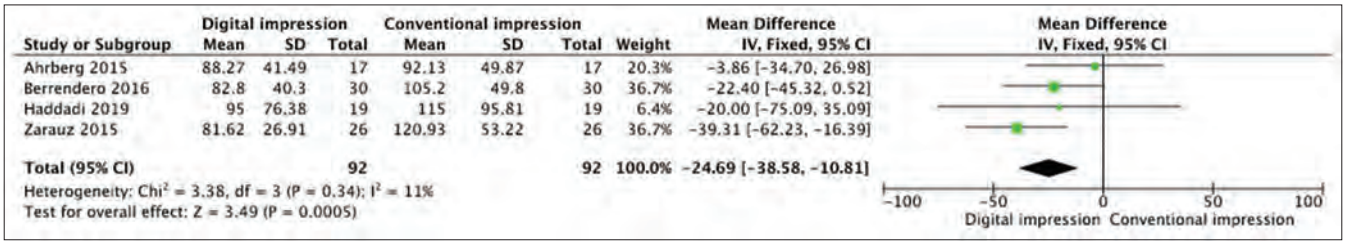

Figure 5: Forest plot of comparison of studies evaluating discrepancy in axial fit. CI: Confidence interval, IV: Inverse variance, SD: Standard deviation

in buccolingual cross-sections, and silicone replica film thickness was measured employing a stereomicroscope;[9] this is a validated and accepted measuring technique used by several studies in our review.[30]

In most of the included studies, the authors have used PVS for conventional technique. Various erstwhile studies have established that when conventional impression materials are compared, PVS gives the most accurate results.[31]

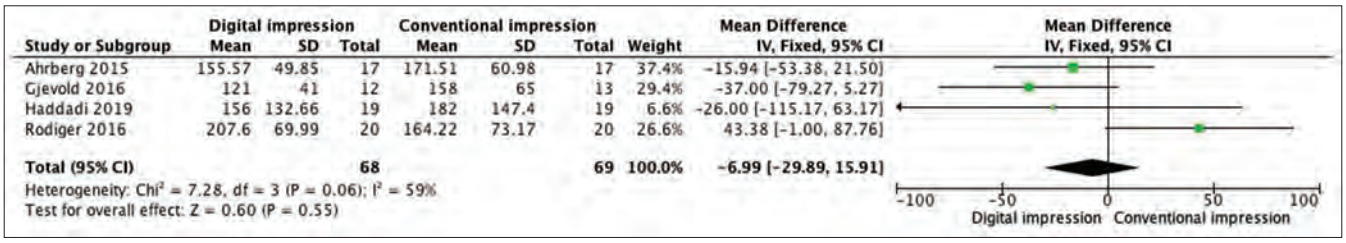

Figure 6: Forest plot of comparison of studies evaluating discrepancy in occlusal fit. CI: Confidence interval, IV: Inverse variance, SD: Standard deviation

When different conventional impression techniques such as the one-step putty wash impression technique, two-step putty wash technique with 2-mm relief space created with prefabricated copings, and two-step putty wash technique with a polyethylene spacer used in the first stage were compared, the putty/wash two-step impression technique with PVS has proven to be the most accurate.[32,33]

A previous systematic review evaluated the marginal fit of the single-unit ceramic restoration. It showed a moderate heterogeneity value (I^2) of 50% for *in vivo* studies, as the same intraoral scanner Lava COS was used in all the included studies.[21] In our study, the calculation of heterogeneity (I^2) for the discrepancy in marginal fit was 93%, for axial fit was 12%, and for occlusal fit 59%. These values are on the higher side except for the axial fit. These heterogeneities are probably due to the diverse generations of the IOS used by the included studies. The different IOS worked on different technologies such as active wavefront technology and confocal microscopy. With the advanced software used in newer generation IOS, the discrepancy values for marginal accuracy will be lower.

Various *in vitro* studies have concluded that the digital impression gives better accuracy for the values of marginal fit than the conventional technique.[20,34] Earlier, different systematic reviews and meta-analyses have been undertaken by different authors. However, they have included *in vitro* studies only[35] or both *in vitro* and *in vivo* studies[36] in their analysis. Different factors, such as saliva, sulcular fluid, blood, and movement of the patient, affect the accuracy of impression in *in vivo* conditions which are absent in the *in vitro* method. Hence, clinical relevance of *in vivo* studies is better than that of *in vitro* studies. As only *in vivo* studies have been included in this systematic review, it has better clinical relevance than the previous reviews which included *in vitro* studies only.

The precision of IOS can be influenced by various parameters such as the position of the finish line, control of moisture, and gingival retraction and scanning strategy. The operator's experience plays a major role in the accuracy of the digital impression. Considering all these factors, future research should be done keeping the abovementioned factors as variables.

CONCLUSION

With the limitations of this systematic review and meta-analysis, it can be concluded that digital impression techniques can be used as a substitute for conventional techniques in the future, as they have comparable accuracy in terms of discrepancy in marginal fit, axial fit, and occlusal fit. Nonetheless, further improvements must be done in digital impressions. Moreover, more studies must be done to draw a concrete differentiation between digital impression and conventional impression techniques.

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Conflicts of interest
There are no conflicts of interest.

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Research

Comparison of antifungal efficacy of commercially available denture cleanser and the extract of *Turbinaria conoides* seaweed against *Candida albicans* adherent to acrylic denture base resin: An *in vitro* study

R. Varsha, Shivasakthy Manivasakan, David Livingstone, E. Rajkumar, Mangaiyarkarasi Ravirajan[1], A. Jenie Rosna

Department of Prosthodontics, Indira Gandhi Institute of Dental Sciences, Sri Balaji Vidyapeeth University, [1]Central Inter Disciplinary Research Facility, Sri Balaji Vidyapeeth University, Puducherry, India

Abstract

Aim: One of the main factors responsible for the development of *Candida albicans* on the surface of denture is improper maintenance of dentures. Denture hygiene can be achieved by regular cleansing of dentures using an appropriate denture cleanser. The aim of the study is to evaluate the antifungal efficacy of commercially available denture cleanser and the extract of *Turbinaria conoides* seaweed against *C. albicans* adherent to the surface of denture base resin.

Settings and Design: This was an *in vitro* experimental study.

Materials and Methods: Twenty-four Acrylic resin samples of dimension 10-mm radius and 2-mm thickness was randomly divided into two groups. The denture base resin was coated with *C. albicans*. The colonies present on the surface of each denture base resin were evaluated by serial dilution method. Group A was treated with commercially available denture cleanser and Group B was treated with extract of seaweed *T. conoides*. The colonies were then evaluated using serial dilution.

Statistical Analysis Used: The colony count values obtained by serial dilution were tabulated. These values were statistically analysed using *t*-test.

Results: Reduction of colony count is more in *T. conoides* than commercially available Fittydent; the difference was statistically significant with a mean difference of 65 at dilution 10^{-2} and 29.25 at dilution 10^{-3} using *t*-test with $P < 0.001$.

Conclusion: Within the limitations of this *in vitro* study, it was proved that the extract of *T. conoides* seaweed and commercially available denture cleanser Fittydent was effective in reducing the colony count of *C. albicans*. *T. conoides* seaweed is statistically significant than commercially available Fittydent.

Keywords: *Candida*, complete denture, denture cleanser, seaweed, *Turbinaria conoides*

Address for correspondence: Dr. R. Varsha, Department of Prosthodontics, Indira Gandhi Institute of Dental Sciences, Sri Balaji Vidyapeeth University, Puducherry - 607 402, India.
E-mail: varsha95chandran@gmail.com

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INTRODUCTION

A significant view of dentistry revolves around maintaining the oral health of geriatric people. Older people are prone to several oral mucosal diseases and it has a multifactorial etiology. Tooth loss is a condition that is noticed prevalently among older adults. Replacement of teeth is of importance as it tends to increase the quality of life. The most commonly chosen cost-effective and practical replacement for total tooth loss is complete dentures. Correct use of the prosthesis and its hygiene maintenance is an essential factor for prognosis of complete denture. This is not followed effectively in the aging population, the reasons of which could be decreasing manual dexterity and physical fitness due to increasing age.[1]

Food particles tend to adhere between the denture and mucosa leading to formation of biofilm on the surface of the denture. The primary colonization of the biofilm in the oral cavity is *Streptococcus mutans*. They produce polysaccharides and extracellular matrix that aids in attachment of various other microorganisms like *Candida albicans*.[2] It is considered a suitable scaffolding for the yeast belonging to normal oral flora to produce a biofilm. There is proliferation of fungi and bacteria leading to pigmentation and staining of acrylic resin, bad breath, formation of calculus, and chronic atrophic candidiasis or denture stomatitis.[3] The most prevalent site for denture stomatitis is the denture-bearing palatal mucosa. Although denture stomatitis is caused by a multifactorial etiology, *C. albicans* is recorded as the most common causative factor. Stomatitis that is related to the denture is an inflammatory process. The etiological factors related to denture stomatitis are a weakened immune system, smoking, continuous wearing of dentures, especially during the nighttime, and very poor oral hygiene. Newton has classified denture stomatitis into three types. Type I is localized simple infection with pinpoint hyperemia. Type II is erythematous type. Type III is a granular type involving central part of hard palate and alveolar ridge. They range from petechiae to generalized inflammation; they are also accompanied by papillary hyperplasia. The treatment of *Candida*-associated denture stomatitis is complex because of its multifactorial etiology. Denture cleansing and maintenance of oral hygiene by the patient are the preventive measures, and the use of antifungal drugs constitutes the therapeutic modality.[4]

Dentures can be cleaned mechanically, chemically, or by a combination of the two. Mechanical cleansing methods are performed using brushes, ultrasonic cleansers, and nail brushes with suction cups.[5] Some of the chemical methods for cleansing dentures are soaking the dentures in a household chemical solution, exposure to oxygen through air drying, soaking the dentures in commercially available denture cleanser solutions, mouthwashes, and microwave radiation.[5] A combination of mechanical and chemical denture cleansing has shown to have promising results in reducing the adherent microorganisms from the surface of the denture.[6]

The use of seaweed extracts for pharmaceutical and medical purpose has been in the rise recently.[7] In recent years, there have been many reports of macroalgae-derived compounds that have a wide spectrum of biological activity. There is special attention on antifungal activities against human pathogens. Some of the marine algae which showed effective antifungal properties are *Acanthophora spicifera*, *Cladophoropsis* sp., *Laurencia paniculata*, *Turbinaria conoides, Tydemania* sp., and *Ulva prolifera*. *T. conoides* was used in this study due to its promising antifungal properties and its ease of availability in the Mandapam coasts of Rameshwaram.[8] It has been used as a traditional medicament for curing fever for children.

Turbinaria is a brown algae Phaeophyceae. It comes under the order Fucales. It is found mainly in tropical marine waters. It grows on rocky substrates, dead corals, and from lower intertidal to upper subtidal zones that are exposed to wave action. They are abundantly found in the tropics and subtropics of the Indian and the Pacific Ocean. There are around 30 species of *Turbinaria*. This genus has the potential to remove lead from aqueous solutions. *T. conoides* is leathery in texture and is bushy; they form branches that are 20–50 cm high. They branch from all directions. Various phytochemicals have been found in *T. conoides*. It has polyunsaturated fatty acids and digestible minerals such as calcium, iron, and potassium and also proteins. It is a rich source of dietary fiber and also contains iodine. This on an overall basis improves the consumer health, thereby reducing the effects of dreadful diseases and improving immune functions. It is also found to have antioxidant, antibacterial, and anticancer properties.[8]

To the best of our knowledge from detailed literature search, we found that there are not many studies using *T. conoides* as a denture cleanser. Since it has antifungal properties, the study aims at testing its antifungal effect on *C. albicans* adhered to denture base resin. This also compares the antifungal efficacy of the extract of marine seaweed *T. conoides* with that of the commercially available denture cleanser (sodium perborate-based Fittydent) against *C. albicans* adherent to acrylic denture base resin. The null hypothesis of the study is that there is no significant

difference in the antifungal efficacy of commercially available denture cleanser and the extract of *T. conoides* seaweed against *C. albicans* adherent to acrylic denture base resin.

MATERIALS AND METHODS

Denture stomatitis associated with *C. albicans* must be treated, even if they are asymptomatic, as this may act as a reservoir for many extensive infections.[9] Management of *C. albicans* can be achieved by proper cleansing of dentures. Only a chemical method of cleansing has been used as a criterion in this study. Seaweed *T. conoides* has been used for this research, especially for its antifungal properties. The *in vitro* experimental controlled trial was presented to the institutional review and ethics board and approval was granted for the same (Ref Number – IGIDSIEC2020NRP24PGVAPRI). Based on the previous studies, the sample size was calculated to be 24. The margin of error was 0.25. The confidence interval was 5%. The 24 samples were divided into 2 groups. Samples belonging to Group A were to be treated by Fittydent and Group B samples were to be treated by extract of *T. conoides* seaweed. Each group consisted of 12 samples.

Preparation of metal die and acrylic specimens

The acrylic samples and the metal die for the study were prepared at Prosthodontics Lab, Indira Gandhi Institute of Dental Sciences, Puducherry. Heat-polymerized polymethyl methacrylate resin was used for fabrication of the specimen ($n = 24$). Metal die of dimensions was 10-mm diameter and 2-mm thickness was prepared and this was subsequently used for preparation of acrylic specimens.[10] The processed acrylic samples were finished and polished. The samples were checked for dimension of 10 mm diameter and 2 mm thickness after polishing. A change in dimension of ±0.1 mm was allowed to compensate for errors occurred during processing or finishing and polishing. Forty acrylic specimens were prepared using the abovementioned technique. From these 40 specimens, 24 acrylic samples were selected that fulfilled the dimensional requirements. These samples were randomly divided into 2 groups, Group A and Group B, each group containing 12 samples.

Collection and preparation of *Turbinaria conoides*

T. conoides seaweed was collected from coastal area of Mandapam, Gulf of Mannar, Rameswaram, Tamil Nadu, India. The seaweed that was present on the surface of rocks and sand was collected. Under sterile conditions, they were transported to the laboratory. The collected seaweed was washed in fresh running water to remove any sand particles, animal castings, epiphytes, and debris that has been attached to its surface. It was then sun dried. The collected sample was ground to a coarse powder using mortar and pestle [Figure 1]. Seaweed preparation was done at the central interdisciplinary research facility CIDRF, SBV, Puducherry.

Soxhlet extraction

The sample was dissolved in n-hexane and the extraction was done using Soxhlet apparatus in n-hexane [Figure 1].[10] In the round bottom distillation flask, n-hexane solvent was taken. *T. conoides* which was ground to a coarse powder was taken and was covered by muslin cloth and kept in a thimble holder in the Soxhlet extractor. The solvent from the distillation flask that is n-hexane, gradually fills the thimble holder. A siphon aspirates once the overflow level is reached. Then, the entire contents of the thimble holder are loaded back into the round bottom flask. The substance which was extracted in this process is also carried with the solvent and is transferred into the round bottom flask. Multiple cycles of this extraction process are repeated till the required extraction is achieved. The sample is then allowed to cool under room temperature. The crude extract of the *T. conoides* seaweed in n-hexane is obtained by this procedure of Soxhlet extraction. Seaweed extraction was done at Refsyn Biosciences Pvt Ltd, Natesan Nagar, Puducherry.

Microbiological analysis

Preparation of broth and agar

From the slant culture, the *C. albicans* was incubated in Potato Dextrose Broth for 24 h at 28°C. After incubation, the cell density was adjusted with a spectrophotometer by adding sufficient sterile saline to increase the transmittance to that produced by a 0.5 McFarland standard at a 530-nm wavelength. The suspension was diluted until an optical density of 0.11 was obtained, resulting in a suspension of 10^5 cells/ml.[11]

Figure 1: Soxhlet extraction of *T. conoides* in n-hexane. *T. conoides*: *Turbinaria conoides*

Formation of biofilm Candida albicans adherence

This procedure is performed from 24 h of preparation of the broth solution inoculated with *Candida*. 1 ml of the suspension 5×10^5 colony-forming units (CFU)/ml was introduced into a 24-well plate containing a disc in each well and was allowed to stand for 24 h. This is placed in the incubator at 37° for 24 h. After 24 h, the broth was removed from the wells and the disc with the film was washed with phosphate-buffered saline (PBS, pH: 7.0) for about three times to eliminate the nonadherent *C. albicans*. The formation of biofilm is confirmed after 24 h.[12]

Serial dilution and pour plate method

After 24 h of introducing the acrylic samples to the prepared broth solution, it is taken for serial dilution procedure. For each of the samples, 10 test tubes were taken and were numbered from 1 to 10. Once all the test tubes have been serially diluted, they were plated using pour plate method. For the pour plate method 10 petri plates were used for each acrylic resin sample. The plates were labelled from 1 to 10. Petri plate number 1 corresponded to serial dilution test tube number 1. The second petri plate corresponded to the second serial dilution test tube. This pattern was similar for all the 10 petri plates. For the pour plate method 1ml of the prepared sample was collected from test tube 1 of serial dilution was and added to petri plate 1, then 15 ml of prepared agar was poured into this plate for solidification. Solution from each of the serially diluted test tubes was taken and was introduced into their respective Petri plates. This was let for 24 h at 37°C. The colonies of *C. albicans* formed in each Petri plate were counted after 24 h [Figure 2].

Treatment of the adherent Candida albicans discs with drug (Fittydent tablet) and sample (Turbinaria conoides [seaweed])

Acrylic samples were divided into two groups: samples in Group A were immersed in Fittydent and samples in Group B were immersed in the *T. conoides* seaweed extract. The samples on which biofilm was formed were taken and washed with running tap water, and they were then placed in separate wells. For the treatment of samples belonging to Group A, commercially available drug Fittydent denture cleanser tablet was used. A solution was prepared for the treatment by dissolving 1 tablet in 100-ml autoclaved distilled water. 1ml of the prepared solution was added to each well containing acrylic resin samples belonging to Group A. To the wells of Group B, *T. conoides* (seaweed) (5 ml of hexane extract of *T. conoides* was diluted with 95 ml of autoclaved distilled water) was added. They were then kept aside for 8 h at normal room temperature. After 8 h of treatment, the drug and the sample were removed from the wells and were washed with PBS (pH: 7.0) for about three times to eliminate the nonadherent *C. albicans*.

Serial dilution and enumeration of adherent fungal colonies after treatment

Serial dilution and pour plate method were performed as mentioned earlier. After evident growth of *C. albicans*, the colonies formed were enumerated using a colony counter [Figure 2]. The values for both the groups are tabulated and are statistically evaluated using *t*-test.

RESULTS

In this study, we have compared the antifungal properties of the extract of seaweed *T. conoides* with that of the commercially available denture cleanser – Fittydent. They were tested for the candidal biofilm formed on the acrylic denture base resin. The *C. albicans* was allowed to grow on the plate; after 24 h, the plates were serially diluted to 10^{-10} dilutions and were plated. The colony count of *C. albicans*

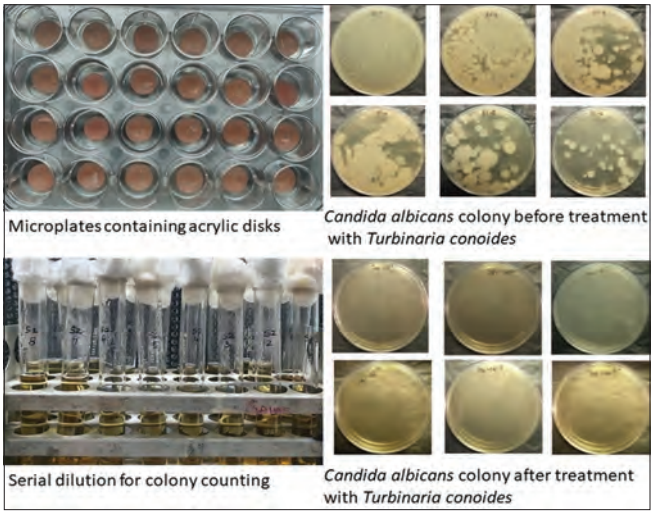

Figure 2: Acrylic discs for serial dilution and plates containing *C. albicans* colony before and after treatment with *T. conoides*. *T. conoides*: *Turbinaria conoides*, *C. albicans*: *Candida albicans*

Table 1: Comparison of *Candida albicans* count between the groups before treatment at different dilutions

Group	*n*	Mean±SD	Mean difference	*P*
10^{-3}				
Fittydent	12	122.50±48.009	0	1#
Turbinaria	12	122.50±48.009		
10^{-4}				
Fittydent	12	114.83±17.456	0	1#
Turbinaria	12	114.83±17.456		
10^{-5}				
Fittydent	12	62.83±14.282	0.083	1#
Turbinaria	12	62.75±14.059		
10^{-6}				
Fittydent	12	37.58±4.144	0.083	1#
Turbinaria	12	37.50±4.034		

#Statistically not significant using *t*-test. SD: Standard deviation

in each disc before treatment was estimated. The disc containing *Candida* was treated with extract of Fittydent tablet and n-hexane extract of the seaweed *T. conoides*. After the treatment, each disc was serially diluted and was plated. The colony count of the *C. albicans* after treatment was estimated. The obtained values were tabulated and statistical analysis was performed.

Table 1 shows the comparison of *C. albicans* count between Fittydent and *Turbinaria* groups before the treatment. The mean count in the dilution 10^{-3} for Fittydent group was 122.50 ± 48.009 and for *Turbinaria* group was 122.50 ± 48.009, and the difference was not statistically significant using *t*-test with $P = 1.000$. For dilution 10-4 the mean and the SD values obtained for Fittydent and Turbinaria groups were 1148.3 +/- 17.456. The same values were obtained for both the groups and hence the statistical difference in t-test was not significant denoting a P value of 1.000. In the dilution 10^{-5}, the mean count in Fittydent group was 62.83 ± 14.282 and for *Turbinaria* group was 62.75 ± 14.059, and the difference was not statistically significant using *t*-test with $P = 1.000$. For dilution 10^{-6}, the difference was not significant similar to other dilutions, where the mean count in Fittydent group was 37.58 ± 4.144 and for *Turbinaria* group was 37.50 ± 4.034.

Comparison of colony count of *C. albicans* between Fittydent and *Turbinaria* groups Were done. Before the treatment for the dilutions 10^{-1} and 10^{-2} the values attained were too numerous to, Count. For dilutions $10^{-7}10^{-8}10^{-9}$ and 10^{-10} the values attained were too few to count. Hence these values were not applicable for statistical analysis.

Table 2 shows the comparison of *C. albicans* count between Fittydent and *Turbinaria* groups after treatment for the dilutions 10^{-2} and 10^{-3}. The mean count in the dilution 10^{-2} for Fittydent group was 279.17 ± 5.340 and for *Turbinaria* group was 214.17 ± 5.606, and the difference was statistically significant using *t*-test with $P < 0.001$. Similarly, the mean count in the dilution 10^{-3} for Fittydent group was 73.42 ± 7.305 and for *Turbinaria* group was 44.17 ± 6.422, and the difference was statistically significant using *t*-test with $P < 0.001$.

The comparison of *C. albicans* count between Fittydent and *Turbinaria* groups after treatment for the dilutions 10^{-1} was too numerous to count in both the groups; similarly, in dilutions 10^{-4}, the count was too few to count, hence this was not statistically applicable. From Figure 3, it is evident that the reduction of colony count is more in *T. conoides* than Fittydent.

Table 2: Comparison of *Candida albicans* count between the groups after treatment at four different dilutions

Group	Number of dilutions	Mean±SD	Mean difference	*P*-value
10^{-2}				
Fittydent	12	279.17±5.340	65	<0.001*
Turbinaria	12	214.17±5.606		
10^{-3}				
Fittydent	12	73.42±7.305	29.25	<0.001*
Turbinaria	12	44.17±6.422		

*Statistically significant using *t*-test. SD: Standard deviation

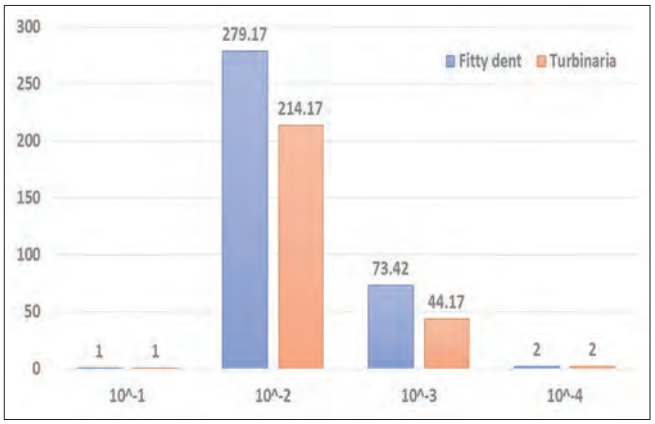

Figure 3: Comparison of *C. albicans* count between the groups after treatment at four different dilutions. *C. albicans*: *Candida albicans*

DISCUSSION

This study compared the efficacy of a seaweed *T. conoides* with a commercially available denture cleanser Fittydent for their antifungal activity against *C. albicans* on the acrylic denture base surface. The prepared acrylic samples were coated with *C. albicans* on the surface. The samples coated with *C. albicans* were serially diluted to evaluate the colony count of *Candida* adherent to denture base before treatment. The coated denture base was treated using Fittydent and n-hexane extract of *T. conoides*. The samples were serially diluted to know the colony count of *Candida* after treatment. These values were tabulated. It was found that *T. conoides* group was statistically significant using *t*-test with $P < 0.001$ in comparison with the commercially available Fittydent group.

Based on an earlier study which evaluated the frequency of maxillary denture related lesions, and its possible risk factors it was found that presence of oral biofilms and lack of denture cleansing was the major cause for denture related lesions. The present research studied only the antifungal efficacy of the denture cleansers, not on the biofilm removal.[13]

A study conducted earlier to determine the denture hygiene in complete denture wearers found that denture related problems were frequently associated with patients having

poor denture hygiene. The authors of the study reinforced on the importance of educating patients regarding usage of denture cleansers.[14]

Retention of microorganisms on the surface of the denture base may lead to the formation of oral biofilm. *C. albicans* is responsible for the formation of oral candidiasis and denture-induced stomatitis. Effective management of this scenario is essential to prevent denture stomatitis. The usage of denture cleansers on a daily basis could effectively reduce the colony count of *C. albicans*.[15] The chemical denture cleansers help the geriatric patients to a greater extent by reducing the need for mechanical removal of plaque from dentures. The present study also explored using the extract of an organic seaweed, compared it with the commercially available denture cleanser for antifungal efficacy without the need for mechanical cleaning.

Literature evidence shows that denture cleanser existing in different composition and different mediums has been compared for their efficiency. Immersion type of denture cleansers is commonly found to be effective and beneficial in reducing the colony count of organisms on the surface of the dentures. Alkaline peroxide tablets generally reduce the colony count of microorganisms, but they are not proven to be effective when used just for a period of 1 h, and various studies have quoted the effective reduction of microorganisms from the denture with overnight immersion in denture cleansers. A study compared the alkaline peroxide cleaning agents such as Fittydent, Efferdent, and Polident and mouth rinses against the *C. albicans* adherent on the surface of denture base resin and found that the mouthwashes had a better effect than these tablets. They have checked the efficacy of denture cleanser after 15,30 and 60 minutes of immersion in the cleanser. The current study has used only denture cleanser made from the extract of marine macroalgae *T. conoides* and compared its efficacy against the commercially available Fittydent denture cleanser. The efficacy of the denture cleansers in the present study was evaluated after immersing the acrylic resin samples coated with *C. albicans* in the denture cleanser for a period of 8 h. It was evident that at dilutions 10^{-2} and 10^{-3}, the results for *T. conoides* group were statistically significant.[16]

A previous study conducted showed that incorporation of amphotericin B and clotrimazole into the dentures reduced the growth of *C. albicans* on the dentures. This study also showed that the porosity of dentures was reduced by this incorporation. In our study, we have used the denture cleanser Fittydent and the extract of seaweed *T. conoides* externally. Further research would be essential for incorporating *T. conoides* seaweed into acrylic denture base resin. The seaweed can be incorporated with silver nanoparticles and could be introduced into the denture. Care should be taken regarding the temperature and properties of the seaweed. The seaweed should not lose its antifungal properties on heating along with the heat-cured acrylic denture base. These open scope for new research with the extract of the seaweed *T. conoides*.[3]

Various herbal and natural extracts have been used as a denture cleanser in the recent times. A study conducted using citric acid as a denture cleanser found that *C. albicans* biofilm formed on the denture surface was comparatively reduced, but the recolonization could not be prevented. Surface roughness of the denture was standardized by grinding it with 300, 400, and 600 grit sandpapers. The denture was coated with saliva pellicle and was followed by coating of *C. albicans*. The current study concentrated only on the antifungal activity of denture cleansers and not on the surface roughness of the denture and recolonization. The surface roughness of the dentures used in our study was not standardized, and there was no formation of saliva pellicle on the denture surfaces.[17]

There are various studies which have used natural and herbal agents as denture cleanser and shown effective results in reduction of *C. albicans*. When the alcoholic extract of *Nigella sativa* was used against *C. albicans,* it reduced the formation of plaque on acrylic denture plates. *N. sativa* has antimicrobial and anti-inflammatory properties. It is also used to treat ulcers. Various concentration of *N. sativa* was used as denture cleansers. It was evident that *N. sativa* in higher concentrations could remove the plaque on the surface of acrylic denture plates. In the current study, only a single concentration of extract of marine macroalgae *T. conoides* was used.[18] Based on the results of the current study, statistical significance was noted. *T. conoides* group proved to be statistically significant in comparison to Fittydent group based on *t*-test at dilutions 10^{-2} and 10^{-3} from Table 2.

An earlier study used essential oils such as *Origanum* oil and grape seed oil. It was estimated that *Origanum* oil can be utilized as an effective alternative to commercially available fluconazole. The zone of inhibition was evaluated in this study. In the current study, only CFU were counted after serial dilution, and the zone of inhibition was not seen. The results proved a statistically significant difference between the two treatment groups.[19]

Based on earlier studies conducted, it was shown that *T. conoides* had profound activity against *C. albicans*. In this

study, the antifungal activity was evaluated by measuring the diameter of inhibition zone. Based on the results of the study, it was proved that the hexane extract showed a well profound inhibitory activity (8.0 ± 0.0 mm) against *C. albicans* at 2000 μg/ml.[10] This was considered a primary factor for selection of the seaweed for the current study. The antifungal efficacy of the marine macroalgae *T. conoides* was compared against the commercially available denture cleanser Fittydent. There is no literature evidence where *T. conoides* have been used to remove *C. albicans* adherent to acrylic denture base resin. Hence, in our study, we aim at seeing the results of extract of seaweed *T. conoides* against *C. albicans* adherent to acrylic denture base resin in comparison to the commercially available denture cleanser. This would open gates toward a green alternative for using *T. conoides* as a denture cleanser. However, more research is necessary to find the active component present in *T. conoides* that is responsible for its antifungal efficacy.

Limitations of the study

The current study being an *in vitro* study did not take into consideration patient-related factors. The study does not test the surface characteristics of denture base resins after usage of the extract.

Future directions

As *T. conoides* has proven to be an effective antifungal agent in reducing the colony count of *C. albicans*, the next step of this study is to formulate a denture cleanser with the incorporation of *T. conoides* seaweed.

CONCLUSION

Within the limitations of this *in vitro* study, it was proved that the extract of *T. conoides* seaweed and commercially available denture cleanser Fittydent was effective in reducing the colony count of *C. albicans*.

T. conoides seaweed is statistically significant in reducing the colony count of *C. albicans* than commercially available denture cleanser Fittydent.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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Research

Comparison and evaluation of the effect of polymerization of resin-modified glass ionomer cement and dual-cure resin cement on the crystalline structure of dentin using synchrotron X-ray diffraction and its clinical correlation with postoperative sensitivity

Akshayaa Balaji, J. Brintha Jei, B. Muthukumar

Department of Prosthodontics, SRM Dental College, Chennai, Tamil Nadu, India

Abstract

Aim: To compare the effect of polymerization of resin-modified glass ionomer cement and dual-cure resin cement on the crystalline structure and to correlate it clinically with postoperative sensitivity.

Settings and Design: The evaluation of crystalline strain in the dentin slabs was done using Synchrotron X-ray diffraction. The post operative sensitivity was measured clinically using Schiff's sensitivity scale.

Materials and Methods: A total of 44 extracted and noncarious premolars were collected. Dentin slabs of dimensions 2 mm × 2 mm × 1.5 mm were prepared from the buccal aspect of the extracted teeth. The dentin slabs were then divided into two groups, Group A dual-cured resin cement and Group B resin-modified glass ionomer cement was applied. The dentin slabs first underwent synchrotron X-ray diffraction before and after the application of cement. Forty-two patients who were undergoing complete metal fixed prostheses on vital posterior abutments were selected. In this, 21 vital abutments were included in each group. Tooth preparation and fabrication of complete metal prostheses were done in the conventional manner and cemented using the 2 luting cements in Groups A and B, respectively. Dentinal hypersensitivity was measured using Schiff 's scale, postcementation, after 1 week and 1 month.

Statistical Analysis: Independent t-test was done for comparing the two cements in two cements in terms of lattice strain. Mann–Whitney U-test was done for comparing the cements with respect to dentinal hypersensitivity. Spearman's correlation coefficient was used for clinical correlation between dentinal hypersensitivity and crystalline strain.

Results: The lattice strain generated in dual cure resin cement was higher than that in resin-modified glass ionomer cement and was statistically significant. Postcementation hypersensitivity was higher in dual-cured resin than resin-modified glass ionomer cement but was not statistically significant in the follow-up visits.

Address for correspondence: Dr. J. Brintha Jei, Department of Prosthodontics, SRM Dental College, Ramapuram, Chennai, Tamil Nadu, India.
E-mail: brinthajei@yahoo.co.in

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Spearman's correlation coefficients did not reveal any significant clinical correlation between lattice strain and dentinal hypersensitivity.

Conclusion: Dual cure resin cements generate greater lattice strain as compared to resin modified glass ionomer cements.

Keywords: Postoperative sensitivity, resin cements, resin-modified glass ionomer cement, synchrotron X-ray diffraction

INTRODUCTION

The cement sealing the interface between the tooth and the permanent prosthesis is a luting agent.[1] It functions as a protective layer, inhibiting microbial assault. Furthermore, it must function as a defense mechanism against dentinal hypersensitivity. This is because postcementation dentinal hypersensitivity is a common complication.[2] As a result, while selecting a luting agent, the prepared tooth's esthetic, functional, and biological requirements must be addressed.[1-4] To achieve maximum performance, physiological, biochemical, and handling characteristics must be considered in a clinical situation.[4] Dentinal hypersensitivity after cementation is more common in resin-based cement, which is a cause for concern; however, their retention is much higher than that of their counterparts.[5-7] Instead of conventional cement that primarily bonds mechanically, resin cements bond micromechanically and resin-modified glass ionomer chemically.[5,7,8]

Although resin-based cement is less soluble, brittle, and has a predictable setting reaction, it undergoes volumetric shrinkage during the setting reaction.[1,6,8] This, in turn, causes stresses to build within the dentin.[8] Because any stress is associated with strain, lattice strain is produced.[8.9] Cuspal deflection tests with restorative composites revealed a substantial strain produced in the enamel lattice due to composite polymerization.[9,10] Luting cement does not contain fillers; thus, polymerization shrinkage is expected to be higher.[3,7-9] Synchrotron X-ray diffraction was used in this study to quantify the strain produced in dentin. Synchrotron X-ray diffraction varies from conventional techniques in that it assesses at the crystalline level and measures the various lattice axes. This type of diffraction does not require the samples to be powdered which can affect the results, hence was chosen.[11,12]

Dentinal hypersensitivity is a common complication, yet research has not shown a correlation between the strain produced in the dentinal lattice and the degree of hypersensitivity. As a result, the objective of this study was to use synchrotron X-ray diffraction to measure the lattice strain generated in dentin as a result of polymerization of resin-based cement and to correlate it clinically with dentinal hypersensitivity.

MATERIALS AND METHODS

The study was performed after obtaining clearance from the Institutional Review Board (SRMDC/IRB/2019/MDS/No. 208). Forty-four noncarious premolars extracted for orthodontic treatment were collected. Dentin slabs were made along the longitudinal aspect of the buccal surface of premolars after enamel removal using a high-speed air rotor. The dimensions of the slabs were 2 mm × 2 mm × 1.5 mm [Figure 1]. These were stored in normal saline to prevent dehydration. The dentin slabs made from the buccal aspect were used for synchrotron X-ray diffraction. They were divided into Groups A and B, with 22 samples in each group. To Group A dual-cured resin cement (Self-Etch, Self-Adhesive Dental Cement Maxcem Elite, Kerr Corporation, Europe) and to Group B resin-modified glass ionomer cement (HYBond Resiglass, SHOFU Dental ASIA-Pacific Pte. Ltd) were applied

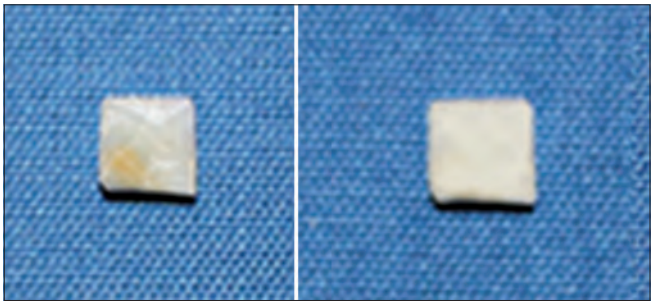

Figure 1: Dentin slabs before and after application of cement

Table 1: Composition of cements used

Luting cement	Composition
Dual Cure Resin Cement (Self-Etch, Self-Adhesive Dental Cement Maxcem Elite, Kerr Corporation, Europe)	Glycerol dimethacrylate dihydrogen phosphate, comonomers- mono-, di-, and tri-functional methacrylate monomers), self-curing activator, redox activator, camphoroquinone, barium glass fillers, fluoroaluminosilicate glass fillers, fumed silica fillers
Resin modified glass ionomer cement (HYBond Resiglass, SHOFU Dental ASIA-Pacific Pte. Ltd)	Glass powder, polyacid, water, 2-hydroxyethyl methacrylate, camphoroquinone

according to manufacturer's instructions only on the buccal aspect longitudinally [Table 1]. The dual resin cement was dispensed on the mixing pad with the automixing dispensing tip placed. Using a Teflon-coated plastic filling instrument, it was applied on the buccal aspect of the dentin slab. For the resin-modified glass ionomer cement, 1.6 g of powder using the scoop provided by the manufacturer was dispensed onto the mixing pad and mixed with 1 g of liquid. Manipulation of the cement was done using an agate spatula (GC Mixing Agate spatula, GC Corporation, Tokyo, Japan) and coated onto the dentin slabs. The thickness of the luting cement was maintained at 25 μ which was verified using an electronic gauge (Minicon Electronic Gage, Seimitsu, Tokyo, Japan) with accuracy of 0.5 pm. These samples were left for 24 h for postpolymerization effects.[13]

For synchrotron X-ray diffraction, the mid-point of the dentin slab was the target. Then, the cement was applied, following which the same point underwent the diffraction test. SXRD measurements were carried out on the BL-11, Indus-2 Synchrotron facility at Raja Ramanna Centre for Advanced Technology, Indore, India [Figure 2]. The incident beam energy was 15 KeV with a wavelength of 0.8266Å and the size of the beam was 100 μ × 100 μ measured using refractive lens. Onto the X-y stage, the dentin slabs were mounted normal to the X-rays to measure in two aspects that may be perpendicular to the incident beam. The incident beam emitted from the bending magnet was monochromated by a Silicon (Si111) crystal-cut monochromator. Kirkpatrick-Baez micro focusing mirror system was used to focus the direct beam. 8-axis motorized goniometric stage was kept at a distance of 160 mm behind the sample to give a 2θ of 25° which would correspond to a Q range of 1.3–15$Å^{-1}$. The exposure time was 180 s, and the diffraction data were collected using Max345 image plate detector with a resolution of 3450 × 3450 pixels. Standard Lanthanum Hexaboride (LaB6) powder was used to calibrate the X-ray detector.

ESRF software Fit2D was used to produce diffraction pattern [Figure 3] and graph of Intensity versus Scattering angle (2θ) [Figure 4]. The Bragg peaks of 10° and 13° were chosen as they are perpendicular to the "c" and "a" axes of the hydroxyapatite crystal. Following the X-ray diffraction, the lattice strain was calculated using,

Equation 1:

$$\varepsilon = \frac{P_{after} - P_{before}}{P_{before}}$$

"P" refers to the lattice parameter before and after the application of luting cement. All 44 samples were tested before and after applying the cement.

In order to correlate it clinically, postoperative sensitivity was evaluated. A total of 42 patients (21 patients in each group) undergoing fixed prosthodontic treatment were chosen. The inclusion criteria were vital right and left premolars and molars mandibular molar requiring full metal crown or three-unit fixed partial denture with edentulous space bounded by premolar and molar teeth requiring full metal crown, patient age between 18 and 50 years with an average of 35.5 years, and willingness to sign the consent form. The exclusion criteria were patients with systemic diseases, caries, pulpitis, periodontal disease, pregnant or lactating women, medication under analgesic drugs and patients receiving desensitizing treatment for more than

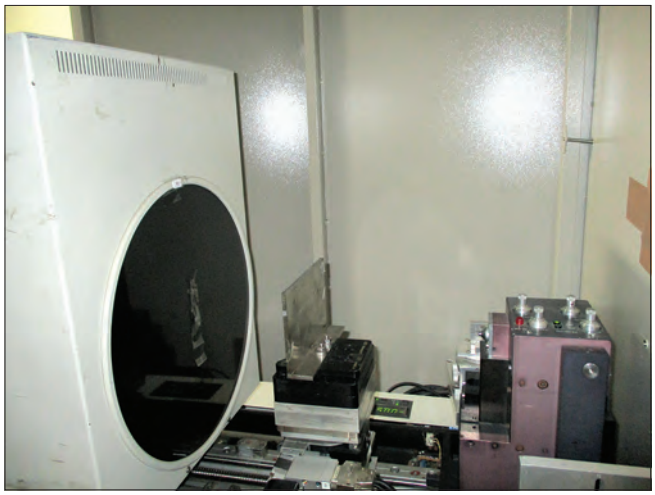

Figure 2: Synchrotron X-ray diffraction unit

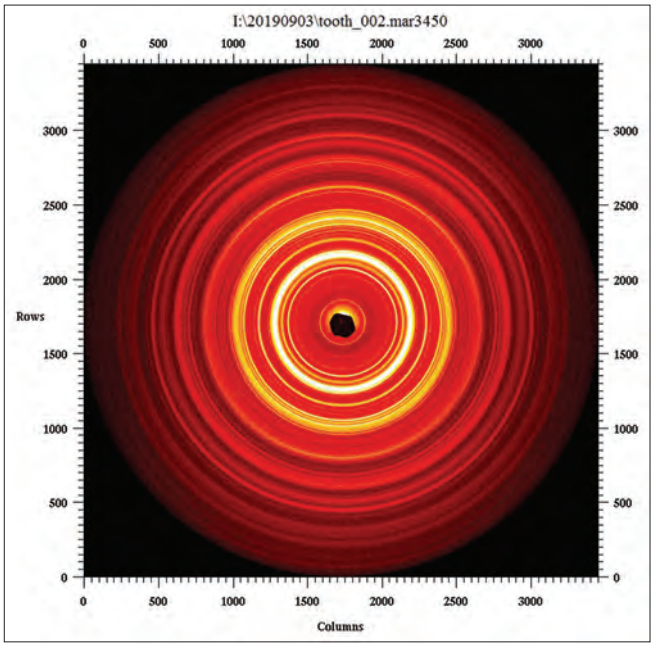

Figure 3: Diffraction pattern

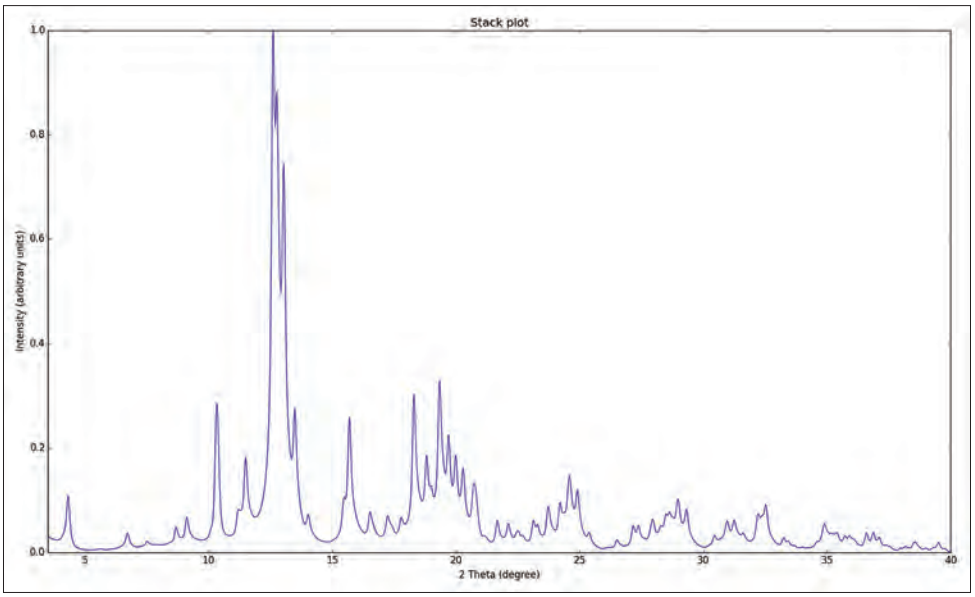

Figure 4: Graph of intensity versus scattering angle

3 months. The patient was blinded to the group which they belonged to. The teeth were prepared for all metal prostheses by a single operator to avoid interoperator variability, and the sensitivity was checked with a cold air blast with a temperature of 12°C and a pressure of 60 psi for 5 s. The cold stimulus was generated using a customized thermoelectric device. After tooth preparation, impressions were made using polyvinyl siloxane impression material-putty and light body consistency (Dentsply aquasil, Charlotte, North Carolina). The casts were poured using type-IV gypsum product (Ultrarock diestone, Mumbai, India), Die hardener (Yeti dental, Germany), and die spacer (Yeti dental, Germany) was applied. The wax pattern was fabricated using pattern wax (Maarc dental, Palghar, India), invested (Bellavest and Bego sol), and casted using nickel–chromium alloy (Denchrome NG, Germany). The metal crowns were luted with resin cement (Group A) and RMGIC (Group B). Without having the knowledge which cement was applied the investigator recorded the patient's sensitivity score. The sensitivity was evaluated immediately after cementation and in follow-up visits of 1 week and 1 month. The stimulus was directed toward the buccal aspect and the evaluation was done by the same operator in all the follow-up visits. The response of the patient to the stimulus was measured using Schiff's cold air sensitivity scale:

0 – Subject does not respond to air stimulus.

1 – Subject responds to air stimulus but does not request discontinuation of stimulus.

2 – Subject responds to air stimulus and requests discontinuation or moves from the stimulus.

3 – Subject responds to air stimulus, considers stimulus to be painful, and requests discontinuation of the stimulus.

Independent *t*-tests were done to statistically analyze the lattice strain generated between the two axes and two cements using IBM SPSS Statistics for Windows, Version 21.0 Statistics for Windows. The evaluation of dentinal hypersensitivity was done postcementation, after 1 week and 1 month and measured using the Schiff's sensitivity scale. The statistical analysis was done using Mann–Whitney *U*-test. In order to correlate the lattice strain clinically with dentinal hypersensitivity, Spearman's correlation coefficient was used.

RESULTS

The lattice strain generated in dentin was measured using synchrotron X-ray diffraction before and after the application of the resin-based luting cement. The lattice parameters were evaluated along the "a" and "c" axes. Independent *t*-tests were done to statistically analyze the lattice strain generated between the two axes and two cements using SPSS Statistics for Windows. The evaluation of dentinal hypersensitivity was done postcementation, after 1 week and 1 month and measured using the Schiff's sensitivity scale. The statistical analysis was done using Mann–Whitney *U*-test. In order to correlate the lattice strain clinically with dentinal hypersensitivity, Spearman's correlation coefficient was used.

The results of synchrotron X-ray diffraction of the dentin slabs are represented in Figure 4. The mean lattice strain along the "a" axis was 0.01986 and 0.0100 in Groups A

and B, respectively. Similarly, the mean lattice strain along the "c" axis was 0.03336 and 0.01955 in Groups A and B, respectively. Statistical analysis using Independent *t*-test with a $P = 0.01$ shows a statistically significant difference between Groups A and B along both "a" and "c" axes. The lattice strain was significantly higher in Group A along the c-axis [Tables 2 and 3].

The mean hypersensitivity score using Schiff's scale was 2.82 and 2.14 in Groups A and B, respectively, immediately after cementation. At the end of 1 week, the mean scores were 1.5 and 1.23 in Groups A and B. At the end of 1 month, the mean was 0.50 and 0.59 in Groups A and B, respectively. Statistical analysis using Mann–Whitney *U*-test shows a statistically significant difference between the two groups with higher sensitivity in Group A immediately after cementation but no statistical significance in the follow-up visits. Spearman's correlation coefficient revealed no significant correlation between lattice strain and dentinal hypersensitivity in both groups [Tables 4 and 5].

DISCUSSION

The amount of strain induced by polymerization shrinkage of resin-based cement on a prepared dentinal surface was measured in this study. Although this strain is detectable, there is a lack of research on the effect on hydroxyapatite crystals, which are regarded as the primary/basic unit of dental hard tissues.[13-15] The strain is mainly caused by polymerization shrinkage during the setting of resin-based cement.[16-19] When these cements are set, they contract in volume, and the tension generated by volumetric shrinkage is imparted to the tooth structure to which they are bound.[3-5] Research has indicated that restorative composites pose stress transfer to the enamel.[11,20,21] Laboratory investigations, such as cuspal deflection methods,[22-25] asserted that some strain is exerted on the tooth's hard tissue, but it could not be quantified. The strain induced at the lattice level was studied using Synchrotron X-ray diffraction in this study. This methodology was adopted because it primarily focuses on the strain fostered in the crystalline structure without altering the sample to powders or liquids.[11,12,26]

Only the strain built within the hard tissue or inorganic component of the tooth was investigated in this study. Nonetheless, research has revealed that the volumetric shrinkage that occurs after the polymerization of resin-based cement cause abnormalities in the protein matrix to which the hydroxyapatite is coupled.[16,17,27] As a corollary, the dentin is already stressed even before it reaches the axis of the hydroxyapatite crystal.[28,29] The strain distribution along the axes demonstrates that the lattice strain was higher along the "c" axis than the "a" axis in both groups. The geographic location of the "c" axis and its orientation to the load direction leading to higher strain.[28,30,31] Meanwhile, they are already under pressure as a result of the protein matrix. As a result, polymerization shrinkage generates additional strain in addition to the strain produced within the axes.[32-35] Cuspal deflection studies provide evidence that the "a" axis in dentin would have more preexisting residual compressive strain than the "c" axis.[36-39] The results of this study are opposed to this. The hydroxyapatite crystals are angled rather than parallelly organized, which explains the higher strain.[11,33,36,40,41] As a result, this variance in crystalline morphology may not have been as significant in a powdered sample as in the dentin slab used in this study.

The magnitude of strain developed within the lattice is affected by the direction of the "c" axis relative to the bending moment.[42] The amount of strain created in resin cement was higher in this study than in resin-modified glass ionomer cement. Resin cement is a composite devoid of fillers. Fillers are often responsible for maintaining a stable matrix, minimizing polymerization shrinkage.[5,6,19,20] Since

Table 2: Independent *t*-test analysis for lattice strain along "a" and "c" axes

	t-test for equality of means						
	t	df	Significant (two-tailed)	Mean difference	Standard error difference	95% CI of the difference	
						Lower	Upper
Lattice strain along a-axis (Ea)	6.272	42	0.000	0.009864	0.001573	0.006690	0.013037
Lattice strain along c-axis (Ec)	6.147	42	0.000	0.013818	0.002248	0.009282	0.018355

CI: Confidence interval

Table 3: Mann–Whitney *U*-test for statistical analysis of hypersensitivity between Groups A and B postcementation, after 1 week and 1 month

	Hypersensitivity - postcementation	Hypersensitivity - 1 week	Hypersensitivity - 1 month
Mann–Whitney *U*	144.000	203.000	214.500
Wilcoxon W	397.000	456.000	467.500
Z	−2.699	−0.957	−0.746
Asymptotic significant (two- tailed)	0.007	0.338	0.456

Table 4: Spearman's correlation coefficient for Group A

		Lattice strain along a -axis (Ea)	Lattice strain along c - axis (Ec)	Hypersensitivity - Post operative	Hypersensitivity - 1 week	Hypersensitivity - 1 month
Lattice strain along a -axis (Ea)	Pearson Correlation	1	0.051	0.347	0.457*	0.010
	Sig. (2-tailed)		0.822	0.114	0.032	0.965
	N	22	22	22	22	22
Lattice strain along c - axis (Ec)	Pearson Correlation	0.051	1	-0.011	0.219	0.139
	Sig. (2-tailed)	0.822		0.962	0.328	0.537
	N	22	22	22	22	22
Calcium without application of cement (ppm)	Pearson Correlation	0.207	-0.206	-0.005	0.361	-0.100
	Sig. (2-tailed)	0.356	0.358	0.981	0.099	0.658
	N	22	22	22	22	22
Calcium with application of cement (ppm)	Pearson Correlation	0.056	-0.338	0.203	-0.148	-0.104
	Sig. (2-tailed)	0.803	0.123	0.366	0.511	0.646
	N	22	22	22	22	22
Hypersensitivity - Post operative	Pearson Correlation	0.347	-0.011	1	0.119	0.000
	Sig. (2-tailed)	0.114	0.962		0.597	1.000
	N	22	22	22	22	22
Hypersensitivity - 1 week	Pearson Correlation	0.457*	0.219	0.119	1	0.046
	Sig. (2-tailed)	0.032	0.328	0.597		0.839
	N	22	22	22	22	22
Hypersensitivity - 1 month	Pearson Correlation	0.010	0.139	0.000	0.046	1
	Sig. (2-tailed)	0.965	0.537	1.000	0.839	
	N	22	22	22	22	22

*Correlation is significant at the 0.05 level, **Correlation is significant at the 0.01 level

Table 5: Spearman's correlation for Group B

Spearman's rho	Lattice strain along a -axis (Ea)	Lattice strain along c-axis (Ec)	Hypersensitivity - Postoperative	Hypersensitivity - 1 week	Hypersensitivity - 1 month
Lattice strain along a-axis (Ea)					
Correlation coefficient	1.000	−0.096	−0.473*	−0.195	−0.137
Significant (two-tailed)		0.670	0.026	0.384	0.542
n	21	21	21	21	21
Lattice strain along c-axis (Ec)					
Correlation coefficient	−0.096	1.000	−0.145	−0.240	−0.354
Significant (two-tailed)	0.670		0.520	0.282	0.106
n	21	21	21	21	21
Significant (two-tailed)	0.763	0.485	0.329	0.245	0.154
n	21	21	21	21	21
Hypersensitivity - Postoperative					
Correlation coefficient	−0.473*	−0.145	1.000	0.367	0.021
Significant (two-tailed)	0.026	0.520		0.093	0.927
n	21	21	21	21	21
Hypersensitivity - 1 week					
Correlation coefficient	−0.195	−0.240	0.367	1.000	0.542**
Significant (two-tailed)	0.384	0.282	0.093		0.009
n	21	21	21	21	21
Hypersensitivity - 1 month					
Correlation coefficient	−0.137	−0.354	0.021	0.542**	1.000
Significant (two-tailed)	0.542	0.106	0.927	0.009	
n	21	21	21	21	21

*Correlation is significant at the 0.05 level, **Correlation is significant at the 0.01 level

resin cement lacks these fillers, and shrinkage occurs to a significant degree.[2,21,22] The primary difference between resin cement and resin-modified glass ionomer cement is resin modification.[3-5,19]

Postoperative sensitivity is a common complication after complete coverage restoration of vital teeth.[39] The use of resin cement and resin-modified glass ionomer cement is one of the causes.[38,39] This study aimed to find a correlation between hypersensitivity and lattice strain in hydroxyapatite crystals. The sensitivity was evaluated with a cold air blast on full coverage all-metal restorations on posterior vital abutment teeth, and scores were determined using Schiff's cold air sensitivity scale.[20] It is response-based testing wherein the stimulus is constant, but the subject's response varies. This study revealed a statistically significant difference between the two groups immediately postcementation but not in the follow-up visits.

Although it appeared to be associated with lattice strain at first, it became insignificant later on. As a result, it was not possible to formulate a precise correlation. When the dentinal tubules are open, dentinal hypersensitivity develops.[38,39] Common reasons include enamel loss due to attrition, abrasion,[40] and deliberate enamel removal during tooth preparation,[41] leading to dentinal tubule opening. When prepared teeth are luted with any cement, they tend to clog the dentinal tubules mechanically.[38-40]

Similarly, hypersensitivity was greatest after cementation and lessened in follow-up visits in this study. The reaction products may cause narrowing of the dentinal tubules, resulting in a reduced hypersensitivity. Previous research has shown that variations in postoperative hypersensitivity might be attributed to changes in the smear layer on the prepared dentin.[40,41]

El-Din Saed *et al*.[42] reported that hypersensitivity with resin-modified glass ionomer cement was substantially lower than with resin cement in the case of PFM crowns. A study by Souza *et al*.[43] made the same claim. The explanation for this might be that resin cement alters the smear layer more aggressively than resin-modified glass ionomer cement. Our findings were partially consistent with previous studies in that hypersensitivity was initially lesser in resin-modified glass ionomer cement with statistical significance but not in follow-up visits. One probable explanation is that the reaction in dual-cure resin cement continues, resulting in the production of reaction products at a later stage, which might mechanically obstruct the dentinal tubules, resulting in a drop in hypersensitivity scores.

The study's limitation was that it is primarily a laboratory investigation. *In vitro* parameters were assessed on extracted premolars, whereas postoperative sensitivity was assessed on all posterior teeth. Other forms of the fixed prosthesis were not considered; only posterior metal crowns were analyzed.

CONCLUSION

1. The resin cement produced more lattice strain than the resin-modified glass ionomer cement
2. Both groups had a higher distribution of strain along the "c" axis
3. After cementation, postoperative sensitivity was higher in resin cement than in resin-modified glass ionomer cement, but this difference was not significant later
4. Considering lattice strain and postoperative hypersensitivity, resin-modified glass ionomer cement is a superior luting cement for full-coverage metal restorations than resin cement.

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Conflicts of interest
There are no conflicts of interest.

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Research

Comparison of titanium dioxide nanoparticles and silver nanoparticles for flexural strength once incorporated in heat-cure acrylic denture base resin: An *in vitro* Study

Ektha Pai, Ajaykumar Nayak, Rajendra B. Hallikerimath, Zarir Ruttonji, Preeti Astagi, Smita Pokale

Department of Prosthodontics, Maratha Mandal's Nathajirao G. Halgekar Institute of Dental Sciences and Research Centre, Belagavi, Karnataka, India

Abstract

Aim: Polymethylmethacrylate (PMMA) resin is the most by and large used denture base material. Denture fractures are sequential to the flexure or impacting forces. Different nanoparticles such as titanium dioxide and silver nanoparticles have been used to improve its antimicrobial properties. There are limited data on their effect on flexural strength. The aim of the study was to assess the effect of silver nanoparticles and titanium dioxide nanoparticles addition on flexural strength of PMMA resins.

Settings and Design: One hundred and thirty specimens divided into four groups: Control Group A, TiO_2-reinforced Group B, silver nanoparticles reinforced Group C, and mixture of TiO_2 and silver nanoparticle reinforced Group D. Each reinforced group further divided based on concentrations -0.5%, 1%, 2%, and 3%.

Materials and Methods: Rectangular metal models of the American Dental Association (ADA)- specified dimensions: 65 mm × 10 mm × 3 mm were used to form a mold space for the fabrication of specimens. Three-point bend test was used to determine the flexural strength of the samples after immersion in distilled water for 2 weeks.

Statistical Analysis: The data collected were subjected to analysis of variance followed by *post hoc* Tukey's test.

Results: The comparison of the mean flexural strengths showed a statistically significant gradual decrease on increasing the concentrations of nanoparticles. Maximal flexural strength was seen in the control group and least with 3% Ag + TiO_2 Nps. The modified specimen also showed color changes.

Conclusions: In an *in vitro* environment, addition of TiO_2 and silver decreases the flexural strength of the PMMA. It also causes visible color changes.

Keywords: Denture base acrylic resin, flexural strength, nanoparticles, silver, titanium dioxide

Address for correspondence: Dr. Ektha Pai, Department of Prosthodontics, Maratha Mandal's Nathajirao G. Halgekar Institute of Dental Sciences and Research Centre, Belagavi, Karnataka, India.
E-mail: drekthapai21@gmail.com

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INTRODUCTION

Advances in the medical field have increased the life expectancy, leading to rise in geriatric population; hence, there is a growing need for removable prosthesis. Ordinarily, polymethylmethacrylate (PMMA) resins are

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used as denture base material for the fabrication of prosthesis such as dentures, oral maxillofacial prosthesis, and implant-supported dentures. It satisfies all the needs for an ideal denture base material such as favorable working characteristics, good stability and fit, stability in color, and excellent esthetics and can be processed with relatively low cost equipments.[1]

PMMA material was discovered by British chemists, Rowland Hill and John Crawford which apart from its use in dentistry, has been used in the fields of medicine and industrial polymeric sciences. It is widely used because of its biocompatibility with host tissues, long-term reliability, and mechanical and esthetic properties.[2,3]

Over the years, various materials, such as nystatin, silver nitrate, aloe vera extracts, and tulsi extracts, have been incorporated to improve the antimicrobial nature of PMMA. Futhermore, recently, inclusion of nanoparticles of silver and titanium dioxide into PMMA has been proven to enhance its antifungal and antibacterial properties.[4]

The fractures of dentures result predominantly due to the flexural fatigue and impact. Flexural fatigue occurs after reduplicated flexing of any material wherein, a structure, after being subjected to minor cyclic loads may eventually fracture the material. Impact failures originate extraorally as a result of a sudden jolt to the denture or accidental drop whereas brushing, coughing, or sneezing.[5]

Multitudinous attempts have been proclaimed to improve the mechanical properties of the acrylic materials, but most of them are not conveyed in clinical dentistry due to processing straits and exorbitant costs.[5] There are studies that have used e-glass fibers, zinc oxide, silica and some nanoparticles of silver, titanium dioxide, silica, and prepolymer, incorporated in PMMA to improve its physical properties.

James Clerk Maxwell proposed the path-breaking concept of nanotechnology in mid 1800s. Few of the widely used nanoparticles in the field of dentistry are carbon-based, hydroxy apatite, zirconia, iron oxide, silica, silver, and titanium dioxide.[6] The incorporation of nanostructures in PMMA has bettered modulus and strength, and it could maintain or improve ductility and esthetic properties. Furthermore, PMMA has developed achievable antimicrobial properties after addition of nanoparticles.[7-9]

As additives to biomaterials, titanium dioxide nanoparticles are used as they are inexpensive, biologically compatible materials that do not cause toxicity. They have been used to enhance antimicrobial properties and overall mechanical properties.[10] Titanium dioxide nanoparticles are efficient against broad range of bacteria, fungi, and viruses.[7]

The nanoparticles of silver are one of the most ordinarily used nanoparticles because of their capacities of ductility, electrical and thermal conductivity, and antimicrobial activity.[11] The incorporation of silver nanoparticles into PMMA has shown to increase the compressive strength but might decrease the tensile strength and the esthetic value due to discoloration. There are no proper conclusive studies regarding its influence on the flexural strength of PMMA.[12]

Hence, this study was to assess the aftermath of addition of silver nanoparticles and titanium dioxide nanoparticles on flexural strength of PMMA resins.

The objectives of the study were to determine the flexural strengths of each of the sample groups and compare them with the control group as well as with each other.

Research hypothesis

There is a significant difference in flexural strength of conventional heat-cure acrylic denture base material on the addition of silver and titanium dioxide nanoparticles.

Null hypothesis

There is no significant difference in flexural strength of conventional heat-cure acrylic denture base material on addition of silver and titanium dioxide nanoparticles.

MATERIALS AND METHODS

The sample dimensions were preferred according to ADA specification No. 12, that are, 65 mm × 10 mm × 3 mm for determining the flexural strength [Figure 1] and used for the study. Specimens with lesser than the specified dimensions, visible surface porosities, and irregular surfaces were discarded.

Five solid stainless-steel block (SS-304) models were prepared to the dimensions slightly larger than the dimensions specified in Figure 1, that is, 65 mm × 15 mm × 5 mm to compensate for the changes in the dimension due to polymerization shrinkage as well as trimming and finishing when replaced with acrylic resin [Figure 2]. An additional 5 mm × 15 mm × 5 mm of modeling wax (Hindustan modelling wax) was used to extend the stainless-steel model for their easy retrieval from the dental stone without damaging the edges of the mold created by double pour technique. The flasks were placed in dewaxing

chamber at 100 for 30 min.[13] This mold was used for fabricating acrylic specimen containing nanoparticles.

For preparation of the control group A specimens, the monomer and polymer of heat-polymerizing denture base resin (Dental Products of India, Mumbai) were mixed according to manufacturer's instructions and packed into the flasks. These flasks were then heat cured at 74°C for 2 h and increasing the water bath temperature to 100°C and processing for 1 h which were then bench cured for 30 min.[13] Subsequently, flasks were immersed in cool tap water for 15 min. After the curing cycle, the resin blanks were removed from the flasks and were trimmed with lathe and finished with #180 Emery Sand Paper (Janson Hardware, Bengaluru), finished, and polished. Their dimensions were then verified to the specified measurements. They were immersed in distilled water to remove any residual monomer and subjected to testing.[14]

Commercially available titanium dioxide and silver nanoparticles (Ultra nanotech, Bangalore) of 25 nm sizes each were weighed using a digital high precision balance (Wensor–TM, Model: PGB 200, Range 0.0019, Okhla, New Delhi) and added to respective test tubes (Borosil glassware Laboratories, Mumbai) containing Methyl Methacrylate–Monomer. This mixture was then sonicated in a sonicator (Q Sonica LLC, Model Q55, U. S. A.) for 1 h to get homogeneous suspension.[14] These test tubes were labeled according to different concentrations. The study required addition of four different concentrations of nanoparticles-0.5%, 1%, 2%, and 3% [Figure 3].

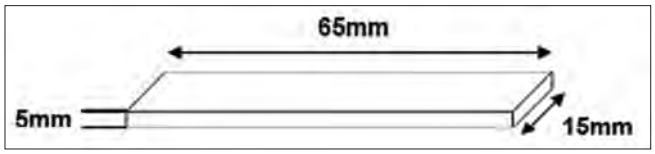


Figure 1: Dimensions of metal model

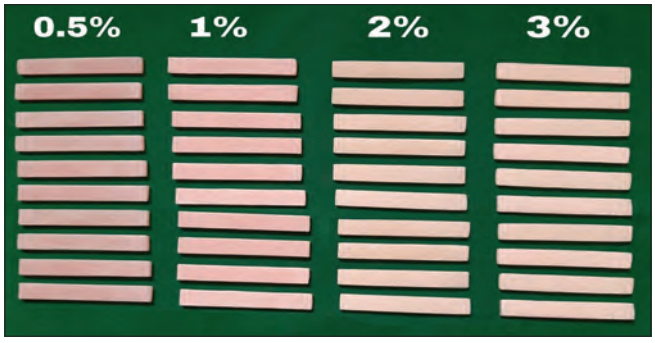


Figure 3: Specimens of Group B PMMA and titanium dioxide nanoparticles. PMMA: Polymethylmethacrylate

The process was repeated for specimens containing silver nanoparticles as well as for specimens containing a mixture of silver and titanium dioxide nanoparticles [Figures 4 and 5] The mixture was packed into prepared mod and processed similar to control group A.

Before flexural strength tests, the specimens were placed in distilled water for 50 h at room temperature[14] and then subjected to fracture in the universal testing machine (ACME Engineers, Pune, Model No. UNITEST-10). Specimens were tested with 3-point bend test by maintaining the cross-head speed at 5 mm/min

The maximum force (F) necessary to produce fracture of the specimen was recorded in Newton (N). The flexural strength Q was calculated in (MPa) for all specimens using Equation:

$$Q = \frac{3FI}{(2BH^2)}$$

"*F*" = maximum force/fracture in Newton (N)

"*I*" = distance between the two supporting points in (mm)

"*B*" = specimen width in (mm)

Figure 2: Metal Models to make the mould

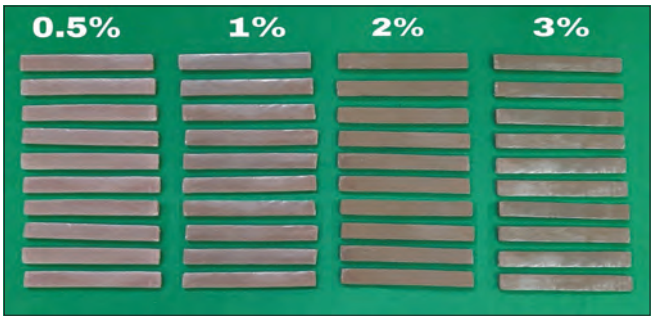


Figure 4: Specimens from Group C PMMA and silver nanoparticles. PMMA: Polymethylmethacrylate

"*H*" = specimen height subjected to bending in (mm).

Sample size was estimated based on flexural strength test results for 0% and 1% titanium dioxide incorporation as per Sodagar *et al*., 2016[14] and 0% and 0.8% by weight concentration of silver nanoparticle incorporation as per Köroğlu *et al*.[15] Sample size was calculated using G-power sample size estimation software version 3.1.9.2 (IBM SPSS Statistics Inc., Chicago, Illinois, USA). The α-error was considered to be 5% and the β-error was considered to be 20%. For ease of calculations, the sample size for each subgroup was estimated to ten samples making it a total sample size of 130 blanks of acrylic.

Comparison of flexural strength between conventional permanent acrylic denture base material (Control Group A) to the flexural strength of titanium dioxide nanoparticle incorporated heat-polymerizing denture base material (Group B: four subgroups 0.5%, 1%, 2%, and 3% by weight), silver nanoparticle incorporated permanent acrylic denture base material (Group C: four subgroups 0.5%, 1%, 2%, and 3% by weight) and titanium dioxide nanoparticles and silver nanoparticles incorporated permanent acrylic denture base material (Group D: four subgroups 0.5%, 1%, 2%, and 3% by weight) was done by analysis of variance (ANOVA) individually. All three tests were succeeded by *post hoc* Tukey's Test. Probability value of <0.05 was considered statistically significant.

RESULTS

The data were coded and entered into a Microsoft Excel sheet. Statistical analysis was done using SPSS version 20 (IBM SPSS Statistics Inc., Chicago, Illinois, USA) software.

The flexural strength of all groups at 0.5%, 1%, 2%, and 3% concentrations were found to be significant at 0.01 level when compared using one-way ANOVA [Table 1].

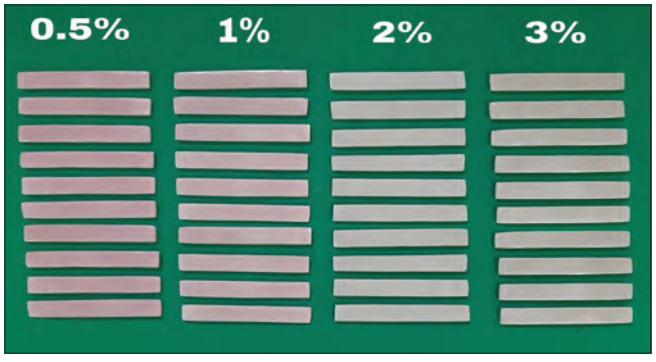


Figure 5: Specimens from Group D PMMA and titanium dioxide and silver nanoparticles. PMMA: Polymethylmethacrylate

The flexural strength of different concentrations of TiO_2 was found to be significant at 0.01 level [Table 2]. Tukey's *post hoc* test revealed that all groups when compared with each other showed a significant difference at 0.01 level except for 0.5% TiO_2 and 1% TiO_2 which was significant at 0.05 level.

The flexural strength of different concentrations of Ag was found to be significant at 0.01 level when compared using one-way ANOVA [Table 3]. Tukey's *post hoc* test revealed that all groups when compared with each other showed a significant difference at 0.01 level.

Table 1: Comparison of flexural strength between same concentrations of different groups with control Group A

	n	Mean	SD	95% CI	*F*	*P*
Control	10	138.56	4.84	135.09-142.02	82.15	0.0001*
0.5% TiO_2	10	125.01	6.07	120.68-129.36		
0.5% Ag	10	115.86	4.26	112.80-118.91		
0.5% TiO_2 + Ag	10	105.64	4.09	102.72-108.57		
Total	40	121.27	13.13	117.07-125.47		
1% TiO_2	10	118.23	5.01	114.65-121.82	193.52	0.0001*
1% Ag	10	106.38	4.08	103.47-109.30		
1% TiO_2 + Ag	10	94.38	2.85	92.33-96.41		
Total	40	114.39	17.02	108.94-119.83		
2% TiO_2	10	106.75	4.89	103.25-110.25	335.88	0.0001*
2% Ag	10	95.40	3.30	93.04-97.76		
2% TiO_2 + Ag	10	83.50	2.90	81.42-85.58		
Total	40	106.05	21.12	99.30-112.81		
3% TiO_2	10	94.97	5.38	91.12-98.82	444.07	0.0001*
3% Ag	10	87.10	2.44	8535-88.84		
3% TiO_2 + Ag	10	75.56	3.23	73.25-77.87		
Total	40	99.05	24.46	91.22-106.87		

TiO_2: Titanium dioxide, Ag: Silver, SD: Standard deviation, CI: Confidence interval. **P* value <0.05

Table 2: Comparison of flexural strength between groups with different concentrations of titanium dioxide and control Group A

	n	Mean	SD	95% CI	*F*	*P*
Control	10	138.56	4.84	135.09-142.02	101.35	0.0001*
0.5% TiO_2	10	125.02	6.07	120.68-129.36		
1% TiO_2	10	118.23	5.01	114.65-121.82		
2% TiO_2	10	106.75	4.90	103.25-110.25		
3% TiO_2	10	94.97	5.38	91.12-98.81		
Total	50	116.71	15.94	112.18-121.24		

Tio_2: Titanium dioxide, CI: Confidence interval, SD: Standard deviation. **P* value <0.05

Table 3: Comparison of flexural strength between groups with different concentrations of silver nanoparticles and control Group A

	n	Mean	SD	95% CI	*F*	*P*
Control	10	138.5590	4.84467	135.09-142.02	264.96	0.0001*
0.5% Ag	10	115.8550	4.26379	112.80-118.91		
1% Ag	10	106.3830	4.07782	103.47-109.30		
2% Ag	10	95.4000	3.29519	93.04-97.76		
3% Ag	10	87.0990	2.43929	85.35-88.84		
Total	50	108.6592	18.40134	103.43-113.89		

Ag: Silver, SD: Standard deviation, CI: Confidence interval. **P* value <0.05

The flexural strength of different concentrations of TiO_2 + Ag was found to be significant at 0.01 level when compared using one-way ANOVA [Table 4]. The test revealed that all groups when compared with each other showed a significant difference at 0.01 level.

Graphs 1 and 2: A comparison of the mean flexural strengths of all groups reveals that the highest flexural strength is seen in the control Group A with unmodified PMMA (mean = 138.56 MPa). Titanium dioxide nanoparticles incorporation to PMMA of the concentration 0.5 wt% shows highest flexural strength (mean = 125.01 MPa) among the modified PMMA. The graph shows a decrease in the flexural strength on higher concentrations of titanium dioxide nanoparticles least in the 3 wt% modified specimen within Group B (mean = 94.97 MPa).

The mean flexural strengths of the specimens in Group C with silver nanoparticles modified PMMA, decrease with increase in concentrations of the nanoparticles. When the mean flexural strength of Group C is compared with that of Group B, it can be seen that the mean flexural strength of 0.5 wt% silver nanoparticles modified PMMA (mean = 115.86 MPa) has similar strength to that of 1 wt% titanium dioxide nanoparticles modified PMMA (mean = 118.23 MPa).

A similar trend is seen with the specimens in Group D when the mean flexural strength is compared with that of Group C and Group A. The mean flexural strength of the 0.5 wt% silver–titanium dioxide modified PMMA (mean = 105.64 MPa) is similar to that of 2 wt% titanium dioxide nanoparticles modified PMMA (mean = 106.75 MPa) and 1 wt% silver nanoparticles modified PMMA (mean = 106.38 MPa) in groups B and C, respectively.

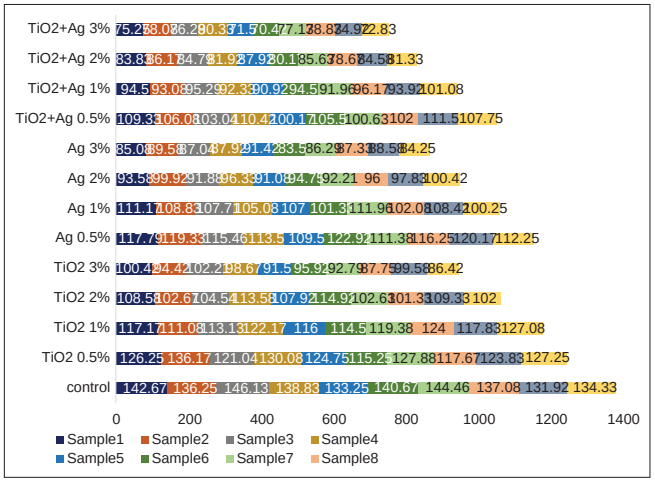
The least mean flexural strength among all the groups and subgroups is seen in 3 wt% silver–titanium dioxide nanoparticles modified PMMA with a value of 74.46 MPa in comparison to 137.18 MPa flexural strength of the unmodified PMMA of the control Group A.

Table 4: Comparison of flexural strength between different concentrations of titanium dioxide + silver with control Group A

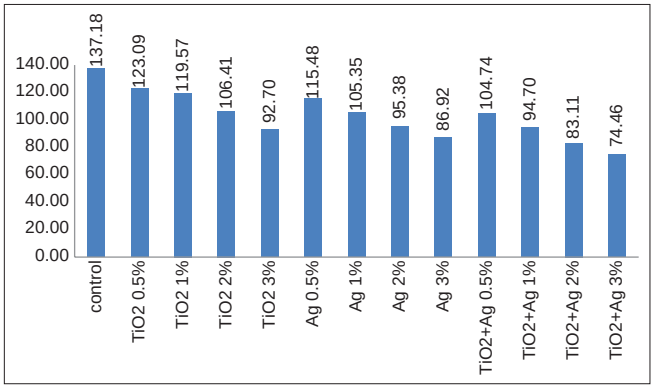
	n	Mean	SD	95% CI	*F*	*P*
Control	10	138.5590	4.84467	135.09-142.02	450.48	0.0001*
0.5% TiO_2 + Ag	10	105.6420	4.08928	102.72-108.57		
1% TiO_2 + Ag	10	94.3750	2.84572	92.33-96.41		
2% TiO_2 + Ag	10	83.5010	2.90143	81.42-85.58		
3% TiO_2 + Ag	10	75.5580	3.22586	73.25-77.87		
Total	50	99.5270	22.49346	93.13-105.92		

Tio_2: Titanium dioxide, Ag: Silver, SD: Standard deviation, CI: Confidence interval. *P value <0.05

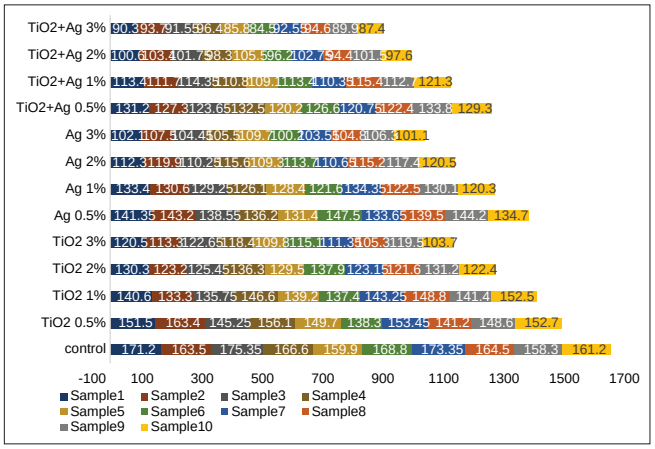
Graphs 3 and 4 show a comparison of the load applied on each sample in each subgroup. The graphs show the mean maximum load applied on the specimens during testing. The mean maximum load required to attain maximum flexural strength was seen to be applied on the specimen in the control group followed by the 0.5 wt% and 1 wt% titanium dioxide nanoparticles modified specimens. The least load required to fracture the specimen was seen in



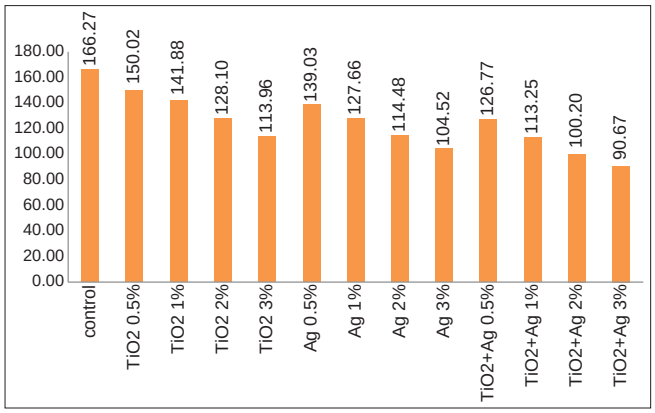
Graph 1: The flexural strength of different materials



Graph 2: Mean flexural strength of all sample groups



Graph 3: Maximum load on different materials



Graph 4: Mean maximum load applied on each specimen of all groups

3 wt% silver–titanium dioxide nanoparticles modified PMMA in Group D.

DISCUSSION

PMMA was introduced by Walter Bauer in the year 1936, after which several researches have been conducted to improve the material in the physical and biological aspects.[16]

The most commonly used material for the fabrication of dentures is the heat-cured polymethyl methacrylate because of its good biocompatibility, strength, esthetics, and ease of repair.[17] This is reflected in the problems associated with denture fracture and accumulation of microorganisms on the denture surfaces, leading to denture stomatitis and Candidiasis.[18]

Denture fractures generally result either from flexural fatigue or due to an impact.[19,20] Flexural fatigue occurs after repeated flexing of a material wherein, a structure, after being subjected to minor cyclic loads may eventually fracture the material. The midline fracture of a denture is often a result of flexural fatigue.

It has been reported that the addition of aluminum oxide fillers increases the flexural strength and thermal diffusivity,[21] whereas the addition of hydroxyapatite fillers increases the fracture toughness.[21] In geriatric patients, 2% of quaternary ammonium compounds[21] and nanoparticles of various compounds have been used to improve the biological properties of PMMA, leading to better oral hygiene.[22]

Since the term "Nanotechnology" was coined by Norio Taniguchi, nanotechnology has been extensively researched and applied.[23] Nanoparticles of zirconia, copper, zinc, silica, hydroxyapatite, titanium dioxide, and silver have been added to PMMA to enhance the mechanical and antimicrobial properties.[24] Studies have found that incorporation of titanium dioxide nanoparticles in acrylic resins improved the antimicrobial properties by drastically reducing the bacterial adherence,[25] and the incorporation of silver nanoparticles reduced the colony-forming units of *Candida albicans*.[26] Several studies indicated that titanium dioxide nanoparticles have the ability to integrate with PMMA matrix both physically and chemically and produce free radicals that aid in its antimicrobial properties.[27] Silver nanoparticles act as a broad-spectrum antibacterial and antifungal agent while having low cytotoxicity.[28]

Titanium being the fourth most abundant material on earth is easily available and inexpensive in the form of nanoparticles. They have an integrated redox reaction mechanism that enhances their photoactivity that can be efficiently activated over time.[29,30,31] A few studies suggest that the addition of these nanoparticles can improve the flexural strength[32] whereas others contradict them.[33]

In this study, the flexural strength of PMMA was specifically tested. The flexural strength of acrylic resin, according to ISO 1565, should not be <65 MPa when processed and cured by any method.[34]

According to this study, the incorporation of titanium dioxide nanoparticles decreased the flexural strength of PMMA. All the specimens were cured and stored in the similar conditions as any changes in these parameters are known to influence the properties of the material.[20,35] The control group showed a maximum flexural strength of 142.02 MPa. Incorporation of 0.5% TiO_2 showed a maximum flexural strength of 129.36 MPa with minimal visible color changes, whereas specimens with 1% TiO_2 displayed slight lightened pinkish color and the flexural strength decreased to 121.82 MPa. On further increase in the concentration of TiO_2 nanoparticles to 2% and 3%, the visible color changes varied from whitish-pink to off-white, respectively. The maximum flexural strength also decreased to 110.25 MPa for 2% TiO_2 and 98.81 MPa for 3% TiO_2. Although all the groups displayed a flexural strength within the ADA specification, there was a decrease in the flexural strength on the incorporation of increased concentrations of TiO_2 nanoparticles. According to Sodagar *et al*.[14] and Ahmed *et al*.,[36] the decrease in flexural strength may be the result of increased levels of residual unreacted monomer acting as a plasticizer present in the PMMA matrix that adversely effects the degree of curing of the material on the addition of nanoparticles.

Silver nanoparticles are one of the most important products of nanotechnology[33] that are commonly

used in dentistry for their electrical conductivity, antimicrobial property, and ductility.[33] Many studies have shown that silver nanoparticles are effective on several common microorganisms of the oral cavity such as *Staphylococcus aureus*, *C. albicans,* and *Streptococcus mutans*.[37] In a few of these studies, it has been mentioned that silver nanoparticles enhance the mechanical properties such as compressive strength[38] and thermal conductivity.[12] The effects of silver nanoparticles on the flexural strength of PMMA have not been extensively studied in comparison to the exploration of its antimicrobial advantage.[39]

In this study, apart from a decrease in flexural strength of the denture base material, significant visible color changes were seen in all the specimens of all the concentrations of silver nanoparticles. The visible color changes ranged from light grey, dark grey, and purple-brown to dark brown on incorporation of 0.5%, 1%, 2%, and 3% silver nanoparticles, respectively. The maximum flexural strength of the material decreased to 118.91 MPa for 0.5% concentration, 109.30 MPa for 1% concentration, and 97.76 MPa and 88.84 MPa, respectively, for 2% and 3% concentrations. Although the mean flexural strength of all the subgroups lies within the specified range,[40] the color changes will render the material unesthetic and hence color modifiers may be needed to improve the color properties of PMMA which is incorporated with silver nanoparticles. The results are in agreement with the previous studies. According to Sodagar *et al*.[33,14] on the addition of silver nanoparticles, they act as impurities in the PMMA matrix by forming nano-sized oxides. These oxides disturb the internal structure of the PMMA matrix, leading to improper polymerization of the acrylic resin.

Combinations of various nanoparticles to form a composite material have been researched for their applications in dental materials. These studies concluded that the combination of nanoparticles can adversely affect the flexural strength[14] but showed excellent antimicrobial properties.[6,41]

In the current study, a combination of titanium dioxide nanoparticles and silver nanoparticles was incorporated into PMMA in specimens of Group D to assess if there was a synergistic effect to improve the flexural strength. It was found that the combination of these nanoparticles adversely affected both flexural strength and visible color properties. The lowest ranges of flexural strength in comparison with Groups A, B, and C were observed in specimens from Group D. The highest flexural strength among all subgroups of Group D was observed in specimens with 0.5% total concentration of 1:1 TiO2 and silver Nanoparticles valued at 108 MPa, whereas the least flexural strength was seen in specimens with 3% total concentration of 1:1 TiO2 and silver nanoparticles which was 105.92 MPa.

Although the visible color changes of the denture base material were better when compared to the color changes observed in specimens of Group C, the addition of a combination of titanium and silver nanoparticles to PMMA would still render the material unesthetic and may require the use of color modifiers to be clinically accepted by the patient.

CONCLUSIONS

Based on the observations, results and statistical analysis of the study, within its limitations, the following conclusions were drawn:

1. The incorporation of titanium dioxide nanoparticles, silver nanoparticles, and a combination of both nanoparticles adversely affected the flexural strength in comparison to the flexural strength of unmodified polymethyl methacrylate resin
2. Silver nanoparticles when incorporated into polymethyl methacrylate denture base resin have the least esthetic color appearance and will require color modifiers
3. Polymethyl methacrylate resin modified with titanium dioxide nanoparticles show lighter pink appearance of the material and will require color modifiers
4. The highest flexural strength and esthetics among all modified specimen groups were seen in 0.5% concentration of titanium dioxide nanoparticles in PMMA
5. PMMA modified with a combination of titanium dioxide nanoparticles and silver nanoparticles in a combined concentration of 3% showed the least flexural strength
6. Three percent concentration of silver nanoparticles in PMMA displayed poor esthetics due to color changes.

For an optimal balance between mechanical, esthetic, and antimicrobial properties, incorporation of titanium dioxide or silver nanoparticles has to be limited. Further studies need to be conducted to correlate these properties with each other to find an optimal concentration of titanium dioxide and silver nanoparticles.

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Conflicts of interest

There are no conflicts of interest.

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Research

Evaluation of shear bond strength and translucency of zirconia-reinforced lithium silicate and lithium disilicate: An *in vitro* study

Amir Khan, Tabrez Lakha, Supriya Kheur[1], Batul Qamri, Mohit G. Kheur

Department of Prosthodontics and Implantology, M. A. Rangoonwala College of Dental Sciences and Research Centre, [1]Department of Oral Pathology and Microbiology, Dr. D. Y. Patil Dental College and Hospital, Dr. D. Y. Patil Vidyapeeth, Pune, Maharashtra, India

Abstract

Aim: To analyze the effect of various surface treatment protocols on shear bond strength between the ceramic and resin cement (RC) and influence of zirconia on the translucency of LD as compared to zirconia-reinforced lithium silicate (ZLS).

Setting and Design: *In-Vitro* Study.

Materials and Methods: Specimens (14 mm × 12 mm × 2 mm) ($n = 135$) and (14 mm × 12 mm × 1 mm) ($n = 45$) of ZLS computer-aided design/computer-aided manufacturing glass ceramic block and LD were fabricated, respectively. All the ZLS specimens were crystallized and were tested for the translucency parameter and ceramic-resin shear bond strength. Two different types of surface treatment were used on the ZLS and LD samples. The specimens were treated using the hydrofluoric acid (HF) etching or air abrasion with diamond particles (DPs). The specimens were then bonded using self-adhesive RC to a composite disc of 10 mm and thermocycling was performed. A universal testing machine was used to evaluate ceramic-resin shear bond strength after 24 h. The translucency of the specimens was evaluated using the spectrophotometer by calculating the difference in color between the readings over a black background and a white background.

Statistical Analysis Used: Data were statistically analyzed using the independent sample *t*-test and analysis of variance with Bonferroni's correction and comparison was made between the specimens.

Results: Independent sample *t*-test demonstrated statistically significantly higher translucency for group ZLS (61.44 ± 22) as compared to group LD (20.16 ± 8.39) ($P < 0.001$). Group ZLS showed statistically significant higher shear bond strength when surface treatment using HF or air abrasion with synthetic DPs was performed as compared to untreated group (3.58 ± 0.45) ($P < 0.001$). Moreover, air abrasion group (16.79 ± 2.11 megapascal [MPa]) demonstrated statistically significant higher shear bond strength as compared to HF etched group (8.25 ± 0.30 MPa) ($P < 0.001$). Furthermore, statistically significant higher shear bond strength was noted when air abrasion was done for group ZLS (16.79 ± 2.11 MPa) as compared to group LD (10.82 ± 1.92 MPa) ($P < 0.001$). However, on surface treatment with HF, a statistically

Address for correspondence: Dr. Mohit G. Kheur, M. A. Rangoonwala College of Dental Sciences and Research Centre, Pune, Maharashtra, India.
E-mail: mkheur@gmail.com

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significantly lower shear bond strength was noted for group ZLS (8.25 ± 0.30 MPa) as compared to group LD (11.29 ± 0.58 MPa) ($P = 0.001$).

Conclusion: ZLS demonstrated higher translucency compared to LD restorations. DP abrasion of ZLS is recommended to achieve higher shear bond strength between the ceramic and RC.

Keywords: Lithium disilicate, reinforced ceramic, zirconia

INTRODUCTION

Although lithium disilicate (LD) has proven to be a successful esthetic restorative material, one of its drawbacks is poor flexural strength.[1] To overcome this drawback, a material with high flexural strength, yet with esthetics similar to glass ceramics is the need of the hour.

Zirconia ceramics have gained popularity due to their superior mechanical properties and biocompatibility.[2,3] One of the limitations of zirconia restorations compared to glass ceramic's is its greater opacity owing to larger grain size and the presence of porosity at the microstructural level.[4,5] Therefore, the esthetic outcomes with these restorations are inferior as compared to LD and leucite-reinforced ceramics.[5]

A different class of ceramics, zirconia-reinforced lithium silicate (ZLS) glass ceramic has been introduced for the fabrication of inlays, onlays, partial crowns, veneers, anterior, and posterior crowns.[6,7] This type of glass ceramic is enriched with zirconia particles (≈10% by weight) to reinforce the ceramic structure. The addition of zirconia particles enhances its mechanical properties such as fracture toughness, hardness, flexural strength, thus rendering it more machinable compared to lithium disilicate.[8,9] The longevity of these ceramic restorations is dependent on a reliable cementation technique capable of developing a durable bond strength between the restoration and the substrate.[10,11]

The durability of the bond between the restoration and resin cement (RC) is dependent on factors such as the surface treatment of the intaglio surface of restoration and choice of RC.[12] Surface treatment can be carried out by chemical conditioning and/or mechanical methods.[13,14]

Chemical conditioning methods commonly employ the use of hydrofluoric acid (HF),[11] whereas the most common mechanical methods include air abrasion.[12] Amongst these, HF etching of the inner surface of a ceramic restoration followed by the application of a silane coupling agent is a recommended method to achieve high bond strength.[11-18] However, alternative techniques such as airborne abrasion using alumina particles have been evaluated for the surface treatment of LD ceramics.[5] There is an increased interest in using diamond particles (DPs) for abrasion as they are harder than alumina,[19,20] it is hypothesized that air abrasion with DPs would lead to rougher and irregular surfaces leading to an improvement in the shear bond strength compared to air abrasion with alumina particles.

One of the important properties which affects the choice of dental ceramics for clinical application is its translucency, which should be considered when an all ceramic restoration is planned in the esthetic zone.[21] LD has high translucency and therefore is the preferred choice of material in the esthetic zone.[22,23] Zirconia cores have opaque appearance and poor translucency as compared to other ceramic systems.[5,23-27] The presence of zirconia particles in LD would therefore have an effect on the light transmission through such a composite material.

Studies evaluating the translucency of ZLS and more specifically, if the presence of zirconia affects the translucency of reconstructions is currently scarce in the literature.[7,8,28] Furthermore, the literature does not conclusively document how the presence of zirconia particles in lithium silicate matrix would affect the bond strength between this material and the luting resin.[28-31] Thus, the aim of this study was to compare the translucency and shear bond strength of ZLS and lithium disilicate.

The null hypothesis of this study is that the addition of zirconia to LD would not affect the translucency and the shear bond strength of the restoration to self-adhesive RC s.

MATERIALS AND METHODS

Specimens preparation

Distributions of the samples are illustrated in the flowchart [Figure 1] and the material used in the study has been mentioned in a below [Table 1].

Zirconia-reinforced lithium silicate

Pre-crystallized computer-aided design/computer-aided manufacturing blocks of ZLS (VIT A SUPRINITY PC VIT A Zahnfabrik; Bad Säckingen, Germany, LOT NO 62951,

Table 1: Materials used in the study

Product name	Manufacturer	Composition	Lot number
VS (VITA zahnfabrik)	VITA zahnfabrik	SiO_2, Li_2O, K_2O, P_2O_5, Al_2O_3, ZrO_2, CeO_2, pigments	Translucent, shade A2, lot not 62951
LD ceramic	IPS e.max CAD/Ivoclar Vivadent, Liechtenstein	SiO_2 (57–80 wt.%) Li_2O (11–19 wt.%) K_2O (0–13 wt.%) P_2O_2 (0–11 wt.%) ZrO_2 (0–8 wt.%) ZnO (0–8 wt.%) Other and coloring oxides (0–12 wt.%)	Translucent, shade A2, lot number 66029
Rely X u200	3M ESPE	Base paste: Methacrylate monomers containing phosphoric acid groups, silanated fillers, initiator components, stabilizers, rheological additives Catalyst paste: Methacrylatemonomers, alkaline (basic) fillers, silanated fillers, initiator components pigments, rheological additives	Lot number 621124
Monobond S	Ivocalar Vivadent	Ethanol, (3-[methacryloyloxy] propyl) trimethoxysilane	Lot number V20474
Composite resin, restofill	Anabond Steaman Pharma Research (P) Ltd India	Light cure composite resin	Lot number batch number RRO/056
Porcelain etch gel 9.6%	Pulpodent corporation, Watertown massachsetts, USA	HF 9.6%	Lot number batch number YO3912

VS: VITA suprinity, HF: Hydrofluoric acid, LD: Lithium disilicate

shade A2-T, PC14) as provided by the manufacturer were sectioned using low speed diamond disc (flex diamond disc, SS white dental, New jersey) under water irrigation to prepare specimens of 14 mm × 12 mm × 2 mm thickness ($n = 135$) for ceramic-resin shear bond evaluation and 14 mm × 12 mm × 1 mm thickness ($n = 45$) for the evaluation of translucency parameter (TP) [Figure 2]. The sample size was determined by using the effect sizes from a previously published study[7,12,16] and with the help of following formula:

$$n\ (\mathrm{PerGroup}) = 2\ \left[\frac{\left(Z_{\frac{\alpha}{2}} + Z\beta\right)\sigma}{\Delta}\right]^2$$

Where n = Sample size (per group).

$Z_{\alpha/2}$= (1.96) for 95% confidence (i. e. $\alpha = 0.05$). = 1.96

Z_β = Cutoff value for power ($1-\beta$). = 0.8416 (80.0% power).

Δ = Mean difference to be detected (minimum difference) = 2.0 units of Delta E.

Δ/σ = Effect size in standard deviation units. =0.600.

ZLS specimens were ultrasonically cleaned for 15 min and then crystallized in a ceramic furnace (Whip Mix ProPress 100, Whip Mix, Louisville, USA) as per the manufacturer instructions.

Lithium disilicate

IPS e. max specimens were fabricated as per the manufacturers instruction using heat pressed technique to obtain the specimens of dimensions 14 mm × 12 mm and thickness of 2 mm ($n = 135$) and 1 mm ($n = 45$) using wax patterns fabricated from an addition silicone putty mold of corresponding dimension [Figure 3].[14] The ceramic specimens were then divested using 110 μm Al^2O^3 under 2 bar pressure at a distance of 2 cm. The specimens were cleaned in an ultrasonic bath for 60 s.

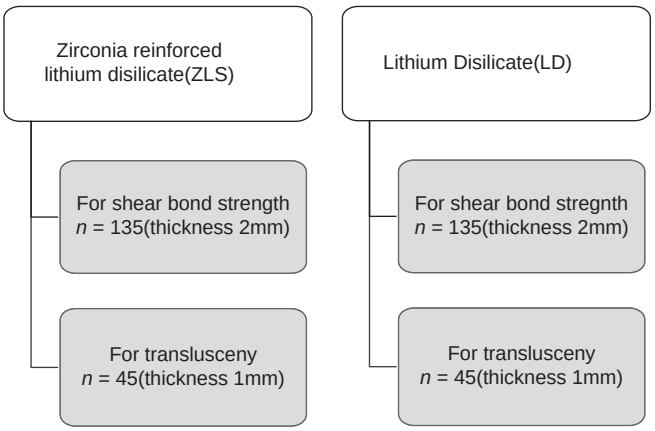

Figure 1: Flow chart showing distribution of samples

Specimens polishing

The specimens were polished using carbide polishing papers (Century Deerfos) of 600, 800, 1000 grits under water irrigation for 10 min each.[13]

Surface treatment of the specimens

Air abrasion

The specimens were subjected to airborne abrasion using 30 μm–50 μm synthetic DPs (Hindustan corporation) for 20 s under 2.8 bar pressure. The experimental surface was held 10 mm away from the nozzle of the abrasion unit. The specimens were then subjected to steam cleaning for 60 s.

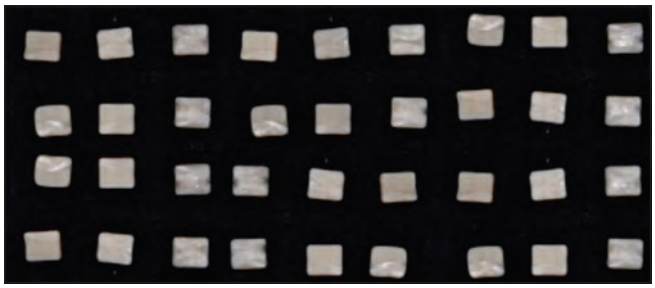

Figure 2: Samples of ZLS group. ZLS: Zirconia-reinforced lithium silicate

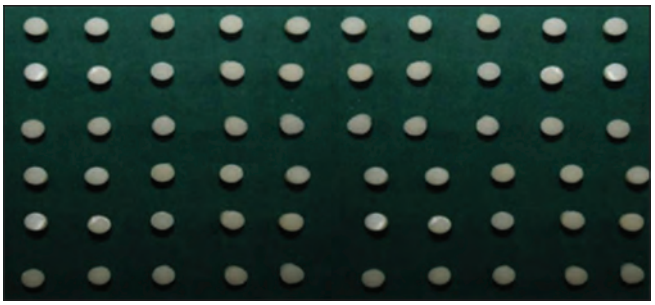

Figure 3: Samples of LD group. LD: Lithium disilicate

Hydrofluoric acid etching

9.6% HF gel (Pulpodent Corporation) (n = 45) for 2 min was used for etching the specimens.

Conditioning/thermocycling of the specimens

After bonding the samples to the composite, the samples were conditioned by storing them in distilled water at 37°C for a time period of 24 h. The samples of ZLS and LiDi group were them subjected to 3000 thermal cycles between the temperature of 5°C–55°C as recommended by Garboza *et al*.[14]

Specimens testing and grouping

The specimens were tested for TP and for ceramic-resin shear bond strength. Untreated specimen from both LD and ZLS group were also bonded and tested for ceramic-resin shear bond strength.

Evaluation of translucency

Translucency was evaluated before the samples were surface treated. The TP of each specimen (n = 45) was determined by calculating the difference in color readings over the black background (standard calibration tile with CIE L* =24.58, a* =0.27, b* =2.58) and white background using spectrophotometer (Vita Easyshade, Vita Zahnfabrik). TP was calculated using the following formula: $TP = [(L^*_B - L^*_W)^2 + (a^*_B - a^*_W)^2 + (b^*_B - b^*_W)^2]^{1/2}$ in which the subscripts "B" and "W" refer to measurements of color over white and black backgrounds as described by Bahgat *et al*.[7]

Evaluation of shear bond strength

Bonding of the specimens

Self-adhesive RC (RelyX™ U200 (3M ESPE, St. Paul MN**)** was used to bond the specimens as per the manufacturer guidelines. The specimens were bonded using the protocol described by Woo *et al*.[16] to a standard composite resin disc (CD) of 10 mm diameter and 2 mm thickness (Restofill, Anabond Stedman Pharma Research [P] Ltd). These discs were fabricated using a split customized metal mold to achieve uniform and standardized bonding surface area for all the specimens. Luting was performed under pressure of 5N using a pressure applicator. Each ZLS and LD specimen was bonded to a CD using silane coupling agent (Monobond-S, Ivoclar Vivadent, Schaan) and RC as recommended by Woo *et al*.[16] and light polymerized (LED Curing Light, Woodpecker, Guilin Woodpecker Medical Instruments Co. Ltd) for 20 s on each surface to ensure optimal polymerization. The bond surface area was calculated using formula, surface area (A) = 3.14× $(\text{radius})^2$.

Testing of the specimens

Each bonded specimen was mounted on a rectangular acrylic mold fabricated using auto polymerizing methyl-methacrylate (DPI RR Cold Cure, Dental Products of India, Wallace Street, Mumbai. Batch No. *P* 7121 and L 7124) as described in various studies.[13,16] The auto-polymerizing resin block were held in a retainer of a universal testing machine (Star Testing Systems, India. Model No. STS-248). Shear bond strength test was determined between ceramic and the RC with a metal blade with an edge thickness of 0.25 mm making single point contact moved vertically at 90°, at a crosshead speed of 1.0 mm/min until the specimen fractured.[16] The load was applied at the Ceramic-Resin interface and fracture load (N) was determined.

Statistical analysis

The values for shear bond strength were calculated in megapascal (Mpa) using the formula, Shear bond strength (MPa) = Fracture load (N)/Area (mm^2). The entire data were statistically analyzed using the Statistical Package for the Social Sciences (SPSS, version 20, Chicago, IL, USA) software for MS Windows. Shapiro–Wilk test was used to test the normality of the data. The inter-group statistical comparison of means of continuous variables was done using the independent sample t-test. The intra-group statistical comparison of means of continuous variables was tested using the repeated analysis of variance with Bonferroni's correction for multiple group comparisons.

Failure analysis

Failure of the analysis was performed under ×3 magnification (Olympus Corp, Tokyo, Japan). Based on the nature of failure, they were classified into following four types: (i) Adhesive failure, (ii) cohesive failure-within the ceramic, (iii) cohesive within the composite, and iv) mixed failure, involving ceramic, composite.

RESULTS

Translucency

Mean distribution of translucency of ZLS and LD specimens was performed using the independent sample *t*-test. Translucency was statistically significantly higher for ZLS as compared to LD ($P < 0.001$) [Table 2 and Figure 4].

Intra-group comparison of ceramic-resin shear bond strength

In group ZLS, statistically significantly higher bond strength was noted for specimens treated with DP and HF as compared to untreated group ($P < 0.001$). Moreover, a statistically significant difference was noted for specimens treated with DP as compared to specimens treated with HF of ZLS with higher values for air abrasion ($P < 0.001$) [Table 3].

LD group demonstrated statistically significantly higher shear bond values for specimens treated with DP and HF as compared to untreated group ($P < 0001$). However, no statistically significant difference between group DP and HF ($P = 0.180$).

Intergroup comparison of ceramic resin shear bond strength

On intergroup comparison, statistically significantly higher shear bond strength was noted for untreated specimens of groups ZLS as compared to untreated LD group ($P < 0.001$) [Table 4].

However, when specimens treated with HF were compared statistically significantly higher shear bond strength was noted for group LD compared to group ZLS ($P < 0.001$).

When specimens treated with DP were compared statistically significantly higher shear bond strength was noted for group ZLS compared to group LD ($P < 0.001$).

Failure mode

All the samples underwent adhesive failure between the cement and the substrate.

DISCUSSION

The results of this *in vitro* study demonstrated that, the ZLS surface treatment with air abrasion using synthetic DPs demonstrated highest bond strength to RC. Similarly, for LD HF etching silane application showed highest bond strength to RC. Specimens of both zirconia-reinforced LD and LD showed adhesive type of failure.

The result of this study is in concurrence with the results of Bahgat, *et al*.[7] that demonstrated higher translucency of ZLS compared to LD. The significantly

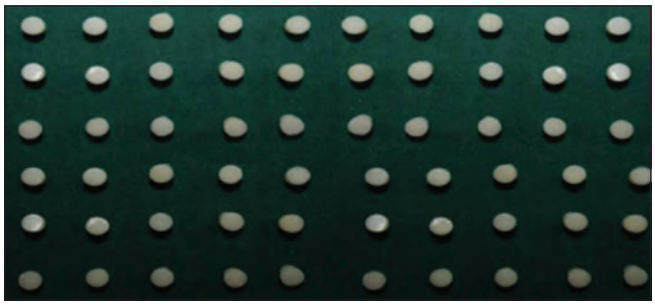

Figure 4: Comparison of translucency between group ZLS and LD. ZLS: Zirconia-reinforced lithium silicate, LD: Lithium disilicate

Table 2: Inter-group distribution of mean translucency parameter (*n*=45)

TP	Mean±SD		*P*
	Group 1: ZLS	Group 2: LS	
TP	61.44±22.00	20.16±8.39	0.001***

***$P<0.001$. *P* value by independent sample *t*-test. $P<005$ is considered to be statistically significant. TP: Translucency parameter, ZLS: Zirconia-reinforced lithium silicate, LS: Lithium disilicate

Table 3: Intra-group distribution of shear bond strength (*n*=45)

Shear bond strength (MPa)	Mean±SD	
	Group 1: ZLS	Group 2: LS
Only silane application (control)	3.58±0.45	2.23±0.28
Acid etch 9% HF+	8.25±0.30	11.29±0.58
Air abrasion	16.79±2.11	10.82±1.92
P (intra-group)		
Control v acid etch 9% HF	0.001***	0.001***
Control v air abrasion	0.001***	0.001***
Acid etch 9% HF v air abrasion	0.001***	0.180 (NS)

***$P<0.001$. *P* value by the analysis of variance with Bonferroni's correction due to multiple group comparisons. $P<005$ is considered to be statistically significant. HF: Hydrofluoric acid, SD: Standard deviation, MPa: Megapascal, ZLS: Zirconia-reinforced lithium silicate, NS: Statistically nonsignificant, LS: Lithium disilicate

Table 4: Inter-group distribution of shear bond strength (*n*=45)

Shear bond strength (MPa)	Mean±SD		*P*
	Group 1: ZLS	Group 2: LS	
Only silane application (control)	3.58±0.45	2.23±0.28	0.001***
Acid etch 9% HF + silane	8.25±0.30	11.29±0.58	0.001***
Air abrasion + silane	16.79±2.11	10.82±1.92	0.001***

***$P<0.001$. *P* value by independent sample *t*-test. $P<005$ is considered to be statistically significant. MPa: Megapascal, ZLS: Zirconia-reinforced lithium silicate, SD: Standard deviation, LS: Lithium disilicate

higher translucency of ZLS glass-ceramic is may be due to the nucleation process and the addition of zirconia results in more homogenous crystalline structure of the zirconia-reinforced LD when compared to the needle-shaped coarser crystalline structure (1.5 μm) of LD glass ceramic.[6,7] Heffernan *et al*. reported that the amount of light absorbed, reflected, and transmitted is dependent on several factors including the particles size compared to the incident light's wavelength (0.4–0.7 μm), distribution of crystalline phase, and optical anisotropy of the grains. Porcelain translucency increases as the size of particles decreases.[23] However, the results of translucency of this study were not consistent with the results of Lee who reported that addition of zirconia particles in alumina/zirconia glass composites resulted in poor translucency.[26] This was due to the addition of the zirconia particles as a filler particles into a composite material which may have led to the inferior light transmittance property.[26] Denry also observed similar findings when zirconia particles were added to feldspathic glass ceramic.[27] However, ZLS consists of a fine crystal size of 0.5 μm and a homogenous glassy matrix which is the probable reason for it exhibiting higher translucency.

When the ceramic-resin shear bond strengths were evaluated for both groups, ZLS and LD, a statistically significantly higher shear bond was noted for specimens undergoing surface treatment (HF or air abrasion) compared with untreated group [Figure 2]. This can be attributed to the fact that surface treatment results in the formation of micro-roughness which increases the surface area for adhesion and bond strength. These results are in agreement with Ayad *et al*. who reported an increase in bond strength with increased surface porosity.[11]

Among the untreated specimens, ZLS demonstrated statistically significantly higher shear bond strength to the resin compared to LD. This can be attributed the fact that ZLS exhibits a more homogeneous crystalline structure (854.5 ± 155.0 nanometers) compared to LD (1500 nanometers) which allows better wettability of bonding surface and more uniform distribution of silane layer can be achieved which results in higher bond strength.[5-7,17,29]

Specimens subjected to air abrasion with DPs demonstrated significantly higher shear bond strength amongst the ZLS specimens, This is in agreement with studies done by Al-Thagafi *et al*.[18] who reported that when ZLS was treated with HF or air abraded with tribochemical silica particles (Co-jet), higher bond strength was observed for the air abraded group.

Kulunk *et al*. explained the probable reason for higher bond strength for surface abrasion with DPs. They suggested that diamond being a harder material causes more abrasion of the surface, thereby increasing surface area for bonding resulting in higher bond values.[19]

Conrad *et al*. reported that airborne abrasion using aluminum oxide particles in glass ceramics resulted in surface irregularities that were shallow and superficial and is therefore not a recommended method to achieve adequate bond strength.[5]

Blatz *et al*. and Kern and Thompson also concluded airborne particle abrasion when done in excess can lead to chipping and high-volume loss of glass ceramics and is therefore not recommended for cementation of silica-based all-ceramic restorations.[30,31] This explains why the values of shear bond strength were significantly less for air abraded LD. Comparatively, LD showed higher shear bond strength for the HF etching protocol. However, there was no significant difference between air abraded and HF-treated specimens in this group. Ozcan and Vallittu reported that HF etching causes higher bond strength with glass ceramic compared to glass-infiltrated alumina and glass-infiltrated zirconia ceramic.[15] Garboza *et al*. in a study demonstrated that air abrasion with alumina particles results in poor bond strength in glass ceramics as compared to HF etching.[14] This differences could be due to the difference in surface morphology produced by various surface treatments.[19,32,33]

Conversely, ZLS demonstrated lower value of shear bond strength for hydrofluoric etching protocols compared to LD. This can be explained on the basis of higher affinity of HF to dissolve SiO_2 which is higher in proportion in LD as compared to the ZLS specimens. The addition of zirconia could possibly be associated with reduced rate of reaction and therefore significantly higher bond strength values were achieved with LD specimens.[12,13]

This study did not evaluate flexural strength and microtensile strength of these restorative materials. Furthermore, combining surface treatment using HF and air abrasion could have provided useful insights; however, this was not performed in the current study. More clinical research should be conducted on ZLS and LD to understand the clinical longevity and esthetic outcome of these materials.

CONCLUSION

Within the scope of the study the following conclusions can be drawn:

1. The transparency for ZLS is higher compared to LD suggesting superior light transmitting ability of ZLS
2. For ZLS surface treatment with air abrasion using synthetic DPs (30–50 μm) showed highest shear bond strength to RC and can be recommended as clinical protocol for bonding these restoration
3. Similarly, for LD HF etching silane application showed highest bond strength to RC and should be recommended clinically
4. Both ZLS and LD samples showed adhesive type of failure.

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Conflicts of interest
There are no conflicts of interest.

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Research

Investigation of the effect of different surface treatments for preventing detachment of polyetheretherketone and titanium attachment matrix housings in overdentures: An *in vitro* study

Pınar Yıldız, Damla Güneş Ünlü

Department of Prosthetic Dentistry, Faculty of Dentistry, Nuh Naci Yazgan University, Kayseri, Turkey

Abstract

Aim: The attachment matrix housing (AMH) of implant overdentures is not chemically bonded with acrylic resins. Therefore, AMH may lose due to insertion and removal forces. This study aims to investigate the effects of different surface treatments to reduce the detachment of AMH and to compare the adhesion of the AMH used in implant-supported overdentures made of different materials with the reline acrylic resin.

Materials and Methods: Titanium and polyetheretherketone (PEEK) AMHs were separated into four surface treatment groups; no treatment, airborne-particle abrasion (APA) applied, universal bond (UB) applicated, APA, and UB applicated. Eight millimeters in diameter and ten millimeters tall straws were used to restrain the reline acrylic resin prepared according to the manufacturer's instructions and the resin was injected onto the surface-treated AMH. After the polymerization was completed, the universal testing machine performed the tensile bond strength (TBS) test with a fishing line passed through the acrylic resins.

Statistical Analysis Used: TBS data were analyzed with two and one-way ANOVA and Tukey HSD *post hoc* tests ($\alpha = 0.05$).

Results: According to the two-way ANOVA results, titanium AMHs (103.78 ± 45.98 N) showed higher TBS than PEEK AMHs (67.81 ± 28.61 N). UB applicated titanium groups showed significantly increased TBS values.

Conclusions: Using titanium AMHs may be a better choice in situations where clinical aesthetic expectations are unimportant for adhesion to reline acrylic resins.

The UB resin significantly increased the bonding of the titanium AMHs with reline resins. The application of UB resin to titanium housings can be easily applied in a clinical situation and can reduce the detachment of the titanium AMHs.

Keywords: Airborne-particle abrasion, overdenture, polyetheretherketone, titanium, universal bond resin

Address for correspondence: Dr. Pinar Yıldız, Ertuğrul Gazi Mah. Nuh Naci Yazgan Yerleşkesi Küme Evler, Kocasinan, Kayseri 38170, Turkey.
E-mail: drpinaryildiz@hotmail.com

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INTRODUCTION

Implant-supported overdentures comprise a treatment option that is applied to edentulous patients because they increase life quality and the ability to chew.[1,2] Various techniques are applied for the adaptation of overdentures to the mouth. Some clinicians prefer attachment matrix housing (AMH) directly in the mouth through a chairside technique or indirectly in a dental laboratory. Both methods have advantages and disadvantages for the clinician and the patient.[3] The direct technique is simple, less expensive, requires fewer prosthetic elements, and allows the patient to retain the prosthesis.[4]

A frequently encountered issues with implant-supported overdentures are the loosening or the complete removal of AMH from the inner surface of the overdentures. In a previous study, it was shown that 36% of 2 implant-supported overdentures and 52% of single-implant-supported overdentures required reattachment of AMH within 5 years.[5] Mangano *et al.*[6] evaluated unsplinted implant-supported overdentures in their 1-year prospective study and reported that the most common prosthetic complication was the need for replacement of the retentive caps in the denture base. Patients tend not to notice the AMH debonding during the use of overdentures and may swallow or drop these parts. Due to this frequently encountered complication, the rebonding of AMH leads to additional costs and can reduce a clinician's confidence.

An implant-supported overdenture AMH is usually made of titanium. The intraoral fixing materials, titanium and acrylic resins, are not chemically bonded, and grooves are mechanically created on the AMH to improve mechanical retention.[7]

In the literature, to increase the metal and acrylic adhesion, methods that provide chemical bonding such as silica coating and bond and/or silane application have been used. Kern and Thompson[8] showed that the use of silica coating and adhesive monomer increased the bond strength between titanium and composite resin by 2–2.5 times. For mechanical fastening, silica coating, and airborne-particle abrasion (APA) have been used.[9-12] APA is one of the simplest and cheapest methods of increasing micromechanical adhesion by increasing surface roughness.

Universal bond (UB) resins are increasingly used today due to their ease of use and their high bond strength to different materials. UB resins are appreciated for increasing the bond strength of all resins with glass ceramics (porcelain), oxide ceramics (zirconia and alumina), and metals (precious or nonprecious). In particular, previous studies have shown that the phosphate monomer that they contain strengthens the bond of titanium and polyetheretherketone (PEEK) with resins.[13,14]

Some implant manufacturers produce AMH from PEEK material as well as from titanium. PEEK's high mechanical properties and biocompatibility and stability with almost all organic and inorganic chemicals make it valuable in dentistry.[15,16] Nowadays, PEEK has increasing usage in temporary abutments, implant bars, and attachments.

Various surface treatments have been applied to increase the bonding of PEEK and composite resins and have been reported in the literature;[13,14,17] some of these treatments are etching, APA application,[13,18] silica coating, and the application of UB or silane.[13,19] However, it is not clear which of these methods enhances PEEK's bonding with resins.

The adhesion of AMH with acrylic reline resin is of great importance with regard to overdentures. Strengthening the adhesion between the reline acrylic resin and the AMH has great importance as it can reduce the frequently encountered AMH detachment. However, studies in the literature on this topic are limited and, as a test design, this study aimed to strengthen the base material and thus reduce prosthesis fractures.[9,20] Furthermore, there is no study in the literature comparing the adhesion of titanium and PEEK AMH with reline acrylic resin.

Therefore, the purpose of this study is to investigate the effects of different surface treatments on the reduction of the detachment of AMH and to compare the adhesion of the AMH used in implant-supported overdentures made of different materials with the reline acrylic resin. The first null hypothesis of this study is: There is no significant difference between titanium and PEEK AMHs in terms of adhesion to reline acrylic resins. The second null hypothesis is that surface treatment has no significant effect on the adhesion of PEEK and titanium AMHs with reline acrylic resins.

MATERIALS AND METHODS

The study involved 80 titanium ($n = 40$) and PEEK ($n = 40$) AMHs (Novaloc, Straumann, Basel Switzerland) that were used to investigate the tensile bond strength (TBS) between reline acrylic material and AMH. All materials tested in this study are shown in Table 1.

First, matrix inserts were removed from AMH. Then, the AMHs were placed in Teflon molds [Figure 1].

Table 1: Brand, manufacturer, lot number and components of tested materials

Material	Trade name	Manufacturer	Lot number	Component/information
AMH	Novaloc TI matrix housing	Straumann	L0068030	Tİ/POM
	Novaloc peek matrix housing	Straumann	L0066972	PEEK
Bond resin material	Universal bond	Tokuyama	049E49	Liquid A: Phosphate monomer, bis-GMA, TEGDMA, HEMA, MTU-6, others. Liquid B: Acetone, isopropanol, water, acryl borate catalyst, γ-MPTES, peroxide, and other
Reline acrylic resin material	New Truliner	The Harry J. Bosworth Company	19B123B	Powder - PEMA Liquid - IBMA and DBP

AMH: Attachment matrix housing, TI: Titanium, POM: Polyoxymethylene, TEGDMA: Triethylene glycol dimethacrylate, PEEK: Polyether-etherketone, Bis-GMA: Bisphenol A-glycidyl methacrylate, HEMA: 2-hydroxyethyl methacrylate, MPTES: Methacryloxy propyltrimethoxysilane, IBMA: Iso-butyl methacrylate, DBP: Dibutyl phthalate, PEMA: Poly-ethyl methacrylate, MTU-6: 6-methacryloyloxyhexyl 2-thiouracil-5-carboxylate

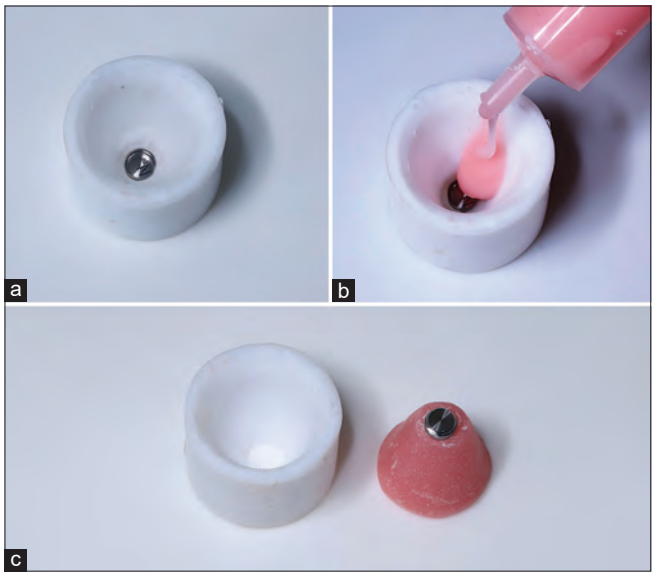

Figure 1: (a) Image of the teflon mold used in the study, (b) Addition of auto-polymerized acrylic resin to teflon mold, (c) Removed from the teflon mold was the side of the sample containing AMH that will be used for the tensile test. AMH: Attachment matrix housing

Autopolymerized acrylic material (Panacryl, Rubydent, Istanbul, Turkey) was mixed according to the manufacturer's instructions (10 g powder, 4 mL liquid) and filled into the part of the AMH where the matrix is extracted, to create a block to ensure continuing partial retention in the tensile test. Samples were auto-polymerized for 15 min and then removed from the Teflon molds. The specimens were stored in distilled water at 37°C for 24 h before being subjected to surface treatments. For different surface treatments, titanium (n = 10) and PEEK (n = 10) AMH were separated into four groups.

Titanium AMH groups:

1. NTT: Titanium AMH with no treatment (NT)
2. APAT: APA was applied with 50 μm Al_2O_3 under pressure (0.3 MPa) for 10 s at a distance of 10 mm, with a vertical angle between the nozzle and the titanium AMH surface. This was followed by ultrasonic cleaning for 10 min in distilled water followed by air-drying
3. UBT: UB resin (UB, Tokuyama, Tokyo, Japan) application using a dental micro brush with equal amounts of mixing liquids a and b and air-drying on the titanium AMH
4. APAUBT: APA was applied with 50 μm Al_2O_3 under pressure (0.3 MPa) for 10 s at a distance of 10 mm, with a vertical angle between the nozzle and the titanium AMH surface. This was followed by ultrasonic cleaning for 10 min in distilled water and air-drying, followed by UB (UB, Tokuyama, Tokyo, Japan) application using a dental micro brush with equal amounts of mixing liquids a and b and air-drying on the titanium AMH.

PEEK AMH groups:

1. NTP: PEEK AMH with NT
2. APAP: APA was applied with 50 μm Al_2O_3 under pressure (0.3 MPa) for 10 s at a distance of 10 mm, with a vertical angle between the nozzle and the PEEK AMH surface. This was followed by cleaning ultrasonically for 10 min in distilled water followed by air-drying
3. UBP: UB (UB, Tokuyama, Tokyo, Japan) application using a dental micro brush with equal amounts of mixing liquids a and b and air-drying on the PEEK AMH
4. APAUBP: APA was applied with 50 μm Al_2O_3 under pressure (0.3 MPa) for 10 s at a distance of 10 mm, with a vertical angle between the nozzle and PEEK AMH surface. This was followed by ultrasonic cleaning for 10 min in distilled water and air-drying, followed by UB (UB, Tokuyama, Tokyo, Japan) application using a dental micro brush with equal amounts of mixing liquids a and b and air-drying on the PEEK AMH.

After the surface treatments, 1 mm thick pink wax was placed below the lower limit of the AMH, and contact between the relining material and the auto-polymerized acrylic blocks was prevented. Pink wax material was also used to provide primary stabilization for the straws that would hold the relining material [Figure 2].

Straws that were 10 mm long and 8 mm in diameter in different colors, were used to help distinguish the groups

and were placed around the AMH with the support of the wax, with the AMH in the center. A hole was created in the middle of the straw to pass a monofilament fishing line through the relining material to use for determining the TBS. The relining material (New Truliner, The Harry Bosworth Company, PA, USA) was mixed according to the manufacturer's instructions (15 mL powder, 7.6 mL liquid) and injected into the straws with the help of an injector. Before completing the polymerization of the relining material, 20 cm of monofilament fishing line (Trilene Big Game, Berkley, Columbia, US) thread was passed through the prepared holes. After the polymerization of the relining materials, a fishing knot was tied to the lines. Samples were immersed in distilled water for 24 h at room temperature to complete polymerization. TBS was measured with a universal testing machine (Instron, Canton, MA, USA), using a crosshead speed of 0.5 mm/min [Figure 3].

One specimen from each group was selected for microscopic examination of surface characteristics. Their surface characteristics were observed using a scanning electron microscope (SEM; LEO 440 Computer Controlled Digital, UK) at ×500 and ×5000 magnifications.

The tensile strength data were analyzed using a statistical software program (SPSS version 15, SPSS Inc., Chicago, IL, USA). The Kolmogorov–Smirnov and Levene tests were used to confirm that TBS values had a normal distribution and a consistent homogeneity of variance. Two-way (for main statistical analysis) and one-way ANOVA (for surface treatments) followed by a Tukey HSD *post hoc* test were used for the analysis of the tensile strength data. Independent samples *t*-test was used to compare the TBS values of the titanium and PEEK materials. In all tests, the confidence level of the study was kept at 95%, hence a $P < 0.05$ indicated a statistically significant difference. In addition, the effect sizes (η_p^2) and statistical power were calculated. *Post hoc* power analysis was performed with statistical software (Minitab 18, Minitab LLC, State College, PA) to confirm that the sample size was large enough to detect significant differences. The statistical power was 1.00 as calculated with α error = 0.05, showing that the sample size used in this study was adequate.

RESULTS

According to the two-way ANOVA test results, the tensile strength between AMH and the reline acrylic resin was affected by the housing material ($P < 0.001$, $\eta_p^2 = 0.395$) and surface treatments ($P < 0.001$, $\eta_p^2 = 0{,}511$), and the interaction between the two factors ($P < 0.001$, $\eta_p^2 = 0.542$) [Figure 4]. The *post hoc* Tukey test results

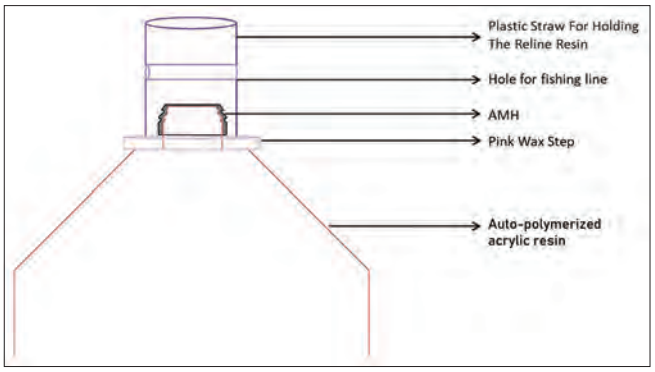

Figure 2: Schematic representation of created samples

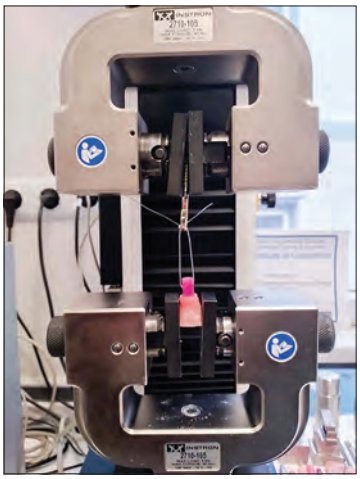

Figure 3: TBS testing of samples with the universal testing machine. TBS: Tensile bond strength

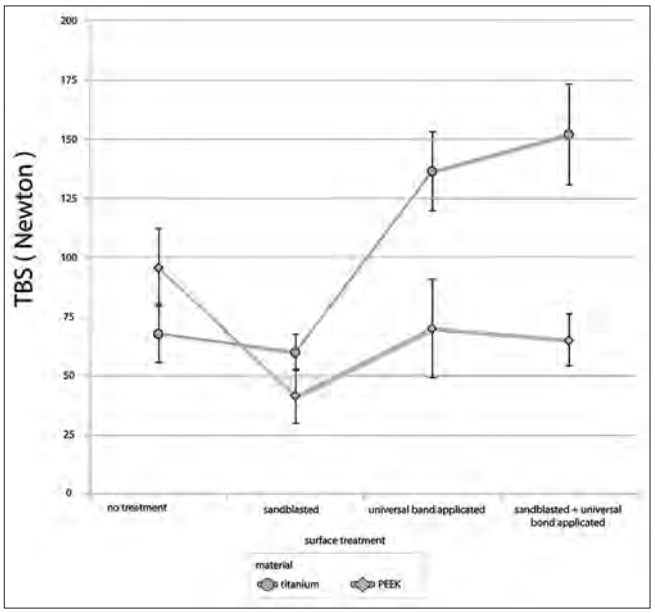

Figure 4: Graphical image of the two-way ANOVA test result. TBS: Tensile bond strength

are shown in Table 2. The APAUBT group showed the highest TBS. The APAP group showed the least TBS.

When the surface treatments were ignored, the titanium housing material (103.78 ± 45.98 N) showed a significantly higher TBS than did the PEEK housing material (67.81 ± 28.61 N) [Figure 5].

When the housing material was ignored, the application of surface treatments was found to significantly affect the housing and the acrylic TBS. The APA groups of surface treatments showed a significantly lower TBS than did all other groups [Figure 6]. The TBS of APA and UB applicated (APAUB) groups were significantly higher than the NT groups and the APA groups, but not significantly higher than the UB applicated groups.

As shown in Figure 7, the titanium and PEEK housing surfaces separated from the reline acrylic resin as a result of the TBS test as observed at ×500 and ×5000 magnification.

Table 2: Mean and standard deviation of all group's tensile bond strength values and significance of Tukey honestly significant difference (*P*) and independent samples *t*-test (*P) results**

	TI housing (N)	PEEK housing (N)	*P**
NT	67.61±17.18^{A,a}	95.60±22.91^{A,b}	0.006
APA	59.67±10.39^{A,a}	41.08±16.26^{B,b}	0.007
UB	136.06±23.43^{B,a}	67.70±29.40^{AC,b}	<0.001
APAUB	151.78±29.57^{B,a}	64.86±15.16^{BC,b}	<0.001
P	<0.001	<0.001	

The majuscule represents the significance of columns, while the minuscule represents the significance of lines. NT: No treatment, APA: Airborne-particle abrasion, PEEK: polyetheretherketone, UB: Universal bond, APAUB: APA+UB, TI: Titanium. *The mean difference is significant at the 0.05 level

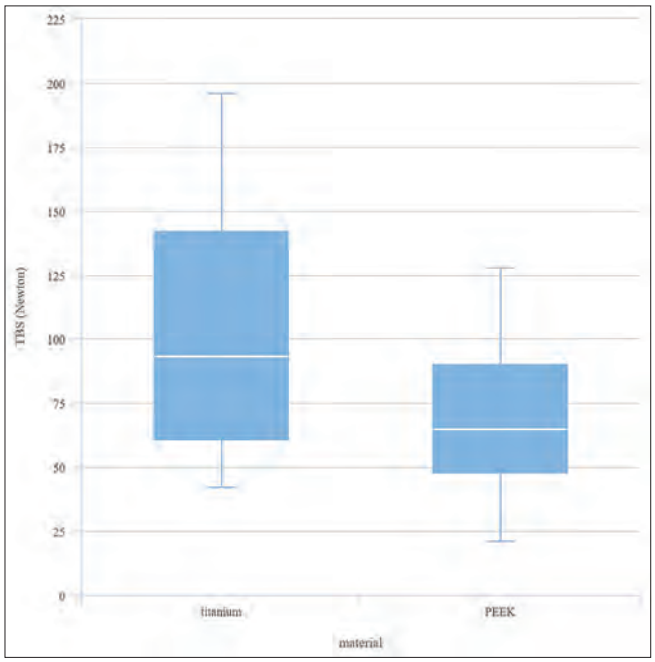

Figure 5: TBS of AMHs is produced from different materials when surface treatments are ignored. AMH: Attachment matrix housing, TBS: Tensile bond strength, NT: No treatment, UB: Universal bond, APAUB: Airborne-particle abrasion and universal bond

The machined titanium surface was observed in the NTT group [Figure 7a]. The machined PEEK surface of the NTP group is observed in Figure 7a. Figure 7b shows a sample of the APAT group and the titanium group roughened by APA, and the aluminum particles embedded in the titanium surface can be observed. In Figure 7b, the APAP group roughened the PEEK surface by APA, and the Al_2O_3 particles embedded in the PEEK surface can be observed. In Figure 7c, for the sample belonging to the UBT group, the UB resin bonding to the titanium surface can be observed. In Figure 7c, with the sample of the UBP group, less UB resin bonding to the PEEK surface can be observed. In Figure 7d, the APAUBT group shows the UB resin bonding to the roughened titanium surface. In Figure 7d, less UB resin bonding to the roughened PEEK surface can be observed.

DISCUSSION

The first null hypothesis was rejected as a significant difference was noted between the titanium and the PEEK groups. The results of this study show that the TBS of titanium AMH and the reline acrylic resin is significantly higher than in the case of the PEEK AMH and reline acrylic resin.

The second null hypothesis was also rejected as a significant difference was noted among the surface treatment groups. The results of this study showed that the maximum TBS was observed between the reline acrylic resin and AMH that was applied to the APAUBT AMH group, compared

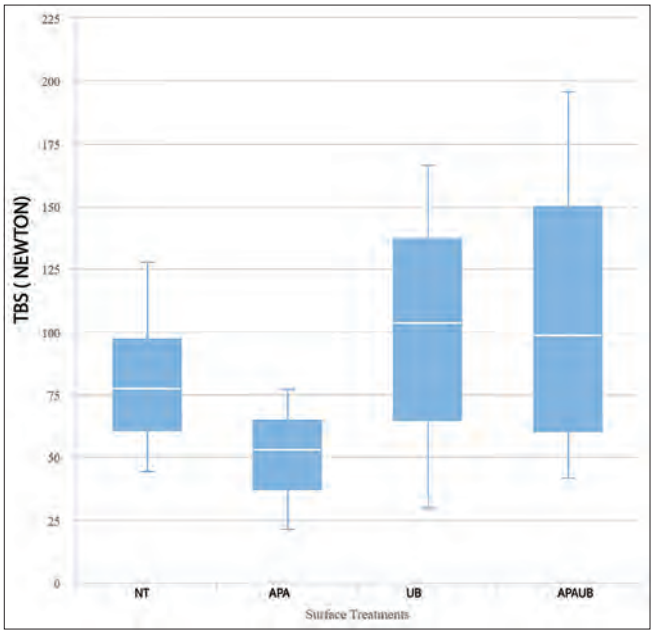

Figure 6: Different surface treatments applied TBS of AMH when different materials are ignored. AMH: Attachment matrix housing, TBS: Tensile bond strength, APA: Airborne-particle abrasion

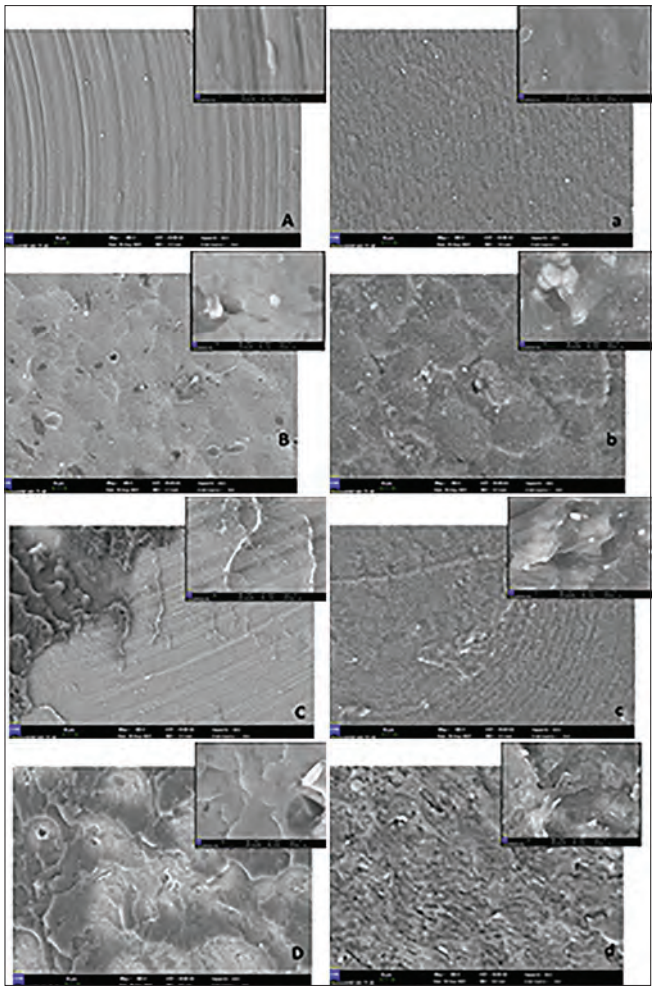

Figure 7: SEM images of one sample of all groups. (A) NTT group, (a) NTP group, (B) APAT group, (b) APAP group, (C) UBT group, (c) UBP group, (D) APAUBT group, (d) APAUBP group. SEM: Scanning electron microscope

with NT, APA, and UB groups in all materials. In the PEEK AMH groups, the APA and APAUB groups have significantly lower TBS values.

Processing the AMH into the overdenture can be performed either by the chairside (direct technique) technique or during a laboratory process (indirect technique). Many practitioners prefer to pick up the housing using the chairside technique to minimize errors resulting from denture processing.[4]

Conventionally, reline acrylic resin, which is more tissue-protective, is used for the direct chairside fixation of AMH. The most common clinical occurrence associated with overdentures is the debonding of AMH from the denture base resin over time, or the denture breaks due to the weakening of the denture in this area.

In the literature, the use of different acrylic materials has been compared to prevent the fracture of overdentures.[9] Various surface treatments have been applied to the AMH[11] or the overdenture has been strengthened by adding glass fibers to the prosthesis acrylic.[20] Since the durability of the overdenture was evaluated in these studies, the 3-point bending test was preferred. Unlike other studies, in this study, the TBS test was preferred because the tensile force will affect the detachment of the AMH to a greater extent.

Bryant *et al.*[5] followed overdentures supported by one and two implants for 5 years. They reported complications in both two-implant-supported overdentures and single-implant-supported overdentures during this period. Re-attachment of the housings was needed on 36 occasions in patients with 2 implants (n = 33), while it was needed 29 times in patients with a single implant (n = 29). The frequency of these complications causes clinicians and patients to lose time and suffer increased costs.

PEEK material is a thermoplastic material that has also been used in the production of overdenture AMH due to its white color and its elasticity modulus that is close to that of dentin.[19] Although it has been shown that PEEK has a low adhesion with resins due to its hydrophobic nature,[21] there is no study in the literature comparing the adhesion of PEEK and titanium materials with reline acrylic resins used in the mouth. As a result of this study, it was found that the AMHs made of titanium material had a significantly higher TBS with relining acrylic resins.

In dentistry, various surface treatments are applied to increase the bond strength of various materials.[22-24] APA and adhesive resin application surface treatments are practical and inexpensive methods that are frequently used in clinics.

Agarwal *et al.* compared the adhesion between the titanium AMH that 30 μm silica-modified aluminum oxide powder applied, and autopolimerized reline and light-polymerized acrylic resins and revealed that APA application would increase bond strength.[11] In this study, unlike that of Agarwal *et al.*, APA in the case of titanium AMHs did not significantly increase the bond strength but instead caused a slight decrease.

In contrast to Agarwal *et al.*,[11] Yanagıda *et al.*[25] reported that APA application on titanium disc surfaces would significantly reduce the shear bond strength with the acrylic resin and stated that it would be appropriate to apply a chemical adhesive resin after APA application and this result is parallel to our study.[11,25] Egoshi *et al.*[26] reported that as a result of APA application titanium discs with small particles of Al_2O_3 (50 μm), some alumina particles remained on the titanium surface and this reduced the

shear bond strength. In this study, 10 min of ultrasonic cleaning after APA application may not have been enough; different processes can be applied to remove the Al_2O_3 from the surface. In this study, Al_2O_3 particles embedded in the titanium surface were observed in the SEM imaging.

Egoshi *et al.*[26] and Yanagida *et al.*[25] suggested applying adhesive resin to titanium surfaces after APA application. Parallel to this, in this study, the highest TBS was found in the group in which APA and universal resin were applied.

UB resins are adhesives used to bond dental materials to dental tissue. In addition to the various monomers they contain, these resins are also used to bond ceramic, zirconium, or metal substructures with resin-containing materials.[27] In particular, previous studies indicated that 10-methacryloxydecyl dihydrogen phosphate (MDP) monomer-containing resins increase the bond of titanium with resin materials.[25-28] This study used a UB containing a three-dimensional self-reinforcing monomer (3D-SR) monomer with phosphate groups similar to the MDP monomer. Like the MDP monomer, the 3D-SR monomer significantly increased the TBS of titanium with acrylic resins.

The results of this study showed that the TBS of the APA-applied groups in the surface-treated PEEK AMHs decreased significantly. The adhesion of the PEEK material to surfaces modified by different mechanical and chemical processes poses a problem.[29] Only one study in the literature has investigated the adhesion of PEEK and reline acrylic resins.[18] Kurahashi *et al.*[18] applied various surface treatments to PEEK surfaces and compared their adhesion with reline acrylic resin and Cr-Co. In parallel with this study, Kurahashi *et al.* found that APA application did not significantly increase bond strength.

Schmidlin *et al.*[13] reported that the PEEK material has a hydrophobic surface feature. Consequently, the adhesion with hydrophobic materials will be low. Han *et al.*[30] also showed that APA application in PEEK material did not increase the contact angle and did not affect the hydrophobic property of the material. In our study, APA application significantly reduced the adhesion of PEEK AMHs with reline acrylic resin probably because APA application did not change the hydrophobic properties. In addition, 10 min of ultrasonic cleaning in the case of PEEK material, as was the case in titanium, was insufficient to purify Al_2O_3 particles we know this because, in PEEK, as in titanium, stuck Al_2O_3 particles were observed in SEM imaging. Similarly, since the applied universal adhesive is hydrophilic, the universal adhesive application did not have a significant effect on the adhesion of PEEK AMH and reline acrylic resin. Studies are needed in which different methods (such as pressured stream application, increasing the ultrasonic cleaning time, or the use of acid cleaning) are applied to clean the residual or buried Al_2O_3.

The usage of PEEK material in dental implantology has increased as a result of its advancement. The advantages and disadvantages of these applications, however, are not yet clear. There are no studies on the use of PEEK AMHs in the literature. This study demonstrated that the detachment of AMHs was influenced by the adhesion of AMH material with reline acrylic resins. Limitations of this study as TBS are not the only factor that may influence the durability of resin material adhesion to AMH. Furthermore, the fact that thermal aging was not used in this study is a limitation. Consequently, careful interpretation of the clinical application of these results is suggested, as the design of the present study, did not consider factors, such as thermocycling and pH changes, existing in the oral environment. The efficacy of the tested systems in providing reliable bond strength needs to be confirmed by long-term clinical studies.

CONCLUSION

Within the limitations of this study:

1. Titanium AMHs have a higher TBS with relining acrylic resins than PEEK AMHs. These data showed that clinicians should prefer titanium AMHs to PEEK AMH as an overdenture attachment housing material, to protect them from detachment when there are no aesthetic expectations
2. Universal adhesive application significantly increased the bonding of the titanium AMH with the reline acrylic resins. When using a titanium AMH, the clinician should consider that the application of 3D-SR monomer-containing UB resin increases the TBS of the titanium AMHs with the reline acrylic resins
3. Any surface treatment is not recommended if PEEK AMH is to be used.

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Conflicts of interest

There are no conflicts of interest.

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Research

Assessment of craniofacial growth in individuals with ectodermal dysplasia after complete denture rehabilitation: A preliminary study

Jyotsna Vimal, Akanksha Gopal Shetye[1], Balendra Pratap Singh[1], Prachi Goel[2], Kaushal Kishor Agrawal[1], Pooran Chand[1]

Department of Dentistry, Uttar Pradesh University of Medical Sciences, Saifai, [1]Department of Prosthodontics and Crown and Bridge, Faculty of Dental Sciences, King George's Medical University, Lucknow, [2]Department of Orthodontics, Chandra Dental College and Hospital, Barabanki, Uttar Pradesh, India

Abstract

Aim: The main purpose was to evaluate the effect of complete denture rehabilitation on the jaw growth pattern in individuals with ectodermal dysplasia from an early age to maturity.

Settings and Design: This was a prospective *in vivo* study performed in the Department of Prosthodontics, King George Medical University, Lucknow, India.

Materials and Methods: Rehabilitation with three sets of conventional complete dentures was completed in an ectodermal dysplasia case at the age of 5, 10, and 17 years. Cephalometric and diagnostic cast analyses were the methods performed to evaluate jaw growth patterns. Linear and angular measurements obtained after denture rehabilitation were averaged and compared with mean standard values of nearly corresponding ages, as given by Sakamoto and Bolton. Conversely, alveolar ridge arch width and length were evaluated for their dimensional changes during the same age intervals.

Statistical Analysis Used: Mann–Whitney *U*-test was used to check the difference between the groups. The significance of the level adopted was 5%.

Results: Nasion-anterior nasal spine, anterior nasal spine-menton, anterior nasal spine-pterygomaxillary fissure, gonion-sella, and gonion-menton lengths were found to be not statistically significant than the mean standard values of nearly corresponding ages ($P > 0.05$). The decrease in facial plane angle, increase in Y-axis angle, and mandibular plane angle after complete denture rehabilitation were statistically significant when compared to their mean standard values ($P < 0.05$). Cast analysis showed more increase in the length compared to the width in both arches.

Conclusion: Complete denture rehabilitation did not significantly affect the jaw growth pattern, although it improved facial esthetics and masticatory activity by establishing adequate vertical dimensions.

Keywords: Cast analysis, cephalometric analysis, complete denture, ectodermal dysplasia

Address for correspondence: Dr. Kaushal Kishor Agrawal, Department of Prosthodontics and Crown and Bridge, Faculty of Dental Sciences, King George's Medical University, Lucknow, Uttar Pradesh, India.
E-mail: drkaushalp@gmail.com

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INTRODUCTION

Ectodermal dysplasia syndrome (EDS) is an inherited type of disease impacting several structures of ectodermal origin, resulting in an immense and vast number of disturbances.[1] Approximately 150 different ectodermal dysplasia (ED) clinical types can be described, with chances of each case appearing per 10,000–100,000 birth.[2] A few mild type EDS variants exist, whereas vast of them can be detrimental. While female carriers exceed affected males, there are little or no signs seen in female carriers as the transmission usually occurs through a sex-linked recessive gene leading to predominant expression in males.[3] Based on the number and function of sweat glands, ED can be classified into two broad types: hidrotic ED (normal sweat glands) and hypohidrotic/anhidrotic ED (sparse/absent sweat glands).[4,5] Hypohidrotic ED is the most frequently occurring type and its characteristic features include hypotrichosis, hypodontia or anodontia, and hypohidrosis.[6,7]

ED children remain a challenge for a dentist toward their dental rehabilitation, including the patient's self-confidence, attitude, and peer group interaction that, if intervened, can show significant signs of improvement.[8] Cephalometric studies have shown that dento-maxillary features such as hypoplasia and maxillary retrusion, counterclockwise rotation and mandibular protrusion, and reduced facial and ramus heights were common among EDs patients.[9] Therefore, clinical measures must be taken to intercept and correct these functional deformities at appropriate times. In complete anodontia cases, oral function and esthetics are restored using complete dentures. Very few follow-up studies on oral rehabilitation of ED cases have been discussed, and moreover, there seem to be scant data to interpret the results of dentures on jaw growth and development.[10-14] The current study aimed to evaluate the effect of complete denture rehabilitation on the jaw growth pattern in individuals with ED from an early age to maturity. The null hypothesis was that complete denture rehabilitation would affect the jaw growth pattern of completely edentulous ED cases.

MATERIALS AND METHODS

This study was performed in the Department of Prosthodontics, King George Medical University, Lucknow, to evaluate the consequences of complete denture treatment on craniofacial growth in hereditary ectodermal dysplasia (HED) cases. A completely edentulous hereditary ED case was followed from 5 to 17 years of age.[15,16] Classic characteristics of HED were displayed at the time of presentation, which included anodontia, prominent forehead, saddle nose, and hypotrichosis [Figure 1a]. A noncontributory family history was detected as both parents and siblings had no alike features. Radiographic examination disclosed complete deprivation of teeth and tooth buds [Figure 2]. Patient consent was obtained before the study, and ethical standards were followed accordingly.

The three sets of complete dentures were constructed for the patient when he was at the age of 5 years, 10 years, and 17 years, respectively [Figure 3]. At all ages, the complete denture fabrication method was the same and mainly consisted of a selection of age-appropriate teeth sets, as discussed in detail in the previous publications.[15,16] Maxillary and mandibular impressions were taken following the selective pressure impression technique. Type IV dental stone (Kalrock; Kalabhai Karson Pvt. Ltd., Mumbai, India) was used to pour the impression to construct master casts. Face-bow transfer and mounting procedures were done on a semi-adjustable articulator (Hanau™ Wide-Vue; Whip Mix Corporation, Louisville, USA). Physiological rest position using phonetic and esthetic techniques was applied to establish the occlusal vertical dimension. The centric relation was established according to the dynamic records formed by unforced jaw movements in the terminal hinge position accomplished by the patient and manually guided. The denture was processed in centric occlusion with balanced articulation using anatomically structured age-appropriate acrylic teeth, finished, and polished [Figure 1b]. After denture insertion, postoperative instructions were given to the patient.

The future recall was scheduled at all years of follow-up to check for the requirement of necessary relining or construction of a new denture. The recurring occlusal changes noticed were loss of posterior tooth contact and anterior tooth contact occurrence, which was

Figure 1: Preoperative (a) and postoperative (b) facial frontal view

subsequently corrected by the addition of self-cure acrylic resin (Trevalon, Dentsply Ltd., Gurgaon, India) to the posterior denture teeth's occlusal surface.

Analysis of jaw growth

Cephalometric and diagnostic cast analyses were the methods used to evaluate jaw growth. Assessments were made on diagnostic casts and lateral cephalograms taken at the ages of 5, 10, and 17 years to evaluate jaw growth [Figure 4].

Measurements for size alterations in alveolar arch length and width were made on diagnostic casts. A segmental method was applied to calculate the arch length and width, where four reference points divided each side of the arch into three sections. The reference points taken were as follows: arch midline (a), the canine eminence (b), the hamular notch for the maxillary arch or posterior extent of the retromolar pad for the mandibular arch (d), and an equidistant point from point b and point d (c) [Figures 5 and 6].

Angular measurements such as facial angle, Y-axis, and mandibular plane angle on lateral cephalograms were analyzed to differentiate the positional association of craniofacial landmarks, while linear assessments such as nasion-anterior nasal spine (N-ANS), anterior nasal spine-menton (ANS-ME), anterior nasal spine-pterygomaxillary fissure (ANS-PTM), gonion-sella (GO-S), and gonion-menton (GO-ME) were measured for dimensions. Derived cephalometric values were collated, averaged, and compared with the mean standard values of nearly corresponding ages, as given by Sakamoto and Bolton standards[17] [Tables 1 and 2].

All collected data were tabulated and analyzed with software (IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.). Linear and angular measurements of cephalometric analysis were represented as mean ± standard deviation and compared with mean standard values using Mann–Whitney *U*-test. A two-tailed ($\alpha = 2$) $P < 0.05$ was considered statistically significant.

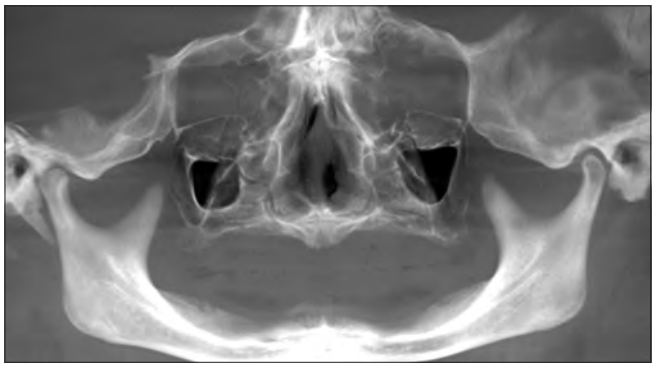

Figure 2: Orthopantomogram view

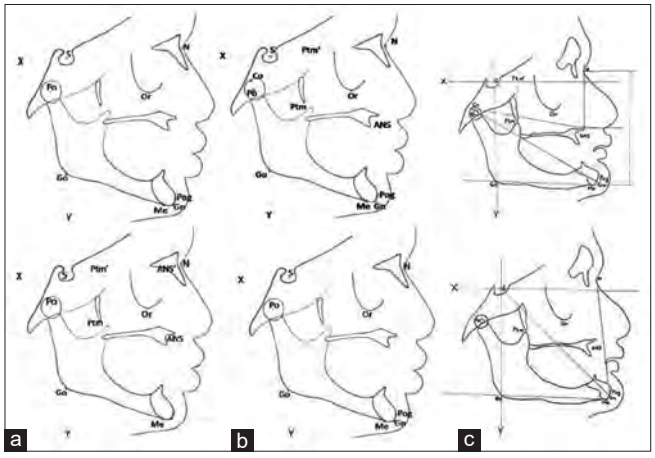

Figure 4: Lateral cephalograms at the age of 5 (a), 10 (b), and 17 (c) years

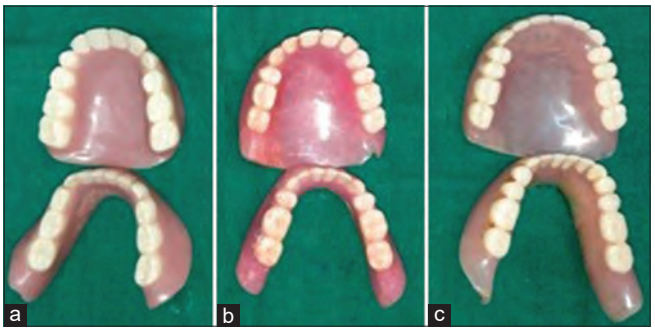

Figure 3: Three sets of complete dentures at the age of 5 (a), 10 (b), and 17 (c) years

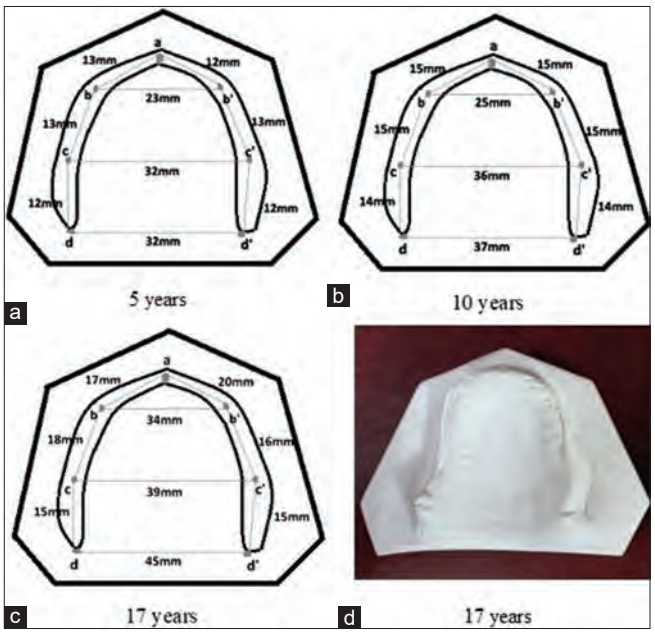

Figure 5: Diagnostic cast analysis of maxillary arch at age of 5 (a), 10 (b) and 17 (c and d) years

Table 1: Cephalometric analysis of the patient at 5, 10, and 17 years of age and values compared with the average values reported by Sakamoto T 1959[17]

Parameters	Patient values				Average values		
	5 years (with dentures)	10 years (with dentures)	17 years (without denture)	17 years (with denture)	5 years	10 years	17 years
Angle (°)							
Facial angle	92.2	85.2	100	92	81.1	83.1	84.1
Y-axis	48.6	59.6	44	54	65.7	65.2	66
Mandibular plane angle	13	13.5	5	14	32.8	31.6	32
Length (mm)							
N-ANS	46.1	50.2	52.1	52.1	43.5	50.6	55.7
ANS-ME	52.5	61.8	42.1	64.3	58.4	61.1	69.7
ANS-PTM	40.3	44.1	54.0	54.0	49.9	51.8	57.2
GO-S	60.2	70.3	74.3	76.2	62.3	71.8	80.6
GO-ME	58.7	67.7	65.0	65.0	55.5	65.5	72.7
Ratio of lengths (%)							
N-ANS/ANS-ME	87.8	81.2	123.8	81.0	74.4	82.8	79.9
ANS-ME/GO-S	87.2	87.9	56.7	84.4	93.7	85.1	86.4

N-ANS: Nasion-anterior nasal spine, ANS-ME: Anterior nasal spine-menton, GO-S: Gonion-sella, GO-ME: Gonion-menton, ANS-PTM: Anterior nasal spine-pterygomaxillary fissure

Table 2: Cephalometric analysis of the patient at 5, 10, and 17 years of age and values compared with the skeletal values as derived from the Bolton standards for age and sex

Length (mm)	Patient values				Standard values		
	5 years (with dentures)	10 years (with dentures)	17 years (without dentures)	17 years (with dentures)	5 years	10 years	17 years
Co-point A (maxillary length)	73.4	77.1	90.0	90.0	81.7	87.7	98.9
Co-Gn (mandibular length)	95.2	100.2	110.1	110.1	99.3	107.7	126.8

Co-Point A: Condylion-Point A, Co-Gn: Condylion-gnathion

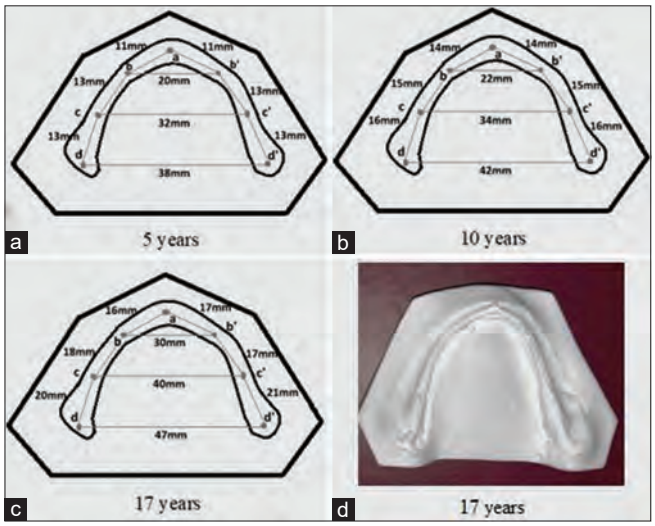

Figure 6: Diagnostic cast analysis of mandibular arch at age of 5 (a), 10 (b) and 17 (c and d) years

RESULTS

Lateral cephalograms showed a continuous increase in length of N-ANS, ANS-ME, ANS-PTM, and Go-S when measured after complete denture rehabilitation at 5, 10, and 17 years of age, revealing continuous growth but remaining posterior to standard values. In comparison, the mean N-ANS, ANS-ME, ANS-PTM, Go-S, and Go-ME were not statistically significant than the mean standard values of nearly corresponding ages ($P > 0.05$). There were a decrease in facial plane angle and an increase in Y-axis angle and mandibular plane angle after complete denture rehabilitation at 17 years of age. The mean values of facial plane angle (89.80 ± 3.98 vs. 82.76 ± 1.52, $P = 0.04$), Y-axis angle (54.06 ± 5.50 vs. 65.63 ± 0.40, $P = 0.02$), and mandibular plane angle (13.50 ± 0.50 vs. 32.13 ± 0.61, $P < 0.01$) after complete denture rehabilitation were found to be statistically significant when compared to their mean standard values ($P < 0.05$) [Table 3].

The ratio of maxillary facial height to mandibular facial height (N-ANS/ANS-ME ratio) after complete denture rehabilitation at 5, 10, and 17 years of age was more than the standard values of nearly corresponding ages, denoting a decreased mandibular facial height, hence showing reduced Y-axis and mandibular plane angle in comparison to standard values. The mean value of the N-ANS/ANS-ME ratio (86.50 ± 10.65 vs. 88.40 ± 4.63, $P = 0.54$) was statistically insignificant to the mean standard values of nearly corresponding ages ($P > 0.05$) [Table 3]. The measured maxillary length (Co-Point A) and mandibular length (Co-Gn) showed a maxillary length increase of 16.6 mm and a mandibular length increase of 14.9 mm from 5 years to 17 years of age, but their mean values did not differ statistically when compared to their mean standard values ($P > 0.05$).

Table 3: Cephalometric values of the patient at all ages compared with the standard mean values using Mann–Whitney *U*-test

Parameters	Means	Normal standard	Mann–Whitney *U*-test	*P*
Facial angle	89.80±3.98	82.76±1.52	0.00	0.04
Y-axis	54.06±5.50	65.63±0.40	0.00	0.02
Mandibular plane angle	13.50±0.50	32.13±0.61	0.00	<0.01
N-ANS	49.46±3.06	49.93±6.13	4.00	0.91
ANS-ME	59.53±6.21	63.06±5.90	4.00	0.51
ANS-PTM	46.13±7.07	52.96±3.78	2.00	0.21
GO-S	68.90±8.09	71.56±9.15	3.00	0.72
GO-ME	63.80±4.61	64.56±8.63	4.00	0.89
N-ANS/ANS-ME	86.50±10.65	88.40±4.63	4.00	0.54
ANS-ME/GO-S	83.33±3.86	79.03±4.26	2.00	0.26
Co-point A (maxillary length)	80.16±8.71	89.43±8.73	2.00	0.26
Co-Gn (mandibular length)	101.83±7.58	111.26±14.09	3.00	0.36

N-ANS: Nasion-anterior nasal spine, ANS-ME: Anterior nasal spine-menton, GO-S: Gonion-sella, GO-ME: Gonion-menton, ANS-PTM: Anterior nasal spine-pterygomaxillary fissure, Co-point A: Condylion-point A, Co-Gn: Condylion-gnathion

Maxillary cast analysis showed an overall increase in arch length of 26 mm and arch width of 11 mm in the anterior section, 7 mm in the middle section, and 13 mm in the posterior section from 5 to 17 years of age. Similarly, the mandibular cast analysis revealed an overall increase in arch length of 35 mm and arch width of 10 mm in the anterior section, 8 mm in the middle section, and 9 mm in the posterior section from age 5–17 years.

DISCUSSION

The present study showed comparable linear measurements of cephalometric analysis after complete denture rehabilitation in the case of ED with mean standard values of nearly corresponding ages. Although improvement was observed in mandibular plane angle after denture rehabilitation and raised vertical dimension, however, lower values were noticed when compared to standard values of nearly corresponding ages indicating a reduced lower facial height. Hence, complete denture rehabilitation did not significantly affect the jaw growth pattern, although it improved the facial esthetics by establishing adequate vertical dimensions, therefore rejecting the null hypothesis of the study. The outcome of our study favored the interpretations of Sarnat *et al*.[10] and Ochiai *et al*.,[18] stating that the absence of teeth did not affect jaw growth, and additionally, the denture flange perhaps did not hinder jaw growth but instead enhanced the masticatory activity by imparting better denture stability and retention.

A tissue-supported removable denture is a reliable treatment option for an ED patient with respect to age and growth of the alveolar bone. The insertion of endosseous implants at an early age, before 18 years of age, can cause implant submergence, as the growth of jaws continues, which consequently increases the risk of implant failure.[19] Therefore, a removable complete denture was chosen as a treatment option in this study. Clinically, vertical dimension was determined during denture construction using physiologic rest position and verified with the aid of facial support, esthetics, and phonetics. The established vertical dimension, besides preventing the development of class 3 malocclusion, also improved the child's skeletal relationship during his growth period.

The periodic recall examination was scheduled at 6 months to make necessary adjustments implying its importance for addressing the growth changes arising in a child. As reported by Shaw,[20] denture underextension and posterior open bite were constant setbacks associated with jaw growth. The posterior contact absence was controlled by the addition of self-cure acrylic resin to the posterior denture teeth's occlusal surface, and subsequently, posterior contact was evaluated using standard means of articulating paper. We thus agree that the application of autopolymerizing acrylic resin and acrylic teeth are satisfactory choices for managing growth alterations in such patients.

During the duration of 5–17 years of age, forward growth was markedly limited at the ANS point as observed on cephalogram, which was also reported by Sarnat *et al*.[10] A minor deflection from average was noticed in the anteroposterior mandibular body length and ramus height. A 16.6 mm maxillary length increase and a 14.9 mm mandibular length increase were detected. Therefore, more growth was perceived in the maxilla than the mandible, although both were almost at par. These growth changes might occur as a consequence of the presence of complete dentures during the period of growth; however, confirmation is inadequate with the present study design. Hamano and Nakata[21] studied anhidrotic ED cases with anodontia and agreed upon the fact that interaction between the lack of teeth and the atrophic rhinitis was the cause of deficient forward growth of the maxilla. Tocchini *et al*.[22] in their anodontia study found a reduced maxillary forward

growth, however, they were unable to distinguish whether it was due to teeth absence or prosthetic replacement.

In this study, the ratio of maxillary facial height to mandibular facial height (N-ANS/ANS-ME) values after complete denture rehabilitation was more than the standard values of nearly corresponding ages, denoting a decreased mandibular facial height, hence showing reduced Y-axis and mandibular plane angle in comparison to standard values. N-ANS/ANS-ME value was noticed to be lesser with complete dentures than without dentures because of the establishment of an adequate vertical dimension. Similar results were reported by Sarnat *et al*.[10] who studied the craniofacial growth in various anodontia cases using cephalometric measurements, portraying the facial structure and jaw growth as placed close to the lower limit of normal. Furthermore, the presence of dentures in our study allowed a backward, downward rotation of the mandible, as also proved by Franchi *et al*.[23] in their early prosthetic rehabilitation for complete anodontia case of ED.

The observations of our study detected an increased arch length compared to the arch width. Studies undertaken individually by Shirakawa *et al*.[24] and Tocchini *et al*.[22] also supported our results. Shirakawa *et al*.[24] evaluated the study casts and measured the alveolar ridge arch for 2 years. They reported a maxillary arch length increase of 5 mm and arch width increase of 6 mm whereas a mandibular arch length increase of 12 mm and arch width increase of 6 mm. The results of Shirakawa *et al*.[24] therefore proved an increased mandibular arch length compared to arch width while there was an overall increase in the dimensions of the maxillary arch. Cast analysis evidently supported the increase in the size of maxillary and mandibular dental arches, as also shown by de Castro *et al*.[12]

This was a long-term, preliminary study but was limited to comparatively analyzing the growth pattern of an ED case from early life to maturity. However, a multicentric, long-term study with a higher sample size is required to elevate the authenticity of data.

CONCLUSION

Within the limitations of the study, it was concluded that the lack of teeth in ED cases did not influence the jaw growth pattern following complete denture rehabilitation, although it improved the masticatory function, speech, and facial esthetics by establishing the adequate vertical dimension.

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Conflicts of interest

There are no conflicts of interest.

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Research

Overview and knowledge of prosthodontic diagnostic aids among interns and post graduates – A cross-sectional questionnaire study

Rangarajan Vedantham, Ganesh Kumar, Rahmath Shameem Shafiullah, Arjun Badimela, Sathiyaseelan Sakthivel, Syed Ajmal

Department of Prosthodontics and Crown and Bridge, Sri Venkateswara Dental College and Hospital, Chennai, Tamil Nadu, India

Abstract

Aim: This study aims to evaluate and compare the knowledge of prosthodontic diagnostic aids among interns and postgraduates.

Settings and Design: A questionnaire survey was conducted to assess and compare the knowledge of prosthodontic diagnostic aids among interns and postgraduates. Based on the pilot study with alpha error 5% and a power of study 80%, the sample size was estimated to be 858 for each group.

Materials and Methods: The self constructed questionnaire consisted of 3 sections, of which each section had 5 questions, a total of 15 questions validated by a team of 6 experts. The questionnaire was distributed electronically among interns and postgraduates in various dental colleges across India. Data were collected and subjected to statistical analysis.

Statistical Analysis: All outcomes of this survey were analyzed using an independent *t* test. The Mann–Whitney test was used to determine the significance of two groups.

Results: From the results obtained, it was found that interns (mean: 6.90; standard deviation: 2.442) had less knowledge regarding diagnostic tools than postgraduate students (mean: 8.76; standard deviation: 1.818).

Conclusion: Diagnostic aids simplifies the process of diagnosis and treatment planning. Moreover, the knowledge of diagnostic aids among younger generation permits them to redefine the way dentistry is practiced and at the same time helps to provide better treatment results and achieve the utmost for the profession. Adequate knowledge of diagnostic aids is the need of the hour. Dental professionals should constantly update knowledge regarding various diagnostic aids in Prosthodontics, so as to arrive at optimum diagnosis and treatment plan with longer prognosis.

Keywords: Diagnostic modalities, diagnostic tool, prosthodontic diagnostic aids, radiographic aids

Address for correspondence: Dr. Sathiyaseelan Sakthivel, Department of Prosthodontics and Crown and Bridge, Sri Venkateswara Dental College and Hospital, Chennai, Tamil Nadu, India.
E-mail: sathyavijay76@gmail.com

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INTRODUCTION

In recent decades, knowledge in dentistry has evolved tremendously, not only in terms of digitalization and evidence-based treatment but also in terms of diagnostic modalities.[1] A precise diagnosis should first determine whether disease is present or not, then identify its type, extent, distribution, severity and finally integrate information obtained from a thorough clinical examination along with various diagnostic aids.[2] According to the Glossary of Prosthodontic Terms, Diagnostic aid is defined as "a tool relating to or used in diagnosis."[3] Diagnostic aids used in Prosthodontics help to assess the soft tissue and hard tissue to restore the stomatognathic system of the patient's normal function, comfort, esthetics, speech, and mastication. Moreover, the long-term prognosis depends on the meticulous care taken during the diagnosis and planning the treatment for the patient. Historically, the diagnosis was made only with clinical examination and clinical history.[2] Over decades, a paradigm shift in the sector of diagnostic methods has occurred, resulting in a tremendous explosion of innovative ideas and information, resulting in rapid breakthroughs in the field. Recently, several sophisticated diagnostic aids to achieve precise diagnosis have been explored in prosthetic dentistry.[4]

Diagnostic aids can be broadly classified into essential and supplementary diagnostic aids. Essential diagnostic aids are considered as essential for the diagnosis of a condition. This includes paper chart, diagnostic instruments like (mouth mirror, explorer, straight probe, periodontal probe, and tweezer), mounted cast, photographs and radiographs (intra-oral periapical radiograph, bitewing radiograph, occlusal radiograph, orthopantomography, lateral cephalogram, computed tomography, and cone-beam computed tomography).

The supplementary diagnostic aids are aids that are not necessary for all types of prosthetic treatment planning. They may vary from simple instruments to specialized equipment's that an average dentist may not possess. The supplementary diagnostic aids are (a) accessory diagnostic instruments such as T burnisher, oral accessibility Spatula, tongue depressor, customized gauge and intraoral performance instruments (IOPI), (b) accessory diagnostic aids are fox plane guide, face bow, Broadrick's occlusal plane analyzer, leaf gauge, alu wax, mold guide, mold selector, flexible ruler, shade guide, pressure indicating paste, fit checker, articulating paper, articulating plastic tape, articulating ribbon, occlusal wax, loupes, Intra oral videography and bone mapping, (c) measuring device are divider, caliper, Trubyte tooth indicator, labiometer, lip force meter, Willi's gauge, Boley gauge, bite force device, (d) accessory radiographic aids are magnetic resonance imaging, stereolithography, and ultrasonography.

Description of all the supplementary diagnostic aids are not comprehensively available in a single standard text book. The details on these are present in a few textbooks and journals which is not easily accessible for the undergraduates as well as postgraduates. In addition, the knowledge about these aids are not imparted to the undergraduate students.

However, the use of these supplementary diagnostic aids helps in deriving at a comprehensive treatment plan with better prognosis. Thus, the knowledge of the practitioner on these diagnostic aids is essential. During dental education students seem to be more interested in improving their clinical skills and give less importance to theoretical knowledge and recent advances in diagnosis. At present, the knowledge of various diagnostic aids among dental students and postgraduate students is questionable. With the available information, the present study aimed to compare the knowledge of prosthodontic diagnostic aids among interns and postgraduates. Based on the results of the study, the dental curriculum could be modified to improve clinical prosthetic dentistry.

Aim

This study aims to evaluate and compare the knowledge of prosthodontic diagnostic aids among interns and postgraduates.

MATERIALS AND METHODS

Study design

A questionnaire survey was conducted to assess and compare the knowledge of prosthodontic diagnostic aids among interns and postgraduates (IEC/SVDCH/2115).

Sample size estimation

Based on the pilot study with alpha error 5% and a power of study 80%, the sample size was estimated to be 858 for each group.

Questionnaire validation

After intense review of literature, a drafted questionnaire consisted of 24 questions segregated into three sections: Section 1 - removable dentures; Section 2 - fixed partial dentures; and Section 3 - implant dentistry was created. The face validity and content validity were assessed by a team of six experts and prototype questionnaire was developed. This was pretested among 10 dental students for feasibility assessments. Modifications were done in the questionnaire

and the number was reduced to 15. After 2 weeks, the questionnaire was administered to the same students for test–retest reliability. Cohen's kappa values and intra-class correlation coefficient (ICC) were measured. ICC was used to assess the answers at two different time points. The inter-rater agreement was found to be 0.7, Cohen's kappa value was considered to be a good indicator. Questions are represented in Table 1. Each question carried one mark for the right answer and no mark for the wrong answer. Based on the scores obtained in the three sections, the knowledge of the participants was evaluated. It was a comparative study between interns and postgraduates (Group 1: Postgraduates; Group 2: Interns).

Response assessment

After obtaining prior permission and consent, this questionnaire survey was conducted in June 2020 through Google Forms across various dental colleges in India. A total of 870 interns and 870 postgraduates participated in this study.

Statistical analysis

Test–retest reliability method was used to validate the reliability of the questionnaire. All outcomes of this survey were analyzed using an independent *t*-test. The Mann–Whitney test was used to determine the significance of two groups. Statistical tests were considered significant if $P < 0.05$. All statistical analysis was performed in SPSS (version 22.0, IBM, Chicago, USA).

RESULTS

The current study report is based on the responses of 870 interns and 870 postgraduates to a questionnaire survey. Graph 1 shows the overall score of knowledge of prosthodontic diagnostic aids among postgraduates and interns. Overall knowledge scores projected that postgraduates had more knowledge (mean: 8.76; standard deviation: 1.818) than interns (mean: 6.90; standard deviation: 2.442). Graph 2 shows the section-wise score of knowledge of prosthodontic diagnostic aids among postgraduates and interns. Among postgraduates, they scored more in Section 3 (implant dentistry) (mean: 3.15, standard deviation: 0.948), followed by Section 1 (removable dentures) (mean: 2.81, standard deviation: 1.235), and least in Section 2 (fixed partial dentures) (mean: 2.80, standard deviation: 0.949). Interns outperformed in Section 1 (removable dentures) (mean 2.43 and standard deviation 1.77), Section 2 (fixed partial dentures) (mean 2.28 and standard deviation 1.127), and Section 3 (implant dentistry) (mean 2.19 and standard deviation 1.167). Table 2 shows the comparison of knowledge of prosthodontic

Table 1: Knowledge of prosthodontic diagnostic aids questionnaire

Questions
Section 1: Removable denture
Based on Neil's classification, Kalavathy N reclassified the lateral throat form using customized gauge. According to customized gauge, Class B is? (cm)
A. 2.5–3.5
B. 1.5–2.4
C. 1.5–3.0
One of the major drawbacks of T scan system is?
A. Unavoidable jaw separation
B. Inaccuracy
C. Induce pain
The outcome measures to determine the validity of the facebow would be?
A. Occlusion
B. Esthetics
C. Both of the above
IOPI is to examine?
A. The relationship between tongue strength and speech
B. The relationship between lip strength and speech
C. The relationship between maxillary central incisor position and speech
In pressure-indicating paste, the term "streaks" indicates?
A. Normal contact of denture base with soft tissue
B. No contact of denture base with soft tissue
C. Impingement of denture base over soft tissue
Section 2: Fixed partial denture
In skeletal class II relationship condition, Broadrick's occlusal plane analyzer is used to construct curve of Spee with a radius of? (inch)
A. Radius of 4
B. Radius of 3.75
C. Radius of 5
The range of magnification of Galilean loupes are
A. Limited than Keplerian loupes
B. Greater than Keplerian loupes
C. Same as Keplerian loupes
Unique advantage of oral accessibility spatula is?
A. Provides retraction along with light source
B. Elastic in nature
C. It can be inserted even if the mouth is closed
Fit checker advanced blue is indicated to check?
A. Resin based crowns and bridges
B. Metal based crowns and bridges
C. Complete and partial removable denture
The virtual facebow transfer can be practically made in dental CAD application based on?
A. Standard frontal photographs
B. Standard lateral photographs
C. Standard frontal and lateral photographs
Section 3: Implant dentistry
Demerits of 2D imaging is?
A. Super imposition of overlying structure
B. Buccal-lingual plane is not possible to assess
C. Both of the above
Digital mock-up for 3D implant treatment planning systems, based on
A. CBCT, digitized dental surface, and virtual planning simulation
B. CT and virtual planning simulation
C. MRI, digitized dental surface, and virtual planning simulation
Using MRI for preimplant assessment, the normal anatomy is being examined with?
A. T1 weighted sequence
B. T2 weighted sequence
C. T3 weighted sequence
Primary implant stability and osseointegration is assessed by
A. Resonance frequency analysis

Contd...

Table 1: Contd...

Questions
B. Reverse torque test
C. Both of the above
In cases where the inferior alveolar canal cannot be differentiated by conventional tomography or CT, the next alternative option will be?
A. MRI
B. OPG
C. CBCT

IOPI: Iowa oral performance instrument, CT: Computed tomography, OPG: Ortho pantogram, CBCT: Cone-beam CT, MRI: Magnetic resonance imaging, CAD: Computer-aided design, 2D: Two-dimensional, 3D: Three-dimensional

Table 2: Comparison of knowledge of prosthodontic diagnostic aids between interns and postgraduates

Questions	Mean±SD		Significance (*P*)
	Postgraduates	Interns	
Section 1	2.81±1.235	2.43±1.177	0.00
Section 2	2.80±0.949	2.28±1.127	0.00
Section 3	3.15±0.948	2.19±1.167	0.00
Overall score	8.76±1.818	6.90±2.442	0.00

Citation: Postgraduates had more knowledge than interns. $P<0.05$ is considered statistically significant

diagnostic aids between postgraduates and interns; it was found to be highly significant in all sections.

DISCUSSION

According to a report by the Ministry for Statistics and Program Implementation in 2016, India has 103.9 million elderly people above the age of 60 years.[5] With the advancement in health-care facilities, these geriatric individuals are given suitable care for healthy living, leading to increased life expectancy. Increased life expectancy, poor socio-economic standards and a lower level of education among geriatrics demands increased prosthetic rehabilitation.[6] In order to meet this demand, it is necessary to acquire high-quality theoretical and practical knowledge about prosthodontic diagnostic aids during the course of their study, which will lay the foundation for their future clinical work.[7]

Dental interns and postgraduates are the budding clinicians. As doctors, they should have thorough knowledge about the latest techniques and advancements in their field, including diagnostic aids as shown in Figure 1. According to The Glossary of Prosthodontic Terms, diagnostic aid is defined as "relating to or used in diagnosis."[3] Accurate diagnosis with the proper use of diagnostic aids would enable them to practice efficiently in treatment planning. Hence, it becomes essential to gauge the knowledge of prosthodontic diagnostic aids and their benefits among the dental interns. To the best of our knowledge, there is only one study titled "Diagnostic Aids in Prosthodontics" that discusses only diagnostic casts, photographs, and

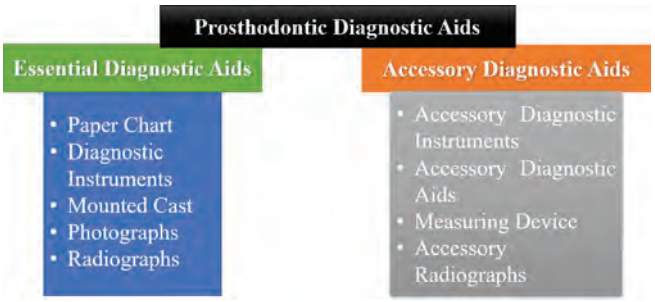
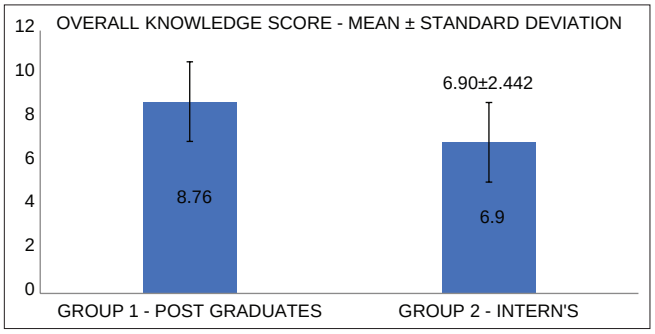
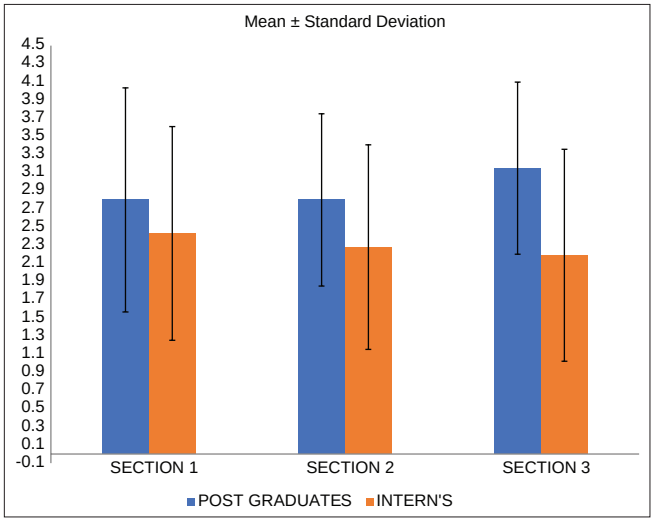


Figure 1: Schematic representation of Prosthodontic diagnostic aids



Graph 1: Overall score of knowledge of prosthodontic diagnostic aids among interns and post graduates



Graph 2: Section-wise score of knowledge of prosthodontic diagnostic aids among interns and post graduates

radiographic modalities and there is no study that has compared the knowledge of undergraduates and postgraduate students. The results of the comparative study would aid in identifying the lacunae in current curriculum and give future insights for modifying the dental curriculum for both undergraduates and postgraduates.

In this study, the first section of the questionnaire was about the complete and removable partial denture. A total of five questions with multiple subsets were asked. The section-wise average revealed that the "interns" had

good knowledge about diagnostic aids in removable dentures. (The mean score is −2.43, and the standard deviation is −1.77.) However, the students showed insufficient knowledge in all the other sections (Section 2 − Fixed partial denture and Section 3 − Implant dentistry). During the undergraduate course, preclinical laboratory work is started earlier, where removable dentures are given utmost importance both theoretically and practically when compared with fixed partial dentures and implant dentistry. Moreover, from an examination point of view, they tend to get more questions about removable dentures than other fields of prosthodontics. Besides, they also had incorrect information or misconceptions regarding several aspects of prosthodontic diagnostic aids. This indicates that the students were not aware of diagnostic aids and had inadequate knowledge in the various fields of prosthodontics during their under-graduation. This is also in accordance with the Al-Jobair study, where it was observed that 91.5% of the surveyed population felt that they were provided with insufficient knowledge at the undergraduate level.[8] A study by Honey *et al*. showed that the dental students were most confident in simpler procedures and procedures during which they had the most clinical experience. They were least confident in more complex procedures, in which they had the least clinical experience.[9] This observation is serious in nature and would limit the complete and correct utilization of the diagnostic aids to arrive at a precise diagnosis.

According to the Dental Council of India, even at the undergraduate level, basic skills such as attaining versus maintaining competence in diagnosis such as recording case history, clinical examination, use of diagnostic aids, and interpretation are required in the Department of Prosthodontics and Crown and Bridge. Yet the same is not followed in the undergraduate curriculum. The prescribed curriculum includes only an introduction to diagnosis without various diagnostic aids at the undergraduate level. The last revision to the curriculum was made in 2007, and since then, the field of diagnostic aids has expanded by leaps and bounds.[9,10] A curriculum revision faces several challenges, including being comprehensive and wealthy, dealing with anticipated student and faculty resistance and having a broad scope of advancements. However, it is critical for dentistry to provide the most basic care to patients. The relatively low knowledge shown by students in this study is an indication that it is time that the curriculum be revised.[8] Apart from several other things, diagnostic aids should be unified both theoretically and practically.

Section 3 (mean - 3.15 and standard deviation - 0.948) was the most familiar to postgraduates, followed by Section 1 (mean - 2.81 and standard deviation - 1.235) and Section 2 (mean - 2.80 and standard deviation - 0.949). This may be attributable to the fact that there is more availability of material and more interest in new topics, and the predominant research these days involves implantology. Even before placing an implant, it becomes mandatory to be precise in the diagnosis by using appropriate diagnostic aids for the long-term success of the prosthesis.[11] Most conferences have a large number of people choosing a topic related to implantology rather than removable or fixed rehabilitation.[12]

Since postgraduates tend to focus more on recent advances such as implants and digital dentistry, they often fail to look at age-old complete and partial denture topics. Complete and partial dentures are the foundations of prosthodontics, from which advances have evolved over time. Only after a thorough understanding of the fundamental concepts, the more advanced concepts will be predictable.

On comparing postgraduates with interns, postgraduates had more knowledge than interns. This may be attributed to the fact that, during under-graduation, they have exposure to all branches of dentistry; their interest in prosthodontics will vary from person to person. This may also be influenced by less access to prosthodontic diagnostic aids. Furthermore, information on most prosthodontic diagnostic aids are not available comprehensively in a single text book but data is scattered in textbooks and articles which may be difficult for undergraduates to access and learn about prosthodontic diagnostic aids.[13] Unlike other specialties, where diagnostic aids are given as a special chapter in standard textbooks and articles, there is no such exclusive chapter covering this section in particular in any standard textbooks and articles in the prosthodontic curriculum. On the other hand, it is obvious that postgraduates had more knowledge because of their clinical exposure and experience.

In prosthodontics, loads of tools or aids are available to arrive at a proper diagnosis. If we had enough literature to support diagnostic aids or a special chapter in standard textbooks, interns would have answered in a better way. Whereas when it comes to postgraduates, for whom prosthodontics is a chosen specialty, they will obviously have more passion and interest than interns. During the postgraduation course, they were exposed to various journals, seminars, and symposiums, and they would have spent a greater number of years studying the subject and practicing it. Hence, they tend to be aware of prosthodontic diagnostic aids in a better way.[14] Comparing the knowledge of prosthodontic diagnostic aids between postgraduates and interns, we found statistically significant results. Thus,

based on the results of the study, it is recommended that modifications in textbooks can be done to include an exclusive chapter on diagnostic aids in prosthodontics along with the clinical application of the same.[15,16]

Most of the questions were advanced diagnostic tools and fewer questions were on basic diagnostic aids. Different levels of postgraduates were not compared and the study was done in an online platform. In person questionnaire distribution with a larger sample size could have ensured more accurate response. Future studies with larger sample size involving more dental colleges and clinical practitioners would give a better insight on curriculum modification to improve knowledge on diagnostic aids.

CONCLUSION

The knowledge of prosthodontic postgraduates was quite fair, especially in an academic field. Despite the advantages of diagnostic aids, the majority of postgraduates did not use diagnostic aids in their practice at dental colleges. As a postgraduate, myself, I feel that if there is a "standardized diagnostic protocol" in prosthodontics and an "exclusive chapter in standard textbooks" covering all diagnostic aids, it could be easier for us to learn and understand the subject to achieve a precise diagnosis with a longer prognosis. Most prosthodontic diagnostic aids evolved from the basics over a period of time, and we have to keep updating ourselves to achieve longer prognosis. Therefore, prosthodontics as a specialty will continue to lead the broader discipline in adopting new diagnostic strategies and improving clinical outcomes.

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Conflicts of interest
There are no conflicts of interest.

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Research

A case–control investigation of the psychological and physiological stress markers with salivary cortisol levels in patients with temporomandibular joint disorders: A short clinical study

Natarajan Aparna, Seethapathy Rajesh, Attavar Ranukumari, Rajaraman Shakila

Department of Prosthodontics, Mahatma Gandhi Postgraduate Institute of Dental Sciences, Puducherry, India

Abstract

Aims: This study aimed to determine the association of stress and salivary cortisol levels in the adult Indian population with and without temporomandibular disorder (TMD) and to validate it with bite force.

Settings and Design: The present study had an observational, case–control study design.

Materials and Methods: This study sample comprised two groups of 25 cases and 25 controls between 18 and 45 years of age. Diagnostic criteria-TMD questionnaire Axis I was used to assess TMD classification, the TMD Disability Index and modified Perceived Stress Scale (PSS) questionnaires were filled, and salivary cortisol levels were measured using electrochemiluminescence immunoassay (ECLIA). Bite force analysis was performed using a portable load indicator.

Statistical Analysis Used: To characterize and analyze the study variables, means, standard deviations, Mann–Whitney *U*-test, and logistic regression were employed (STATA 14.2 [Texas, USA]). Shapiro–Wilk test was used to test the normality of the data. $P < 0.05$ was considered statistically significant (95% power).

Results: Female gender was proportionately higher in both the groups ($P = 0.508$), TMD Disability Index was significantly higher for cases ($P < 0.001$), TMD cases perceived higher stress levels ($P = 0.011$), there was no statistically significant difference in salivary cortisol level between cases and controls ($P = 0.648$), and the median bite force was lower for cases ($P = 0.0007$).

Conclusions: This study concluded that the chance of developing TMD increased with age. An increase in the TMD Disability Index score and modified PSS scores; and a decrease in the bite force increased the likelihood of TMD. Modified PSS score was negatively correlated with salivary cortisol concentrations, indicating a two-way response to TMD symptoms.

Keywords: Bite force, case–control study, immunoassay, psychological stress, temporomandibular disorders

Address for correspondence: Dr. Natarajan Aparna, Department of Prosthodontics, Mahatma Gandhi Postgraduate Institute of Dental Sciences, Puducherry - 605 006, India.
E-mail: draparnanmds@gmail.com

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INTRODUCTION

"Temporomandibular disorders" (TMDs) refer to a wide range of musculoskeletal conditions that impact the temporomandibular joints (TMJs) and the overall stomatognathic system. TMD is the second most typical musculoskeletal disorder that compromises the quality of life. Epidemiological studies have highlighted a significant prevalence of TMD in the adult (5%–60% of the population) with a fourfold higher prevalence in women, especially between the ages of 18 and 45 years.[1]

TMD showed the highest prevalence of 28.38% in Puducherry population. TMDs have recently begun to exhibit a higher incidence percentage in young adults which might be explained by the high levels of stress that youngsters experience in the extraordinary post-COVID situation.

The literature search has so far linked stress to TMD; however, the adult Indian population (particularly Puducherry residents) had not been studied for this association with bite force. Stress is a potential predisposing factor that induces increased masticatory muscle activity, which can be measured using salivary biomarkers, such as cortisol, and confirmed by a bite force analysis. Thus, the objective of this study was to determine the association of stress and salivary cortisol levels in the adult Indian population with and without TMD and confirm it with bite force.

MATERIALS AND METHODS

Participants

Fifty subjects aged between 18 and 45 years were selected for this study, with 25 placed in the TMD/case group and 25 participants placed in the control group. Subjects were screened over a period of 12 months from November 2021 to September 2022 from the outpatient registry of our institute. The Research and Ethical Committee on Human Research of our institute approved this study on October 18 and October 25, 2021, with the following permission number: 290/MGPGIDS/Aca-I/2021–22/1692.

Study design

A case–control study was chosen as the study design, as it is comparatively faster and more economical.[2] The clinical and biochemical evaluation of all the cases and controls was conducted in the same way.

Study settings

Center of research

This study was conducted at the Department of Prosthodontics.

Study population

The adult Indian population of Puducherry were enrolled in the study.

Study duration

The study duration was 12 months.

Sampling strategy

A simple random sampling method was used to obtain the required sample size.

Sample size

For comparing between independent sample groups, the sample size was calculated using G*Power software (Version 3.1.9.4) Mac OS X and windows XP/vista/7/8. The number of subjects per group will be $n = 15$ for each group using a maximum significance level of 0.05 and a maximum test power of 95%.[3] Expecting a 30% dropout and wide inter-examiner bias in a case–control study, we decided to include a slightly bigger sample of 50 samples (25 cases and 25 controls).

Samples involved

After obtaining informed consent, willing dentulous and partially edentulous dental students (only undergraduates) or outpatients between the ages of 18 and 45 years who attended the outpatient registry were chosen with an unequal distribution of men and women.

Selection criteria

Inclusion criteria

- Subjects who agreed to take part in the study were included
- Dentate or partially edentate students (18–25 years) and patients attending the outpatient department (18–45 years)] from both genders with TMD were included in the case group
- Dentate or partially edentate students (18–25 years) and patients attending the outpatient department (18–45 years) from both genders without TMD were included in the control group.

At least two symptoms (clicking, deviation/deflection, etc.) or a single painful symptom was required for inclusion.

Exclusion criteria

- Subjects who were not willing to participate in the study
- Subjects under the medications that affect salivary cortisol (eg. corticosteroids, antidepressant medications, and hormone supplements)
- Subjects with a history of TMJ trauma or orofacial infections

- Subjects undergoing TMJ splint therapy or orthodontic treatment and
- Subjects with distal extension partially edentulous situations were excluded from the study.

After the Ethical and Research Committee approval, the participants were given ample time to read the consent form (with Patient Information Sheet) themselves thoroughly and to sign it. The study participants were made to fill out two questionnaires, the TMD Disability Index (TDI) and the modified Perceived Stress Scale (PSS), and then underwent sampling of 5 mL of saliva followed by a bite force analysis using a custom-designed portable load indicator.

TMD Disability Index (TDI)

TDI is a tool that includes ten questions regarding TMD disability, and each question is assigned a score of 0–4. The final rating of each research questionnaire is expressed as a percentage (%) of disability.

Psychosocial stress assessment

Modified Perceived Stress Scale

PSS was originally proposed by Cohen *et al.* and Williamson. It was modified with the help of a psychotherapist to suit Indian standards.[4] The score of the respondent's stress perception ranged from 0 to 40, with higher numbers indicating higher levels of stress. People were asked to fill out questionnaires about the uncontrollable situations that stressed them out in the past year using a 5-point Likert scale: 0 = never, 1 = almost never, 2 = sometimes, 3 = fairly often, and 4 = very often.

The PSS is an instrument with good reliability (Cronbach's alpha score of 0.84 or greater), construct validity, and significant association with other aspects of stress assessment. It has a reverse scoring for four positively stated items (items no: 4, 5, 8, and 10).

Saliva sample collection

The passive drool method was used to collect 5 ml of unstimulated saliva from 25 TMD sufferers and 25 controls in a sterile disposable plastic tube. Two hours before sample collection, participants in the study were instructed not to brush their teeth, drink or eat anything, or smoke. Between 10:00 a. m. and 12:00 p. m., saliva samples were collected.[5] Automated electrochemiluminescence assay (ECLIA) was performed to measure the salivary cortisol concentration by qualified professionals at Anderson Diagnostics and Labs in Nungambakkam, Chennai.

Maximum voluntary bite force

The maximum voluntary bite force was measured using a custom-made portable load indicator developed specifically for oral situations. It was an electronic bite force analyzer with a biosensor for intraoral pressure and a digital display monitor. Study participants were given a biosensor (with a sterile, single-use sleeve) instructed to be bite on as firmly as possible, which recorded the bite force in the permanent first molars on the right and left. The final outcome was achieved by repeating the process three times, with a 2-min break between each repetition. The data quality was managed by two examiners entering the data, and all the data entry was constantly monitored by the co-investigators periodically.

Ethical and human participant protection considerations

The Research and Ethical Committee on Human Research of our institute approved this study on October 18 and October 25, 2021, with the following permission number: 290/MGPGIDS/Aca-I/2021–22/1692. In order to uphold the principles of anonymity, decency, beneficence, nonmaleficence, and justice, any information acquired that may be used to identify the patient was kept secret. All the procedures have been performed as per the ethical guidelines laid down by the Declaration of Helsinki (2013) after obtaining informed consent. Furthermore, the research protocol was strictly adhered to.

Statistical analysis

Mean with standard deviation (if the data follow normal distribution), median with range (if the data not follow normal distribution), and frequency with percentage were used to describe the summary information about data. Shapiro–Wilk test was used to test the normality of the data. Student's *t*-test/nonparametric Mann–Whitney *U*-test was used to test the difference of continuous variables between the groups. Logistic regression analysis was used to find out the risk factors associated with the groups. $P < 0.05$ was considered statistically significant (95% confidence interval with degree of freedom = 28). All statistical analysis was done by STATA 14.2 (Texas, USA).[6]

RESULTS

Demographic data

In the current study, the mean age of all the cases was 25.72 years (range: 21–35 years). The mean age in the control group was 22.24 years (range: 19–24 years). Age was significantly higher in the case group than the control group ($P = 0.0003$, using *t*-test [Table 1].

Samples comprised both males (12 ± 24.0) and females (38 ± 76.0) in an unequal proportion. The distribution of males and females in cases was 7.0 ± 28.0 and 18 ± 72.0, respectively [Table 1]. Female gender was proportionately higher in both the groups, and it was

Table 1: Mean distribution of various parameters (age, gender, bite force, modified Perceived Stress Scale, Temporomandibular Disorder Disability Index, and salivary cortisol) between cases and controls

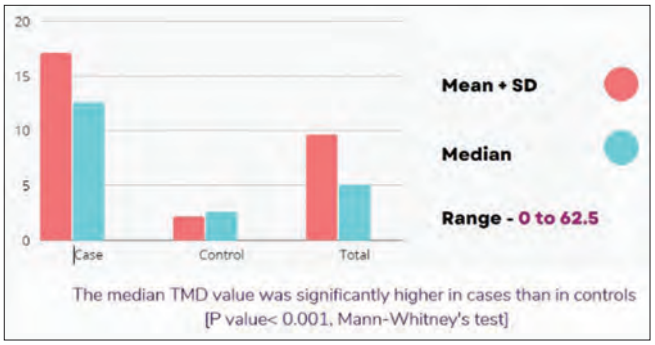
Variable	Case (*n*=25)	Control (*n*=25)	Total (*n*=50)	*P*
Age*				
Mean±SD	25.72±4.36	22.24±0.97	23.98±3.59	0.0003
Minimum–maximum	21–35	19–24	19–35	
Gender				
Male	7 (28.0)	5 (20.0)	12 (24.0)	0.508
Female	18 (72.0)	20 (80.0)	38 (76.0)	
TMD**				
Mean±SD	17.00±14.09	2.10±2.57	9.55±12.53	<0.001
Median	12.5	2.5	5	
Minimum–maximum	0.00–62.50	0–10	0–62.5	
PSS index*				
Mean±SD	21.00±4.31	18.04±3.54	19.52±4.18	0.011
Minimum–maximum	12–30	13–29	12–30	
Salivary cortisol**				
Mean±SD	0.270±0.164	0.241±0.114	0.255±0.141	0.648
Median	0.239	0.254	0.251	
Minimum–maximum	0.013–0.713	0.055–0.540	0.013–0.713	
Bite force (right)**				
Mean±SD	147.35±117.54	192.15±75.90	169.75±100.50	0.009
Median	106.70	183.10	147.38	
Minimum–maximum	20.63–555.23	71.13–379.7	20.63–555.23	
Bite force (left)**				
Mean±SD	163.52±148.40	204.03±118.87	183.78±134.63	0.068
Median	132.83	177.30	149.10	
Minimum–maximum	9.30–704.8	54.50–601.10	9.30–704.80	
Bite force**				
Mean±SD	127.10±114.47	198.09±93.57	162.60±109.51	0.0007
Median	100.26	163.33	134.78	
Minimum–maximum	9.30–555.23	68.13–490.40	9.30–555.23	

**t*-test, ***Mann–Whitney's test. SD: Standard deviation, PSS: Perceived Stress Scale, TMD: Temporomandibular disorder, TDI: TMD Disability Index

showing a statistically significant difference ($P = 0.508$, using Chi-square test). The results of the current research indicated that women had a higher risk of TMD than men (females 76% and males 24%).

Temporomandibular Disorder Disability Index (TDI) scores

According to Table 1, the mean TMD Disability Index for cases was 17.00 ± 14.09, which was significantly higher than the 9.55 ± 12.53 for controls ($P < 0.001$). Furthermore, the Mann–Whitney *U*-test, with $P < 0.001$, demonstrated that the median TMD was substantially greater in the case group compared to the control group [Graph 1].



Graph 1: Distribution of TMD Disability Index [TDI] values between cases and controls. TMD: Temporomandibular disorder

Modified Perceived Stress Scale scores

In the present study, TMD cases perceived statistically significant higher stress levels (21.00 ± 4.31) than controls (18.04 ± 3.54) ($P = 0.011$, *t*-test) [Table 1 and Graph 2].

Salivary cortisol estimation

Table 1 demonstrates that there was no statistical difference between the mean levels of salivary cortisol in the cases (0.270 ± 0.164) and the controls (0.241 ± 0.114). Furthermore, the median salivary cortisol did not show any statistically significant difference between both the groups ($P = 0.648$, Mann–Whitney *U*-test) [Table 1 and Graph 3]. In fact, there was a negative correlation between salivary cortisol and psychological stress in the case group, and this association was not strong.

Bite force analysis

When compared to the controls, the maximum bite force of cases on both the sides was significantly decreased. The median bite force in affected side of cases (127.10 ± 114.47) was significantly lower than the control group (198.09 ± 93.57) ($P = 0.0007$, Mann–Whitney *U*-test) [Table 1] [Graph 4], indicating that TMD is associated with a decrease in the bite force.

Diagnostic criteria for TMD (DC/TMD) history questionnaire and clinical assessment data were used to derive Axis I. According to Table 2, the most frequent TMD was anterior disc displacement with reduction (ADDwR), which was found in 52.0% of patients. This was followed by ADDwR with intermittent locking and myalgia (each 20.0% of cases) and ADDwR + intermittent locking + localized myalgia (each 8% of cases).

Logistic regression analysis was used to find out factors associated with risk factors of disease. Higher age (odds ratio = 1.98, P = 0.066), biting force ≤ 100 (odds ratio = 6.61, P = 0.117), and TMD index values more than 2.5 (odds ratio = 25.76, P = 0.001) were significantly associated with the TMD case group [Table 3].

DISCUSSION

Stress can lead to positive and negative outcomes, such as motivation and improved task performance, but can also cause anxiety, depression, melancholy, and social dysfunction. 25 TMD cases and 25 healthy controls had their salivary cortisol and psychological stress levels examined to prove that psychological stress plays a significant role in the development and maintenance of TMD.[7]

DC-TMD Axis I questionnaire was used to diagnose TMD. The participants completed 2 questionnaires – a modified 10-item PSS questionnaire and TMD Disability Index questionnaire. The results of this study revealed that TMD is more likely to develop with advancing age. It is more common in females than in males. Nadendla *et al.* included more women than men, and the participants' mean age was greater (29.2 years) than it was in the latter (23.98 years).[8] An increase in TMD Disability Index score >2.5, modified PSS scores, and bite force <100 Newton indicates a higher likelihood of TMD. This is in accordance with a study by Johnston *et al.*[9]

According to the present study, the mean salivary cortisol level of the case group was marginally higher

Table 2: Prevalence of various types of temporomandibular disorder

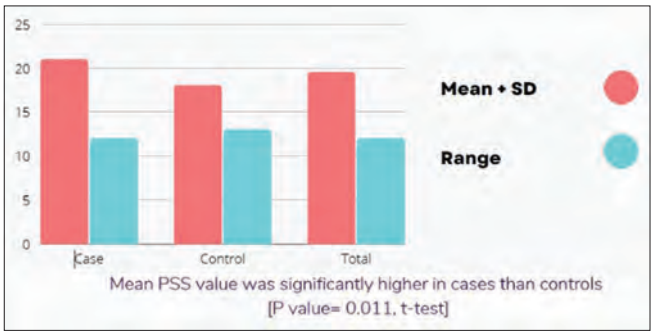
TMD types	*n* (%)
ADDwR	13 (52.0)
ADDwR + IL	5 (20.0)
ADDwR + IL + localized myalgia	2 (8.0)
TMJ myalgia	5 (20.0)
Total	25 (100.0)

TMJ: Temporomandibular joints, TMD: Temporomandibular disorder, ADDwR: Anterior disc displacement with reduction, IL: Intermittent locking

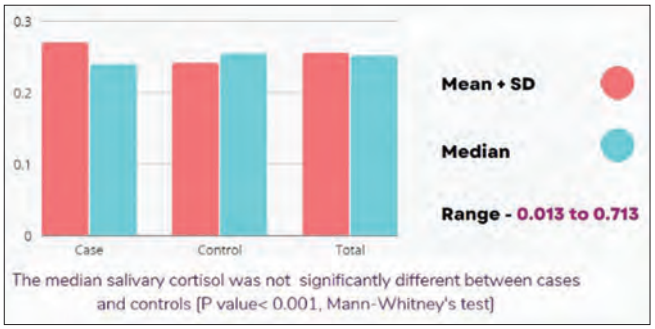
Table 3: Risk factors associated with cases

Variable	Case (*n*=25)	Control (*n*=25)	OR (95% CI)	*P*
Age				
Mean±SD	25.72±4.36	22.24±0.97	1.98	0.066
Minimum-maximum	21-35	19-24	(0.96-4.11)	
TMD				
≤2.5	3 (12.0)	21 (84.0)	1.00	-
>2.5	22 (88.0)	4 (16.0)	25.76 (3.68-180.54)	0.001
Bite force				
>100	13 (52.0)	23 (92.0)	1.00	-
≤100	12 (48.0)	2 (8.0)	6.61 (0.62-69.99)	0.117

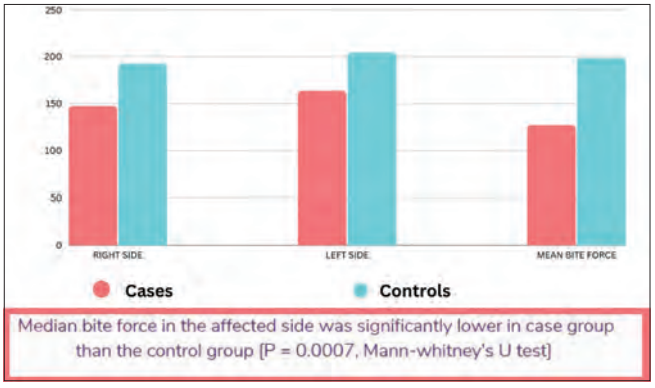
OR: Odds ratio, CI: Confidence interval, SD: Standard deviation, TMD: Temporomandibular disorder



Graph 2: Distribution of PSS values between cases and controls. PSS: Perceived Stress Scale



Graph 3: Distribution of salivary cortisol values between cases and controls



Graph 4: Distribution of bite force between cases and controls in affected and unaffected sides

than those of the control group. It was unexpected to see the TMD cases to have a low cortisol response. The low cortisol response in the case group and its potently inverse relationship with modified PSS value implied that each patient responded to stress in a different manner. Some subjects with stress had increased salivary cortisol concentration. Some subjects with stress had decreased salivary cortisol concentration (due to deficient cortisol awakening response).

Thus, salivary cortisol elicited a two-way response to chronic stress and TMD symptoms in the present study. This is in accordance with the investigations of Jones *et al.*, who found that patients with TMDs appeared to be more stressed than controls but did not discover any significant variation in salivary cortisol levels.[10] This was also supported by the findings of Salameh *et al.*, Crnkovic *et al.*, and Mirzaei *et al.*[5,11,12] Contrary to the results of the present investigation, studies by Nadendla *et al.*, Goyal *et al.*, and Lu *et al.* found a significant positive correlation between salivary cortisol levels in both the case and control groups.[8,11-14] According to Delboni, 2007, and Di Laccio *et al.*, every person had a varied threshold for stress.[15,16]

In the current study, the case group's mean maximal biting force was significantly lower than that of the control, which conforms to the study by Koc *et al.*[17] However, according to Pizolato *et al.*, the bite force was lower in women with TMD whereas there was a rise in the bite force in men with TMD.[18] According to earlier investigations, patients with TMD have a significantly lower bite force, which might be due to the articular pain.[19]

CONCLUSIONS

- A weak negative correlation was demonstrated between self-reported modified perceived stress score (chronic stress) and salivary cortisol concentrations
- Thus, salivary cortisol elicited a two-way response to TMD symptoms
- This might be because of the biologic changes brought about by TMD-induced changes reducing the adaptive cortisol response to chronic psychological stressors
- Low cortisol-secreting cases would have responded to the stress in the same way as that of the controls. This might be attributed to the way they had handled their stress (coping mechanism)
- This study concluded that the etiopathogenesis of TMD was significantly influenced by psychosocial stress. When compared to men, women have a higher risk of TMD. This study concluded that the chance of developing TMD increased with age. An increase in the TMD Disability Index score and modified PSS scores; and a decrease in the bite force increased the likelihood of TMD. Additionally, it may be concluded that salivary cortisol levels may not necessarily indicate psychological stress.

Recommendations

The patient's coping strategies might be vital in the control of stress, the regulation of the hypothalamus–pituitary–adrenal axis, and the prevention of TMJ damage. TMD sufferers should be taught about the coping strategies to combat stress.[20]

Future scope/clinical significance

The biopsychosocial model of TMD has emerged, recognizing a multifaceted etiology. The two-way response demonstrated by the salivary cortisol in the present study depends on the individual's stress perception and coping mechanism. In future studies, it would be interesting to collect saliva samples at several time points to compare their diurnal rhythm.

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3.	Mr.B. Vijayakumar Technical assistant (Statistics) ICMR-Vector Control Research Centre Indian Council of Medical Research Puducherry -605009	Statistical assistance

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Conflicts of interest

There are no conflicts of interest.

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Research

A study on relationship between dynamic postural balance and masticatory efficiency in the elderly population with complete dentures: An *in vivo* study

Pranati Pai, Dhanya Kumar B. H., D. B. Nandeeshwar

Department of Prosthodontics and Crown and Bridge, Bapuji Dental College and Hospital, Davanagere, Karnataka, India

Abstract

Aim: Mastication is an important consideration for patients seeking prosthodontic treatment. Individuals with mastication problems have increased risk of systemic diseases which can negatively affect a person's postural balance control, which in turn increases the risk of falls. This study aims to correlate masticatory efficiency and dynamic postural balance in complete denture patients at 3 and 6 months after denture insertion.

Settings and Design: *In vivo* – observational study.

Materials and Methods: Fifty edentulous healthy patients were rehabilitated with conventional complete dentures. The dynamic postural balance was evaluated using the timed up-and-go test. The masticatory efficiency was evaluated using a color-changing chewing-gum and a color scale. The values for both were recorded 3 and 6 months after denture insertion.

Statistical Analysis Used: Spearman's correlation.

Results: The correlation between the values of dynamic postural balance and the values of masticatory efficiency was negative (values are inversely proportional) at 3 months (−0.379) and at 6 months (−0.246).

Conclusions: This study showed that there is a correlation between dynamic postural balance and masticatory efficiency. Prosthodontic rehabilitation of edentulous patients is important for improving postural balance by generating adequate postural reflex through mandibular stability for the prevention of falls in the elderly population and improving masticatory efficiency.

Keywords: Complete dentures, masticatory efficiency, postural balance

Address for correspondence: Dr. Pranati Pai, C/o Dr. P K Pai, "Parishkruti", 2nd Cross, Panchavati Colony, Shivamogga - 577 202, Karnataka, India.
E-mail: pranatippai@gmail.com

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INTRODUCTION

Falls in older people are a common cause of morbidity and mortality.[1] The higher risk of falls in older people may be due to impaired mobility and balance problems. One aspect of physiological dysfunction with advancing age is loss of postural balance.[2] A well-balanced masticatory, head-and-neck muscles are an important factor in postural stability.[3]

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The masticatory ability of the elderly is compromised by their oral health status, because of few or no natural teeth.[4] The loss of natural teeth can affect mastication due to bone resorption, temporomandibular dysfunction, muscular hypotonicity and can alter the mandibular rest position and dental occlusion.[5] The mandibular position has an influence on the body posture, which is associated closely with body equilibrium.[6]

Complete denture use has a positive effect on the body's balance in static conditions. However, there was less literature on the correlation of masticatory efficiency to postural balance in complete denture patients. This study was designed to correlate masticatory efficiency and dynamic postural balance in complete denture patients 3 and 6 months after insertion of the denture.

MATERIALS AND METHODS

Eighty-two edentulous subjects, above 60 years, were screened for the study from a dental college and hospital. Fifty-seven edentulous subjects after rehabilitation with removable complete dentures were selected consecutively by the operator after informed consent. Seven subjects dropped during the follow-up and fifty subjects were included in the study. The ethical clearance was given by the institutional review board. It was a nonrandomized open-label study.

Inclusion criteria

i. Age: Above 60 years
ii. Completely edentulous with retentive complete removable dentures given on both maxillary and mandibular arches (good denture bearing tissue, dentures with moderate, and good retention according to conventional Kapur criteria)[7]
iii. Patients with good general health (ASA classification I and II).

Exclusion criteria

i. Patients with uncontrolled systemic diseases
ii. Masticatory dysfunction due to temporomandibular joint (TMJ) and neuromuscular disorders
iii. History of traumatic injuries to the jaws
iv. Resorbed/flabby ridges
v. Patients with orthopedic problems
vi. Patient unable/unwilling to return for the follow-up.

Measurement of dynamic postural balance

Timed up and go test (TUGT) was utilized to measure the dynamic balance for each subject. This test was a valid tool to identify older people at risk of falling.[8] It was a reliable tool, simple to use, and reduced the need of additional equipment.

Each subject sat (hips all the way to the back of the seat) in a stable chair with armrests [Figure 1]. The subject could wear their regular footwear, use any walking aid that they usually use, but cannot be helped by another person. Three meters away from the chair, a tape was positioned on the floor so that the subject could easily see it [Figure 2].

After receiving a "start" signal, they stood up, walked 3 m, turned, walked back, and sat down [Figure 3]. Each participant's time spent doing the test was recorded 3 times to create an average (10 s intervals between consecutive measurements) [Figure 4]. The subject was instructed to walk at their regular pace. TUGT value was lower, indicating greater independent walking.[9,10] Each patient underwent a TUG test 3 and 6 months after getting a denture.

Measurement of masticatory efficiency:

The test substance was chewing gum that changed color (Masticatory Performance Evaluating Gum XYLITOL, Lotte Co. Ltd., Tokyo, Japan) [Figure 5]. The reasons for using color-changing gum[11] are to evaluate masticatory efficiency as follows:

i. It simulated natural and stable chewing
ii. It did not stick to the denture material
iii. It was factory-produced, which ensured consistent quality such as uniform hardness, weight, and adhesiveness.

This color-changing gum (70 mm × 20 mm × 1 mm, 3.0 g) contained red, yellow, and blue dyes: Xylitol; citric acid. This color-changing gum appeared yellowish-green before mastication. When the gum was chewed, blue and yellow dyes seep into the saliva, and red color showed up because of citric acid excretion into the saliva.[12]

Figure 1: Sitting posture of the patient in a chair with arm rests before the start of the timed up and go test

Figure 2: Setup for the evaluation of dynamic postural balance

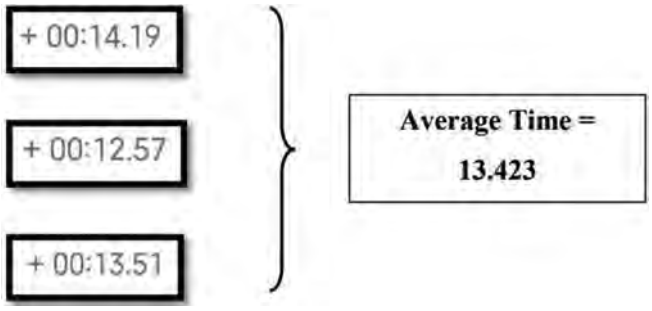

Figure 4: Example of average time recorded with a timer for the measurement of dynamic postural balance during timed up and go test

The subjects chewed the color-changing chewing gum freely while wearing both the maxillary and mandibular complete dentures, seated on a chair in an upright position. They were instructed to chew for 3 min (average of 120 chewing strokes considered, as high interclass correlation coefficient of 0.83)[11] on both sides of the mouth. Using a five-point color scale, the operator collected the chewing gum and assigned it a score (1–5) for the degree of color change [Figures 6 and 7]. A higher score indicated better masticatory ability.[13] This was performed in each patient 3 and 6 months after denture insertion (since the baseline period of adaptation of denture is around 6–8 weeks).[14]

RESULTS

The data obtained from the tests were subjected to statistical analysis. Spearman's correlation test was used to correlate dynamic postural balance and masticatory efficiency at 3 and 6 months after denture insertion. The *P* value was set at 0.05 to be significant and $P < 0.01$ was highly significant.

The value of the correlation coefficient ranges from −1 (inverse relation) to +1 (directly proportional). "0" implies no relationship between the two variables.

The mean values and the standard deviation of dynamic postural balance were 14.5883 (±4.90323), 13.3472 (±4.41625) at 3 and 6 months after denture insertion, respectively; and those of masticatory efficiency

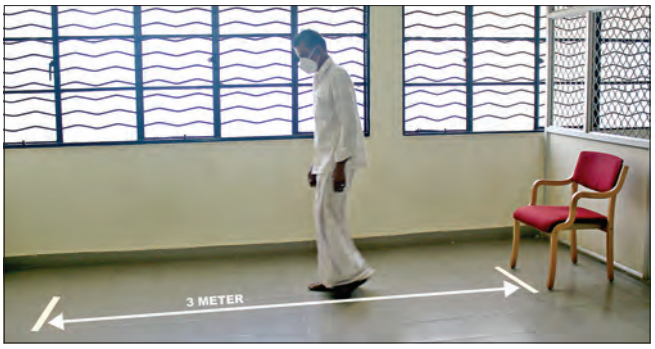

Figure 3: Measurement of dynamic postural balance by timed up and go test

Figure 5: Color changing chewing gum (XYLITOL Lotte®, 70 mm × 20 mm × 1 mm, 3.0 g) for evaluation of masticatory efficiency

were 2.84 (±0.467), 3.42 (±0.609) at 3 months and 6 months after denture insertion [Table 1 and Figures 8, 9].

Correlation between dynamic postural balance and masticatory efficiency 3 and 6 months after denture insertion is shown in Table 2.[15]

At 3 months, as the *P* value ($P = 0.007$) is <0.01, the above correlation between the two is statistically highly significant. The value of −0.379 implies that the strength of the correlation is weak. The correlation between the values of dynamic postural balance and masticatory efficiency at 3 months is negative, weak, and statistically highly significant [Figure 10].

At 6 months, as the *P* value ($P = 0.085$) is more than 0.05, the above correlation between the two is statistically not significant. The value of −0.246 implies that the strength of the correlation is mild. The correlation between the values of dynamic postural balance and masticatory efficiency 6 months is negative, mild, and statistically not significant [Figure 11].

In this study, a decrease in the value of dynamic postural balance (i.e., better postural balance) was related to increase in the value of masticatory efficiency (i.e., better masticatory efficiency), since both the values were inversely proportional to each other at 3 and 6 months.

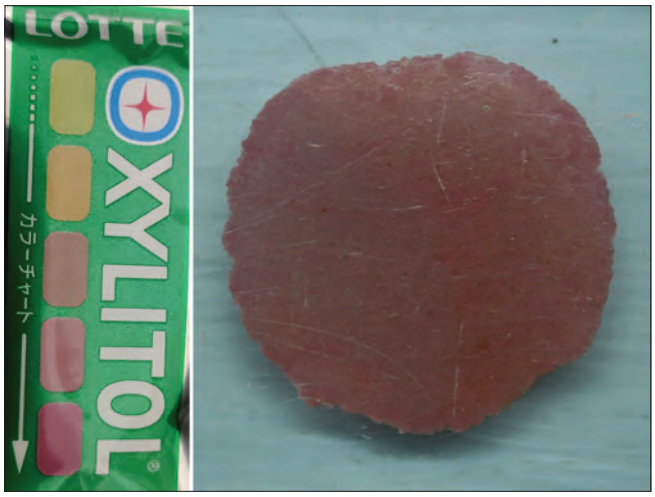

Figure 6: Chewed color changing chewing gum (test sample) obtained for measuring masticatory efficiency at 3 months

Figure 7: Chewed color changing chewing gum (test sample) obtained for measuring masticatory efficiency at 6 months

Figure 8: Graph showing comparison of the mean values of dynamic postural balance at 3 and 6 months after denture insertion

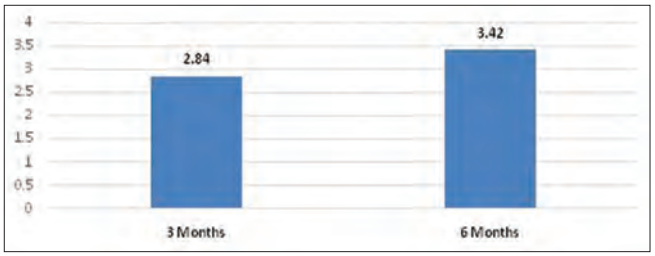

Figure 9: Graph showing comparison of the mean values of masticatory efficiency of complete dentures at 3 and 6 months after denture insertion

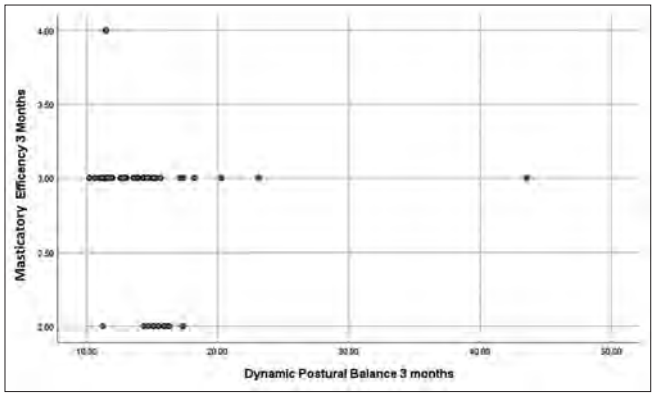

Figure 10: Graph containing scatter plot showing the relationship between the dynamic postural balance and masticatory efficiency 3 months after denture insertion

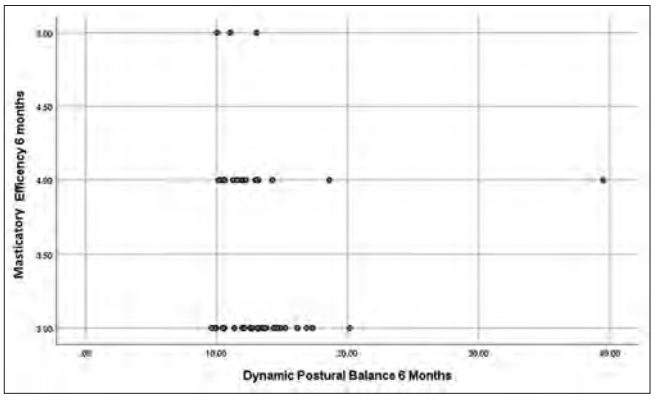

Figure 11: Graph containing scatter plot showing the relationship between the dynamic postural balance and masticatory efficiency 6 months after denture insertion

DISCUSSION

Although the occurrence of total edentulism has decreased over the past ten years, tooth loss is still a serious condition that primarily affects the elderly globally.[16] The tooth loss in community-dwelling older adults over 65 years is associated with lower gait velocity.[17]

The connection between posture and denture intervention has been shown in numerous earlier studies.[18-20] Posture is determined by the tonic contraction of the extensor muscles that oppose gravity, enabling joints to support the body weight. The elevator muscles of the jaw (antigravity muscles) maintain mandibular posture by means of the myotatic reflex, which works by the activation of

Table 1: The mean values of dynamic postural balance (s) and masticatory efficiency (1–5 scale) at 3 and 6 months after denture insertion

Sample (*n*=50)	Dynamic postural balance (s)		Masticatory efficiency	
	3 months	6 months	3 months	6 months
Mean±SD	14.5883±4.90323	13.3472±4.41625	2.84±0.467	3.42±0.609

SD: Standard deviation

Table 2: Spearman's correlation between dynamic postural balance and masticatory efficiency 3 and 6 months after denture insertion

Variable	Time duration (months)	Spearman's correlation coefficient§	*P*
Dynamic postural balance versus masticatory efficiency	3	−0.379	0.007†
Dynamic postural balance versus masticatory efficiency	6	−0.246	0.085 (NS)

$P<0.05$ is statistically significant, †$P<0.01$ is statistically highly significant, §Spearman's correlation test applied. NS: Not significant

proprioceptive receptors of the same elevator muscles, TMJ, and periodontal receptors. The control of mandible posture originates also from other nervous structures, which together with the trigeminal structures contribute to the perfect adjustment of the mandible position in relation to the position of the head and various body segments.[21]

There are many factors that affect postural control, including biomechanical and motor coordination, the visual, proprioceptive, and vestibular systems, psychosocial factors, and the environment. Theoretically, trigeminal sensory afferent signals from proprioceptive receptors, particularly in the dentoalveolar ligaments, could explain the mechanisms underlying these associations. These signals may change postural stabilization by modulating certain body or head and neck muscles.[22] There are neurological connections between the trigeminal, neck sensory, and motor systems, according to studies. Alghadir *et al*. have suggested that postural control mechanisms can be modulated by the jaw sensory-motor system.[23] Fujimoto *et al*. reported that the alteration of mandibular position influences the body function equilibrium, which is concerned in the postural control system under static condition.[6] Morozumi *et al*. reported that wearing dentures influenced head posture and changed the body sway positively.[24]

A study had been conducted by Khare *et al*.[18] to understand the impact of complete dentures on head posture in various age groups of the Indian edentulous population following placement of complete dentures at different time intervals. This study consisted of patients aged between 45–60 years in Group "A" and patients of age 61–75 years in Group "B". The study found that placing dentures in patients with complete edentulousness dramatically changed their head posture. Between the intervals of 30 min and 24 h, the extension of head posture varied very little. Although changes in group "A" remained considerable after 30 days, group "B" individuals showed no signs of significant change. This showed that the age of the complete denture patients also had some significance.

TUGT selected to measure the dynamic postural balance, was introduced by Podsiadlo and Richardson in 1991.[9] Gait speed and functional mobility are closely correlated with TUGT. It is easily performed and reliable. TUGT encompasses standing, turning, and sitting, therefore, it provides more information than gait speed concerning the likelihood of falls and other consequences.[25] Intra-tester and inter-tester reliability of TUG have been reported as high in elderly populations. However, in a group of mostly community-dwelling older adults without cognitive impairments, test–retest reliability of measurements obtained with the TUG was only moderate.[26] TUGT has an inter-rater reliability of about 0.99 among patients in hospitals and about 0.98 among senior adults living in the community. It has good specificity and sensitivity.[27]

In the present study, the mean values and standard deviation of dynamic postural balance (in seconds) were 14.5883 (±4.90323), 13.3472 (±4.41625) at 3 and 6 months after denture insertion, respectively [Table 1 and Figure 8]. The values obtained at 6 months are in correlation with the mean values 13.0 ± 2.6 for 65–86 years (Hughes *et al*. 1998).[28] Other studies reported TUG values for community-dwelling individuals as 10.8 ± 4.9 for the mean age of 74 years (Davis *et al*. 1998),[29] 12.8 ± 6.4 for 65–93 years (Arnadottir and Mercer, 2000)[30] were less than the values of our study. Higher TUG values compared to our study was reported by Newton *et al*. 2001,[31] i.e., 16.9 ± 15.0 for 60–69 years, 17.1 ± 10.8 for 70–79 years, 26.8 ± 14.6 for 80–89 years male, and 28.3 ± 22.3 for 80–89 years female.[32]

In previous studies, it has been demonstrated that wearing dentures helps older people maintain and improve their balance.[13,33] In our study, there was a significant improvement in body balance ($P = 0.000$) ($P < 0.01$) after 6-month denture wearing.

The improvement at 6 months period of denture wearing is supported by a study of Tallgren *et al*.[19] on the alterations in jaw relations, hyoid position, and head posture in complete denture wearers. In the first 6 months of wearing dentures, there were noticeable alterations in cervical and craniocervical posture, which were thought to be

adaptations to the pronounced initial change in mandibular position due to the rapid pace of alveolar ridge resorption. These changes in mandibular position in 6 months may have an influence on the postural balance.

Another study compared older persons living in communities with and without dentures in terms of forward head posture (FHP), neck muscular strength, and postural balance. It comprised 107 participants (56 in the nondenture use group and 51 in the denture use group). Using the craniocervical angle, FHP was measured. Postural balance was assessed with the use of TUG and postural sway. The usage of dentures was found to reduce the strength of the neck muscles, raise FHP, and reduce the static and dynamic balance. The duration of denture use was substantially associated with TUG. Their finding suggested that using dentures frequently may be a significant contributing factor to poor balance.[34]

The studies have used different methods for the evaluation of body balance in static and dynamic conditions. Complete dentures had an impact on edentulous patients' stability in static and dynamic situations, according to Okubo *et al*.[21] When wearing dentures, gait stability as measured by gait velocity significantly increased.

Well-fitting dentures may positively contribute to postural control under both static and dynamic conditions.[35] There was a possibility of change in postural control function after the new dentures were adjusted because of the adaptation of dentures maybe another factor for changing postural control. According to Zarb and Bolender,[36] the muscles of mastication need 6–8 weeks to develop new memory patterns. However, Farias-Neto and Carreiro Ada[14] stated that 6–8 weeks' period may not be long enough to achieve optimal use with new dentures. Up to 6 months later, denture adaptation continued to improve. Therefore, change in the postural balance after 6 months also maybe due to the adaptation time of the denture, which might influence the change in postural control.

In the present study, color-changing chewing gum (Masticatory Performance Evaluating Gum XYLITOL, Lotte Co. Ltd., Tokyo, Japan) was used and graded using a five-point color scale for the degree of color shift. Hama *et al*.[12] showed that the use of color scale with a color-changing chewing gum possesses good reliability and validity.

In the present study, the mean values and standard deviation of masticatory efficiency were 2.84 (±0.467) at 3 months after denture insertion [Table 1 and Figure 9]. These values can be correlated to another study by 2.340 ± 0.517 (right side) and 2.100 ± 0.426 (left side) recorded after the adaptation of complete dentures. The mean values and standard deviation of masticatory efficiency in our study were 3.42 (±0.609) at 6 months [Table 1 and Figure 9] after denture insertion, which is higher than those at 3 months. Leles *et al*.[37] suggested that masticatory performance improved with the continual usage of newly inserted dentures.

Suzuki *et al*.[38] divided edentulous elderly individuals into intervention group (received simple dietary advice) or a control group (received denture care advice) and their masticatory function was tested using color-changeable chewing gum. Mixing ability was assessed at pre-treatment, and 3- and 6 months' post-treatment. In the intervention group, mixing ability significantly increased at 3 months ($P = 0.41$) ($P < 0.001$) and 6 months ($P = 0.31$) ($P < 0.001$) post-treatment whereas in the control group, mixing ability considerably increased at 6 months ($P = 0.002$) ($P < 0.001$) post-treatment. Since the values were calculated as mixing ability, these are not comparable to the mean values of our study [Table 1 and Figure 9].

The mean values of our study [Table 1] show that the masticatory efficiency is better at 6 months than at 3 months and this difference is statistically highly significant ($P = 0.000$) ($P < 0.01$), which correlates to the significant increase ($P = 0.002$) ($P < 0.001$) in masticatory efficiency (measured as mixing ability) at 6 months' post-treatment in the control group.

Previous research has shown that people with mastication issues are more likely to have a variety of systemic disorders, which can significantly affect a person's ability to maintain their postural balance and hence increase their risk of falling.

Many studies have identified connections between oral function and postural balance. Higher masticatory ability may be related to better posture, according to a Takata *et al*. study.[39] Moriya *et al*.[40] found a positive correlation between self-assessed masticatory ability and postural balance in static condition. He also stated that modifications of dental occlusion influence postural stability in young-, middle-aged adults, and falling occurs more frequently in persons with functionally insufficient oral health than in those with functionally adequate occlusion. The alteration of the occluding pair pattern and the self-assessed masticatory ability may be related to trigeminal sensorial afferent signals from proprioceptive receptors arising from dentoalveolar ligaments, the masticatory muscle, and

TMJ. These sensorial afferent signals may influence whole body muscles, head-and-neck muscles through the central nervous system, and finally alter postural stabilization. In Japanese senior edentulous males wearing complete dentures, Moriya *et al*.[22] discovered that the masticatory skill may be related to static balance.

A community-based cohort study of older persons was used by Watanabe *et al*.[41] to evaluate the relationship between the objective mixing ability of masticatory functions and physical and overall frailty. Results revealed that the participants with the lowest color-changing chewing gum score (the worst mixing ability) were older and more likely to wear dentures. With prevalence rates of 11.8% and 27.9%, respectively, physical and comprehensive frailty were more prevalent in groups with lower color-changing chewing gum scores.

Hwang *et al*.'s study[10] on how improved dynamic postural balance is influenced by masticatory efficiency was undertaken in dentate adults. The study had 74 participants, with a mean age of 70.24 ± 7.88 years. 39 (52.7%) participants were included in the group with high masticatory efficiency (mixing ability index [MAI] <1.05), whereas the remaining 35 (47.3%) had a low masticatory efficiency (MAI ≥1.05). The masticatory efficiency was assessed by making the participants chew a two-colored wax cube and the MAI was calculated. The dynamic postural balance was measured by the TUGT. The results showed that the participants with MAI of ≥ 1.05 experienced a 0.14-fold lower risk of exhibiting postural imbalance. In comparison to the group with low masticatory efficiency, the group with high masticatory efficiency finished the TUGT exercise more quickly while maintaining postural balance. This study was done in the dentate individuals where as our study was in edentulous subjects.

The present study aimed to correlate masticatory efficiency with dynamic postural balance in the elderly wearing complete dentures, 3 and 6 months after denture insertion. The findings demonstrated a negative correlation between dynamic postural balance and masticatory efficiency at 3 and 6 months. It meant that as the values of dynamic postural balance (in seconds) decreased, the masticatory efficiency (1–5 on color scale) increased. While the values of dynamic postural balance decreasing denote an improvement in the dynamic postural balance, the values of masticatory efficiency increasing denote an improvement in the masticatory efficiency.

The correlation in our study however does not denote the causal relationship between the variables, i.e., dynamic postural balance and masticatory efficiency. A weak negative correlation would indicate that while both variables tend to go down in response to one another, the relationship is not very strong. Further studies need to be done to find out the causal relationship between dynamic postural balance and masticatory efficiency.

Limitations

- Limited number of subjects
- Duration of evaluation-6 months was short
- The craniocervical angle might have been measured during the FHP assessment
- Matching the number of remaining teeth between the denture use and nondenture group could have been carried out to help bring out the correlation of denture use, postural balance, neck muscle strength, and posture of the head.

CONCLUSION

According to the findings and the limitations of the study, elderly people's dynamic postural balance and masticatory efficiency both improved after adjusting to dentures for 6 months. There was a correlation between the values of dynamic postural balance and masticatory efficiency at 3 and 6 months (values of both are inversely proportional).

The prosthodontic rehabilitation of edentulous patients is important for improving postural balance by generating adequate postural reflex through mandibular stability for the prevention of falls in the elderly and is also important for the improvement of masticatory efficiency.

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Conflicts of interest

There are no conflicts of interest.

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Research

Comparative evaluation of shear bond strength at the interface of monolithic zirconia with two distinct core build-up materials: An *in vitro* study

Parmar Aditi, Sonal Mehta, Ruchi Raj

Department of Prosthodontics, Manubhai Patel Dental College, Vadodara, Gujarat, India

Abstract

Aim: The study aimed to evaluate and compare the shear bond strength (SBS) at the interface of monolithic zirconia with zirconomer (Zr) core build-up, a new type of glass ionomer cement to monolithic zirconia with composite resin core build-up material.

Setting and Design: *In vitro* a comparative study.

Materials and Methods: A total of 32 disk-shaped samples of monolithic zirconia and two distinct core build-up materials: Zr ($n = 16$) and composite resin ($n = 16$) were used. The two components, monolithic zirconia with Zr core build-up and monolithic zirconia with composite resin core build-up, were bonded using zirconia primer and self-adhesive, dual-cure cement. The samples were subsequently thermocycled, and the SBS was tested at their interfaces. The failure modes were determined using a stereomicroscope. Data were evaluated using the descriptive analysis for mean, standard deviation, confidence interval, and independent *t*-test for intergroup comparison.

Statistical Analysis Used: Descriptive analysis, independent t-test, Chi-square test.

Results: The mean SBS (megapascals) of monolithic zirconia to Zr core build-up (0.74) was statistically significant when compared to monolithic zirconia with composite resin core build-up material (7.25) ($P \leq 0.001$). Zirconomer core build-up showed 100% adhesive failure; composite resin core build-up had 43.8% cohesive, 31.2% mixed, and 25.0% adhesive failures.

Conclusion: When evaluating the two core build-up materials' bindings to monolithic zirconia, Zr and composite resin core build-up showed statistically significant differences. Although Zr has been demonstrated to be the optimal core build-up material; however, additional investigation is required to determine how it bonds to monolithic zirconia more effectively.

Keywords: Bond strength, core build-up materials, failures, monolithic zirconia, zirconomer

Address for correspondence: Dr. Parmar Aditi, C5 Hari Vinayak Bungalow, Manjalpur, Vadodara - 390 011, Gujarat, India.
E-mail: aditi.p27@gmail.com

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INTRODUCTION

Dental use of zirconia began in the early 1990s. Zirconia's superior mechanical and biocompatible qualities have allowed it to play a significant role in prosthetic dentistry. Zirconia manufactured using computer-aided design-computer-aided manufacturing (CAD-CAM)

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technology gives several benefits, including excellent flexural strength, pleasing cosmetic outcomes, minimum tooth preparation, and reduced lab time.[1] Despite having these characteristics, its bonding is quite challenging. Zirconia has a glass free polycrystalline structure, i.e., unlike glass ceramics, it is not susceptible to etching, making it difficult for adhesive procedures.[2] Therefore, applying hydrofluoric acid (5%–9.5%) and a subsequent silane-coupling agent does not help to its bonding.[3]

Over the years, there have been a lot of data collected from studies that suggest various mechanical and chemical methods to enhance the bonding of zirconia. The improvement of the bonding between resin cement and zirconia includes techniques such as airborne-particle abrasion with alumina, silica deposition methods, plasma spraying, selective infiltration etching, and the application of primers such as 10-methacryloyloxydecyl dihydrogen phosphate (MDP), 4-methacryloxyethyl trimellitic anhydride, and thiophosphoric acid methacrylate.[4]

Magne *et al*.[4] proved in their study that MDP primer forms a better bond for zirconia. The MDP molecule allows copolymerization between the organofunctional part of the organophosphate monomer and the monomers of the resin-luting agents, besides the establishment of a bond between its phosphoric acid groups and the metal oxide in zirconia. Carboxylic acid is the other constituent monomer in this primer, contributing to the bond's development.[3]

A severely damaged tooth requires an intracoronal support which is cemented to extra coronal prosthesis. The intracoronal support is provided by core build-up or foundation restoration. The core build-up material should have desirable properties such as sufficient compressive strength, flexural strength, and biocompatibility with surrounding tissues and should also have a good bond with the tooth structure, pins, posts, and luting cement. Certain materials have been employed as core build-up materials such as casting core build-up, amalgam, composite resin, glass ionomer cement (GIC), porcelain, compomer, and cention N.[3]

A new material, zirconomer (Zr), has recently been introduced as a restorative material. It is a composition of powder: fluoroaluminosilicate glass, zirconium oxide, pigment, etc., and liquid: polyacrylic acid and tartaric acid.[5] The homogenous incorporation of zirconia particles in the glass component further reinforces the material for lasting durability and high tolerance to occlusal load.[6] It shows better mechanical properties and claims to have a similar shear bond strength (SBS) to that of amalgam. However, Zr has not been challenged clinically, and there is only laboratory-based evidence.

The post and core build-up, as well as the dental prosthesis, are subjected to a variety of stresses during mastication. The type of core build-up material, the type of luting cement, and the bond between the two all determine the durability of fixed prosthesis. Therefore, this study attempted to explore the combinations of Zr and composite resin as core build-up materials in terms of SBS when cemented to MZ. The null hypothesis was formulated as, there is no difference in the SBS at the interface of MZ to Zr core build-up and MZ to composite resin core build-up material.

MATERIALS AND METHODS

Before the start of the study, permission to conduct the study and ethical clearance was obtained from the Institutional Ethics Committee. The sample size was calculated for the study using STATA/ IC 13. Stata Corp LP, College Station, Texas to check the midpoint difference in SBS between the two groups by 1.2 with standard deviations (SDs) of 1.15 at 95% confidence and 80% power. Hence, for this experimental *in vitro* study, 32 samples (16 samples of MZ to Zr, Group A, and 16 samples of MZ to composite resin, Group B) were fabricated.

Sample preparation

The thirty-two MZ disk-shaped samples (5 mm × 3 mm) were fabricated using the CAD-CAM technique (3M Lava ESPE St Paul, MN). For preparing the samples, a same-dimension composite disc (Ivoclar Vivadent Te Econom Plus Composite Resin—Refills, Schaan Principality of Liechtenstein) was prepared and scanned using EXOCAD software. The zirconia lava block (3M ESPE, St Paul, MN) was utilized to mill the scanned specimen. A 7–8-min 3-axis milling process was followed by a 1200 C sintering process for 8 h. These samples were examined for any irregularities and further polished. They were divided in two groups (n = 16) based on the use of core build-up materials which were Zr and composite resin. Figure 1 shows the groups of the specimens.

The disk-shaped core build-up specimens (n = 16 per core build-up material) were prepared in a (7 mm × 7 mm) mold. A polymerized box was filled with addition silicone elastomeric impression material (Aquasil Dentsply/caulk, Kontanz, Germany) in which a similar dimension prototype was impressed to form a mold. The Zr (Conventional GIC, SHOFU, Japan) core build-up specimens were made by simply hand mixing a powder-liquid ratio of 2:1 according

to the manufacturer's instructions on a glass slab with an agate spatula. This mix was packed into the mold and allowed to be set at the room temperature. The composite resin (Ivoclar Vivadent Te Econom Plus Composite Resin—Refills, Schaan Principality of Liechtenstein) core build-up specimens were built up in two 3.5 mm high increment layer within the mold cavity. Each layer was segmentally light-polymerized using a light-emitting diode device (Woodpecker Light Cure Unit LED D) at 800 mW/cm^2 for the 20s.

Each sample was evaluated for irregularities and the final dimension was confirmed using a micromotor (Kolylong 150 mm, LCD Digital Electronic Carbon Fiber Vernier Caliper Gauge). All the core build-up samples were embedded in an acrylic resin mold to a height such that 1 mm of the core build-up material was exposed, and this was verified using a surveyor. Figure 2 shows the samples of Group A and Group B embedded in acrylic.

The MZ disks were painted with zirconia primer (ZPrime Plus; Bisco, Illinois, USA) on the front side. The front side of core build-up materials was covered with dual-cure resin cement (Kerr Maxcemelite, Kerr Corp., Orange, CA, USA), and then, the core build-up specimens were pressed onto the MZ specimens. A 5 kg weight was placed over all specimens, and excessive cement was wiped with a brush followed by light polymerization on both side for a total of 80s.

The prepared specimens were kept in artificial saliva (Wet Mouth ICPA Health Products Ltd.) at 37°C for 24 h in an incubator (LG Model:-051SA Mahavir, India). The specimens were mounted in the jig of a universal testing machine (Model: UNITEST 10, ACME., Maharashtra, India) [Figure 3]. The adhesive interface was then loaded with 0.5 mm/min force at a constant crosshead speed until failure occurred. The results obtained for load depending on the moment of fracture for each specimen, and the maximum load was recorded at the fracture. The maximum load was calculated by dividing the load (N) by the bonding area (mm^2).

All the specimens were observed for the three types of failure adhesive, cohesive, and mixed and were analyzed using a stereomicroscope (Wuzhou New Found Instrument Co., Ltd., China, Model 3400E) at ×10. Then images were viewed using an image analysis system (Chroma System Pvt. Ltd., India) (MVIG 2005). The failure mode was defined as an adhesive when more than 75% of the core build-up surface was visible. The cohesive failure mode was defined when more than 75% of the core build-up surface was covered with resin or the fracture was inside the core

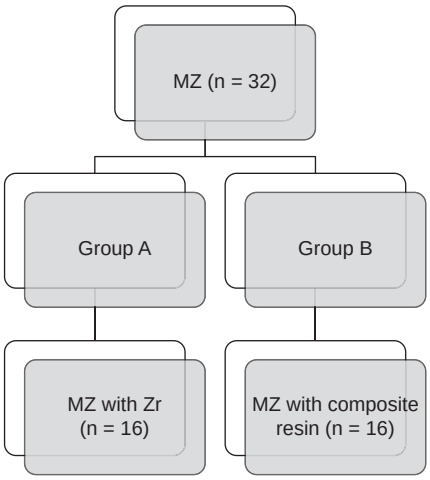


Figure 1: Flowchart of the groups

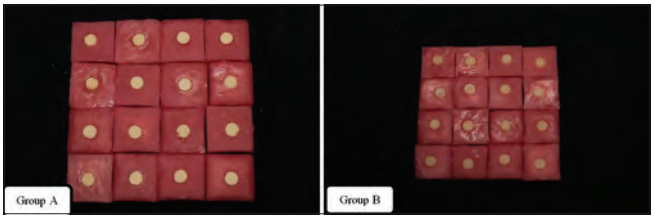


Figure 2: Samples of Group A and Group B embedded in acrylic, respectively

Figure 3: Prepared sample placed in the universal testing machine for shear bond strength

build-up material. All other cases were classified as having mixed failure modes.

The statistical analysis was performed using the SPSS software (Version 20.0; IBM Corp., Illinois, USA). The quantitative data were subjected to descriptive analysis for mean ± SD. The qualitative data were subjected to an independent *t*-test and a Chi-square test $P < 0.05$ was considered statistically significant.

RESULTS

Graph 1 shows the maximum load of Groups A and B. As shown in Graph 2, the SBS of Group B, i.e., MZ to composite resin core build-up is higher than Group A, i.e., MZ to Zr core build-up material.

As displayed in Table 1, the results of the independent *t*-test on comparing the two groups. A comparison of the maximum load (N) between the two groups showed the maximum load (N) is higher in Group B with a $t = -5.63$ and is statistically significant ($P < 0.001$). As well as the SBS megapascals (MPa) between the two groups showed that it is higher in Group B with a $t = -5.732$ and is statistically significant ($P < 0.001$).

According to Table 2, the failure mode for Group A was 100% adhesive and Group B was 25% adhesive, 43.8% cohesive, and 31.2% mixed. Figures 4 and 5 depict the failure patterns in Groups A and B, respectively. The test used to compare the failure modes was the Chi-square test [Table 3].

DISCUSSION

This study tried to investigate if the SBS of MZ to two different core build-up materials: Zr and composite resin. The findings proved that MZ to Zr core build-up had a significantly lower SBS compared to MZ to composite resin core build-up material.

The bonding mechanism of MZ is quite challenging due to its inert nature. A vitreous phase (<1%) in MZ makes it resistant to acid etching, determining a poor bond strength to its counterpart core build-up material.

Table 1: Independent *t*-test comparing the two groups A and B

	Mean±SD		*t*	*P*
	Group A (*n*=16)	Group B (*n*=16)		
Maximum load (*n*)	14.55±5.96	143.36±91.32	−5.63	<0.001*
SBS (MPa)	0.74±0.3	7.25±4.53	−5.732	<0.001*

*Significant ($P<0.05$). SBS: Shear bond strength, SD: Standard deviation

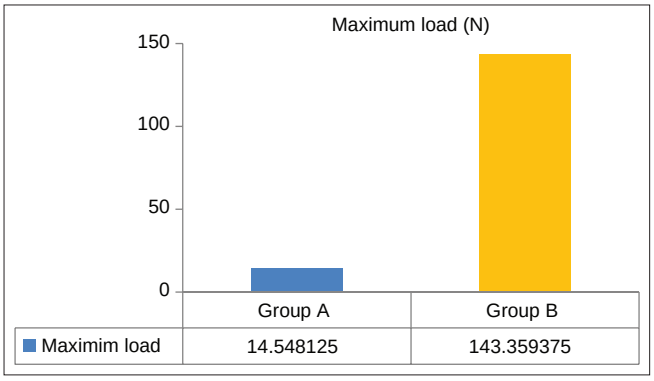
Table 2: Rate of failure and failure modes

Groups	Failure modes (%)		
	Adhesive	Cohesive	Mixed
Group A	100	-	-
Group B	25.0	43.5	31.2

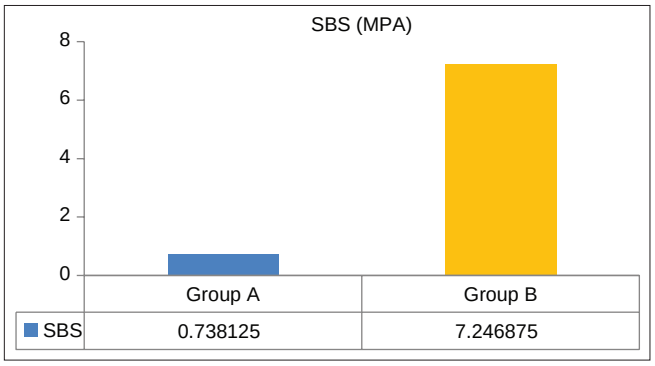
Table 3: The results of the Chi-square test on comparing failure modes

Chi-square test	Value	df	*P* (<0.05)
Pearson's Chi-square	19.200	2	<0.001

df: Degree of freedom



Graph 1: Maximum load (N) between Group A and Group B



Graph 2: SBS between Group A and Group B. SBS: Shear bond strength

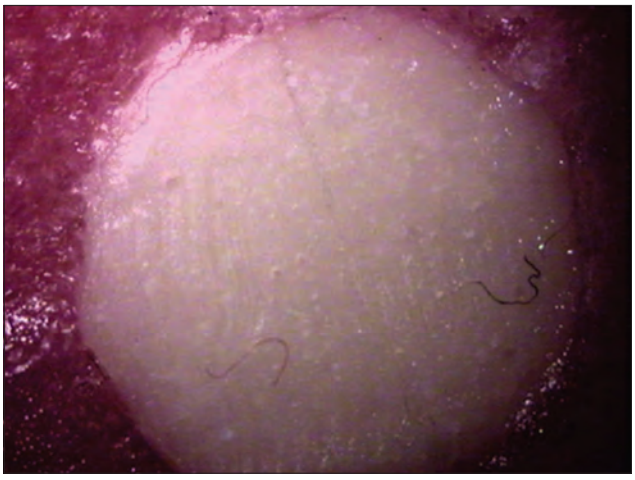


Figure 4: Adhesive failure pattern of Group A at ×10 magnification by a stereomicroscope

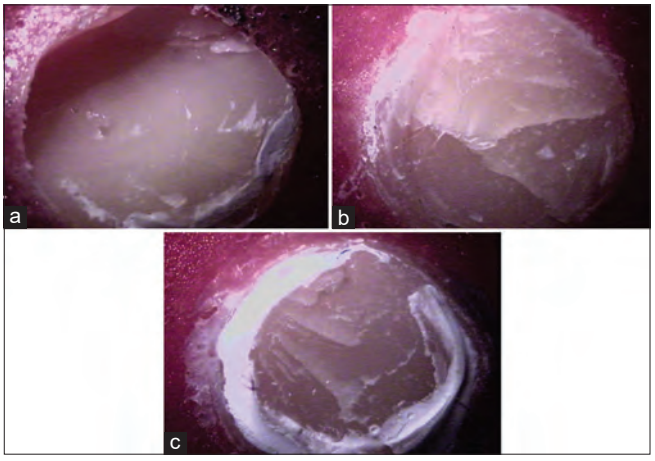


Figure 5: (a) Cohesive failure (b) adhesive failure (c) mixed failure pattern of Group B at ×10 magnification by a stereomicroscope

Various investigations over the years suggest different mechanical and chemical methods to enhance the bonding of MZ. The MDP primer has been suggested to provide favorable bond of all methods. The MDP primer is an organophosphate monomer that exhibits a terminal functional group containing phosphoric acid, which combines with zirconia to create P-O-Zr bonds. The presence of a vinyl terminal group at the opposite end of the molecule permits copolymerization with the resin. When self-adhesive composite cement is used, this chemical attachment increases.[3]

Seabra *et al*.[7] the study proved that two coats and light polymerization of zirconia primer application effectively promote adhesion between composite resin and zirconia. Torabi Ardakani *et al*.[8] reported similar results where zirconia primer strengthened the bond between zirconia posts and the root canal dentin cemented with either self-etch or self-adhesive resin cement.

The prosthesis and the core build-up are linked via the cement. Dual cure resin cement has improved mechanical qualities, including flexural strength and hardness, in addition to the advantage of favoring better polymerization to MZ.[9] This has been proven by Magne *et al*.[4] with different luting types of cement and zirconia primers; zirconia exhibits improved bond strength. Therefore, the current study used a self-adhesive, dual-cure resin cement.

Ideally, a core build-up material should have good mechanical properties to transfer forces like a tooth. Materials such as casting core build-up, amalgam, composite resin, GIC, porcelain, compomer, and cention N have been used for a long time. With newer materials emerging, Zr is introduced to address all the tissues that plague conventional GIC. Composite resin has been shown to have good bond strength to MZ.

Confirming that, in the current study, MZ to composite resin had a higher SBS value at the interface than MZ to the Zr. This higher bond strength is due to the chemical bond between the composite resin and MZ at the interface because of the primer and resin cement. Prabakaran *et al*.[10] concluded that nanocomposite possessed better mechanical properties as a core build-up material than Zr. A similar study by Abraham *et al*.[11] compared the SBS of GIC, Zr, and Luxacore build-up core build-up materials to zirconia. The results of the study showed SBS values of 9.51 MPa, 13.94 MPa, and 17.48 MPa for GIC, Zr, and Luxacore build-up to zirconia, respectively. Hence, the study suggested the use of both chemical and mechanical methods to increase the SBS between MZ and Zr. Tavakolizadeh *et al*.[12] examined the SBS of zirconia to various core build-up materials, including nonprecious gold alloy, zirconia ceramic, natural dentin, and composite resin. Composite resin was the most valuable core build-up material when compared to the others (11.58 to 1.74 MPa).

The failure of the bond between MZ to core build-up materials can be differentiated by where the failure occurs, i.e., adhesive, cohesive, or mixed. For the current study, stereomicroscope analysis revealed a 100% adhesive failure between MZ and Zr; a 25% adhesive, a 43.8% cohesive, and a 31.2% mixed failure mode between MZ and composite resin. In a similar study, Giti and Zarkari[3] discovered 100% cohesive failure for the composite resin to zirconia disc. These failure patterns express the bond strength between MZ and core build-up materials. One hundred percent adhesive failure between MZ and Zr means a lower bond strength, despite the use of MDP primer and self-adhesive dual-cure cement. Therefore, an investigation needs to be done to enhance the bond strength between MZ and Zr.

In viewing the limitations of the study, using crowns instead of geometry specimens could have given better results. As SBS is a technique-sensitive test, the specimens could have been kept in a mold or sealed while being placed in the thermocycler. Zr has proven to be good material in other aspects. A study by Paul *et al*.[13] concluded that Zr is more efficient in initial and fluoride re-release and cariostatic performance in real environmental circumstances. Along with that, Zr has a higher compressive strength than amalgam. Further, extensive *in vitro* and *in vivo* studies are required to examine the performance of a new member of the GIC family, Zr

CONCLUSION

According to the results of this study and keeping in mind the limitations, MZ with Zr has a significantly lower SBS value when compared to MZ with composite resin. Despite the wide range of core build-up materials available, composite resin continues to be the wisest option. Although marketed as a strong, durable, and fluoride-rich material ideal for bulk-filling the structural core build-up, Zr has yet to fill the research gaps as the material of choice for core build-up.

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Nil.

Conflicts of interest
There are no conflicts of interest.

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Research

Comparative evaluation of osteogenic cell growth on titanium surface and titanium coated with boron nitride surface: An *in vitro* study

Avinash Chaurasiya, Naveen S. Yadav, Puja Hazari, Harsh Mahajan, Shweta Narwani

Department of Prosthodontics, Crown and Bridge and Implantology, Peoples Dental Academy, Peoples University, Bhopal, Madhya Pradesh, India

Abstract

Context: To promote better biological response and osseointegration continuous research is going on to modify the titanium (Ti) implant surface for successful implant treatment modality.

Aims: This study aims to evaluate the osteogenic cell growth upon the uncoated Ti discs and boron nitride (BN) coated Ti to assess osseointegration and clinical success of dental implants.

Settings and Design: This is an descriptive experimental study which includes coating of uncoated titanium alloy suraface with boron nitride in the form of hexagonal boron nitride sheets. Than comparative evaluation of osteogenic cell growth upon both coated and uncoated titanium surfaces was done using specific cell growth determinants.

Materials and Methods: In this descriptive experimental study, both BN-coated and uncoated Ti discs were assessed for osteogenic cell growth using 3-(4, 5-dimethyl thiazolyl-2)-2, 5-diphenyltetrazolium bromide assay, 4',6-diamidino-2-phenylindole, is a fluorescent stain assay, and cell adhesion assay.

Statistical Analysis Used: As this study is a descriptive experimental analysis between two variables only so there is no need of statistical analysis or p-value.

Results: Overall good cell adhesion, cell differentiation, and cell proliferation occurred in the BN-coated Ti discs as compared to uncoated Ti discs.

Conclusions: To promote osseointegration of dental implants, surface coating with BN proved to be an effective approach toward better osseointegration and long-duration success of dental implants as a single unit or implant-supported prosthesis BN which is a biocompatible graphene material with advantages in chemical and thermal stability. BN promoted better osteogenic cell adhesion, differentiation, and proliferation. Hence, it can be used as a new promising Ti implant surface-coating material.

Keywords: Boron nitride, boron nitride nanotubes, cell adhesion, cell differentiation, cell proliferation, osseointegration

Address for correspondence: Dr. Avinash Chaurasiya, Department of Prosthodontics, Crown and Bridge and Implantology, Peoples Dental Academy, Peoples University, Bhopal, Madhya Pradesh, India.
E-mail: avinashchaurasiapanna@gmail.com

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INTRODUCTION

Since titanium (Ti) has high biocompatibility and outstanding mechanical qualities, it is frequently utilised for dental implants.[1] However, Ti-based implants can also occasionally fail because they don't osseointegrate properly and don't generate enough new bone, especially in older patients and those who have systemic diseases such as diabetes[2] and osteoporosis.[3]

Dental implants' clinical success depends on osseointegration. The contact between the implant and the surrounding bone tissue is a crucial aspect that depends on both local and systemic factors.[4,5] Different materials, including plasma-sprayed hydroxyapatite (HA), Ti plasma spray, calcium metaphosphate ceramics, aluminium oxide blasted, and fluoride[6] were evaluated and coated above the Ti implants for improved osseointegration to decrease the likelihood of implant failure.

Aim

This study aims to evaluate the osteogenic cell growth on Ti implant surface and boron nitride (BN)-coated Ti implant surface for better osseointegration and clinical success of dental implants.

Objectives

1. To evaluate cell adhesion on uncoated Ti discs and BN-coated Ti discs
2. To evaluate cell proliferation on uncoated Ti discs and BN-coated Ti discs
3. To evaluate cell differentiation on uncoated Ti discs and BN-coated Ti discs.

A refractory substance consisting of boron and nitrogen is called BN. It can crystallize in a variety of shapes, including hexagonal, rhombohedral, diamond-like cubic, and wurtzite, depending on temperature and pressure; however, hexagonal is the most stable shape at ambient temperature.[7] The biological effects of BN on the body are numerous and include the promotion of wound healing, the release of growth factors and cytokines, and the stimulation of endothelial cells that are involved in the development of new blood vessels.[8]

Surface coatings with BN can be an effective approach toward better osseointegration and long-term success of dental implants.[6] Hence, in the present *in vitro* study, BN-coated Ti surface was evaluated for osteogenic cell growth. There are various methods of coating BN on the surface of Ti such as radio frequency-magnetron sputtering, physical vapor deposition, chemical vapor deposition, and spin coating method. This is the first study attempting to coat the Ti surface with BN by the spin coating method to assess the success of this technique.

MATERIALS AND METHODS

This *in vitro* research evaluated osteogenic cell growth on uncoated and BN-coated Ti discs. The study consisted of 20 samples of Ti alloy [Ti_6Al_5V] discs of size (10 mm diameter × 2 mm thickness) which were divided into two groups Ethical clearance certificate no. IEC/2020/300/2 dated on 28/12/2020:-

- Group A/control Group-10 uncoated Ti alloy discs
- Group B/experimental Group-10 BN-coated Ti alloy discs. Which were coated using the spin coating method for uniform coating.

Preparation of boron nitride nanosheets solution

Hexagonal BN (hBN) powder (Vedayukt India Private Limited) was converted into nanosheets. For uniform coating required quantity of hBN nanosheets (h-BNNSs) was obtained by ultra-sonication.

BN powder was mixed in the solvent, consisting of a mixture of isopropyl alcohol and De-ionized (DI) water (in a 3:7 ratio) which was used for the synthesis of h-BNNSs through liquid phase exfoliation method. The Lewis acid − base interaction mechanism was responsible for the exfoliation of h-BN due to the electron deficiency of boron atoms.

The solution was subjected to centrifugation thrice for a 10-min cycle each at 1000 rpm, 3000 rpm, and 5000 rpm, respectively [Figure 1], which in turn produced h-BNNSs [Figures 2 and 3].

Coating procedure

The Ti alloy discs of size (10 mm diameter × 2 mm thickness) were ultrasonically cleaned with sequential solvents of acetone water, DI water and absolute ethanol followed by absolute air-drying of the discs. The h-BNNSs solution was again sonicated for 10 min. The discs were then placed into the SPIN COATER (APEX, USA), using a micropipette, h-BNNSs solution was poured drop by drop onto the discs and coating cycles of 500 rpm for 1 min was carried

Figure 1: REMI centrifugation machine and centrifuged test tubes during centrifugation of BN solution. BN: Boron nitride

Figure 2: Pasteur pipette

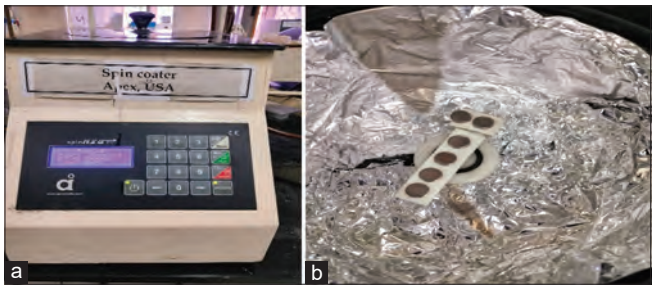

Figure 4: (a) SPIN coating machine, manufactured by APEX, USA. (b) Discs into the coating machine during coating procedure

out [Figure 4]. Five cycles for each disc were performed and between every cycle, the solution was dropped using a micro-pipette. After coating, the discs were air dried for 1.5 h and then kept in a petri dish with an aluminum foil cover to protect them from dust contamination.

All these discs (coated and uncoated) were ultrasonically cleaned sequentially with acetone, DI water and absolute ethanol, followed by air-drying and high-pressure steam sterilization. All the Ti discs including the control group and experimental group were then transferred to sterile cell culture plates and were exposed to UV radiation for 30 min before cell seeding. Then, the cell culture was prepared for the rat bone cell line (UMR 1O6) using Dulbecco's Modified Eagle's Medium with high glucose (Cat No-11965–092), fetal bovine serum (Gibco, Invitrogen) Cat No-10270106 Antibiotic-Antimycotic × 100 solution (Thermo Fisher Scientific) Cat no-15240062.

Next, sub-culture was carried out when cells had covered approximately 75% bottom of the culture plates and after 3 and 7 days, osseointegration was confirmed by basic cell growth determinants which are mentioned below along with the method to confirm their presence.

Cell adhesion was checked by phosphate-buffered saline (PBS) wash method, cell proliferation by

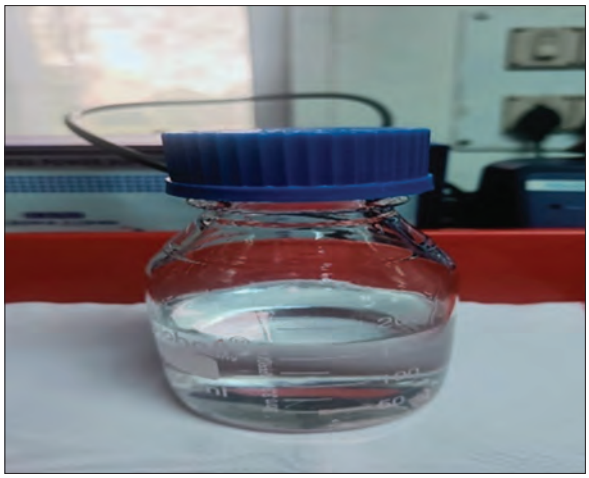

Figure 3: Clear (h-BNNSs) solution. h-BNNSs: Hexagonal boron nitride nanosheets

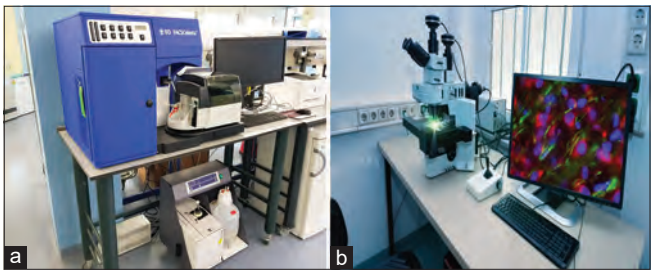

Figure 5: (a) florescence microscope (b) inverted microscope

3-(4, 5-dimethyl thiazolyl-2)-2, 5-diphenyltetrazolium bromide (MTT) assay, cell differentiation assay by cell flow cytometry, and cell fluorescence was measured.

Cell adhesion assay

Experimental procedure

A MAPTrix screen plate was rehydrated under very sterile conditions by adding 200 L of PBS (×1) to each well and letting it sit for 20 min at the room temperature. The PBS was then taken out of the rehydrated plates. Thereafter, in serum-free medium, a cell suspension was made with 0.1–2.0 × 106 cells/mL. The test samples inside each well received 150 L of the cell suspension, which was then centrifuged to encourage contact with the plate surface. PBS washes were used to carefully remove the nonadherent cells. By comparing the fluorescence [Figure 5] of Calcein AM before and after the wash process, it was possible to calculate the proportion of adhering cells [Figure 6].

Cell differentiation assay

Experimental procedure

In 0.5 mL of PBS, the discs were suspended in around 106 cells. Using a Pasteur pipet, gently aspirate several times or vortex for about 5 s to get a mono-dispersed cell solution with little cell agglomeration. The cells were then fixed by centrifuging 4.5 mL of 70% ethanol into centrifuge tubes

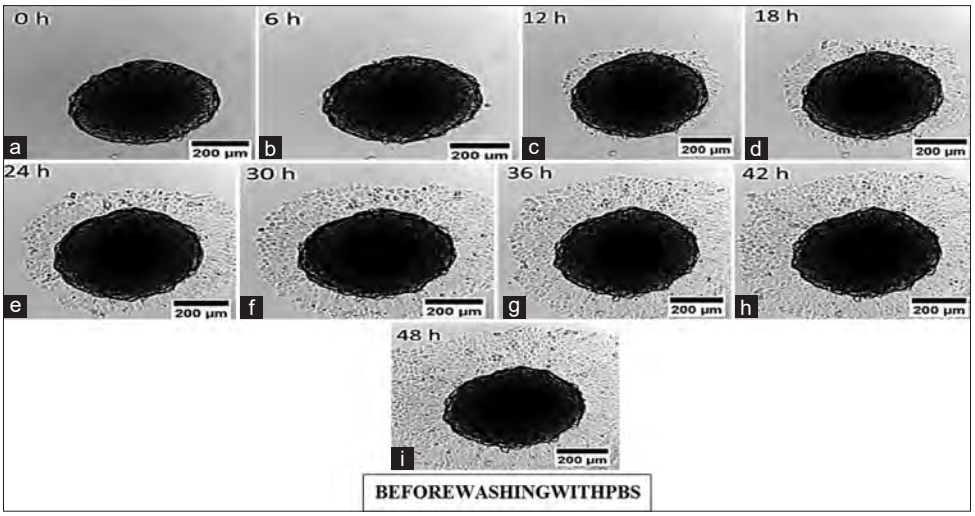

Figure 6: (a-i) Inverted microscope images of the discs at 0 hrs. to 48 hrs. to see for the amount of cell adhesion to the discs

containing the solution using a Pasteur pipet. At least, 2 h were spent keeping the cells in ethanol at 4°C. Moreover, cells can be kept for weeks in 70% ethanol at 4°C.

The ethanol-suspended cells were centrifuged for 5 min at 300 rpm followed by Decanting thoroughly using ethanol. The cell pellet was suspended in 5 mL of PBS, followed by a waiting period of approximately 30 s and again centrifuged at 300 rpm for 5 min. Again the cell pellet was suspended in 1 mL of propidium iodide (PI) staining solution. The Petri dishes were kept in the dark at the room temperature for 30 min or at 37°C for 10 min [Figure 7]. Then, the sample was transferred to the flow cytometer and cell fluorescence was measured. The maximum excitation of PI bound to DNA was at 536 nm and the emission was at 617 nm. Blue (488 nm) or green light lines of lasers were optimal for the excitation of PI fluorescence.

DAPI assay

Experimental procedure

A 12-well flat-bottom microplate with coverslips was used to seed the cells, and the microplate was kept at 37°C in a CO_2 incubator overnight. For 48 h, the coated and uncoated discs were stained with 100 l/mL of a positive control quercetin stain; both groups' nuclear morphology was then examined using DAPI stain. The cells were then permeabilized with Triton X-100 (0.5%) before being treated with paraformaldehyde (4%) for 20 min to fix the cells. The cells were then viewed using a confocal microscope after being treated with a 10 g/ml DAPI solution (IXplore Spin microscope system, Olympus life Sciences Ltd., Evident Scientific Private Limited, Gurgaon, Haryana, India).

The treated cells were rinsed with PBS and then fixed with 4% paraformaldehyde for 30 min to further examine the cell morphology.

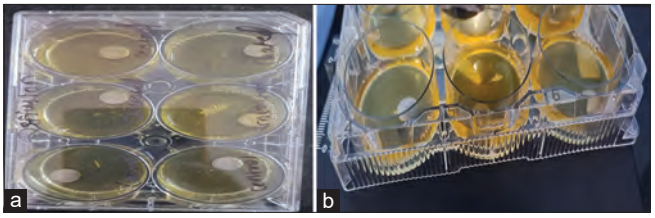

Figure 7: (a and b) cell culture plates during the cell culture procedure

3-(4, 5-dimethyl thiazolyl-2)-2, 5-diphenyltetrazolium bromide assay

Experimental procedure

The cells were seeded at a concentration of 104 cells per well in 100 ml of culture medium, and both groups were placed into 24-well tissue culture grade microplates, respectively. The cells were incubated at a concentration of 104 cells/ml in culture medium for 24 h at 37°C in an atmosphere of 5% CO_2 [Figure 8]. The cell line and dimethyl sulfoxide (DMSO) (0.2% in PBS) were incubated in the control wells. To calculate the proportion of live cells after culture and the control cell survival, controls were kept. In a CO_2 incubator, 30 cell cultures were cultured for 72 h at 37°C and 5% CO_2. The media was totally withdrawn following incubation and 20 L of MTT reagent (5 mg/min. PBS) was then added.

Cells were cultured for 4 h at 37°C in a CO_2 incubator following the addition of MTT. Under a microscope, the production of formazan crystals in the wells was studied. Only live cells were able to transform the yellowish MTT into dark-colored formazan. After fully removing the medium, 200 µl of DMSO was added, stored, and incubated for 10 min at 37°C with aluminum foil covering it. The absorbance of each sample was determined in triplicate using a microplate reader set to a wavelength of 550 nm.

RESULTS

After cell culture of UMR 106 in the control group and the experimental group, we found satisfactory results for the osteogenic cell growth upon both coated and uncoated discs. Following the parameters for the cell growth study the cell viability was analyzed: although cell adhesion assay showed positive adhesion of cells at the surface and edges for both the coated and uncoated discs at 3 days. The results were better for BN-coated discs at the magnification of ×200 further the number of adhered cells was more on the surface of BN-coated discs at 7 days interval of cell culture [Figure 9].

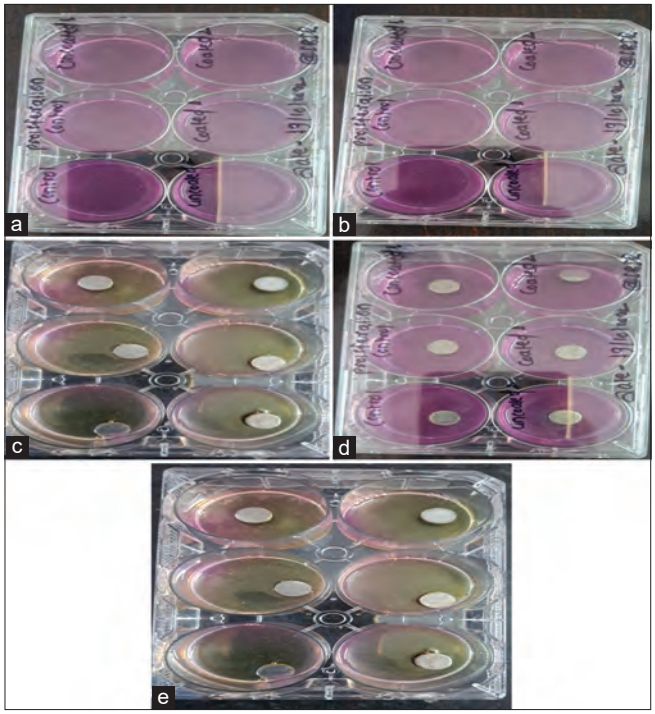

Figure 8: (a-e) Culture plate images during the proliferation test in the laboratory of both coated AND unncoated discs

The MTT assay was performed to check the proliferation of cells in both groups and the percentage of cell inhibition and cell viability was analyzed, as shown in Table 1.

On observation [Figures 10-14] initially coated discs showed a mild percent of inhibition against the UMR 106 rat bone cell line as compared to the standard drug 5-fluorouracil (5FU) which gradually decreased at the 7th and 9th day interval. Further, the rate of proliferation of cells increased with an increase in a time interval.

Cell differentiation assay results

The cytometer graph [Figure 15] showed 34.8% of cells in the G1 phase as compared to 8.38% in the G0 phase. This was assessed using fluorescence staining for DNA expression which showed stronger fluorescence in the G1 phase as compared to the G0 phase concluding that BN did not inhibit the cell cycle.

Further, the cell cycle analysis at the S phase showed 25.2% cell viability using simple PI DNA content analysis. At this stage, the DNA content was between 2°C and 4°C hence concluded that BN started the cell cycle arrest at the s-phase.

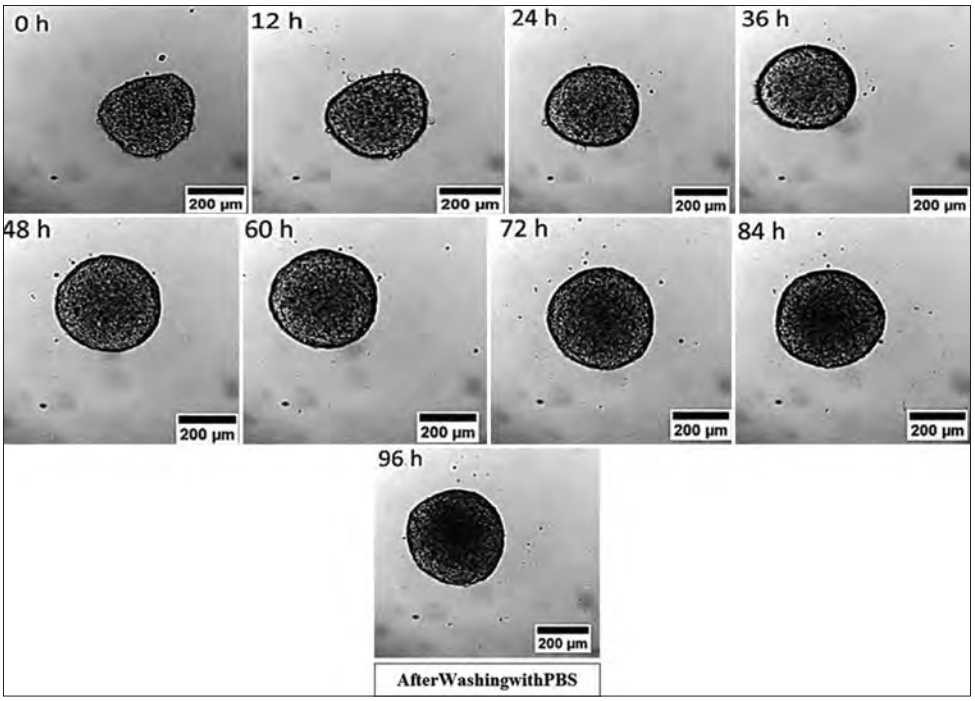

Figure 9: Inverted microscope images of the discs surafce after washing with PBS (phosphate buffer solution) to check for the amount of adhered cells onto the surafce after wash at 0 hrs. to 96 hrs.

Table 1: Effects of the compound against UMR 106 rat bone cell line

Sample code	Concentration (μg/mL)	OD	Inhibition (%)	Viability (%)	IC50 (μg/mL)
Control		1.256	-		
Standard	-	1.073	14.57	85.42	NE
Control discs 1	-	0.917	28.99	71.01	NE
Control disc 2	-	0.914	29.22	70.78	NE
Coated disc 1	-	0.613	25.64	74.36	NE
Coated disc 2	-	0.618	24.62	75.38	NE
Coated disc 3	-	0.602	13.67	86.33	NE
Coated disc 4	-	0.621	18.62	81.38	NE
Coated disc 5	-	0.58	11.67	88.33	NE

UMR 106: Cell line name/code, OD: Optical density, NE: Not evaluable, IC50: Inhibitory concentration

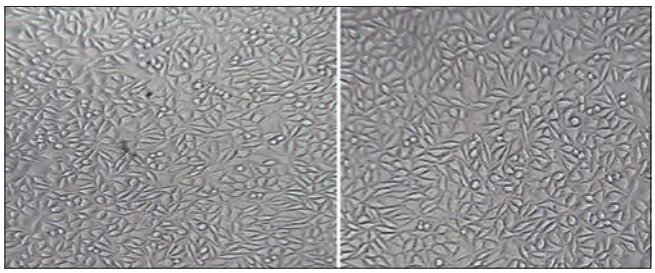

Figure 10: Inverted microscopic images of the control group (Ti alloy discs uncoated). Ti: Titanium

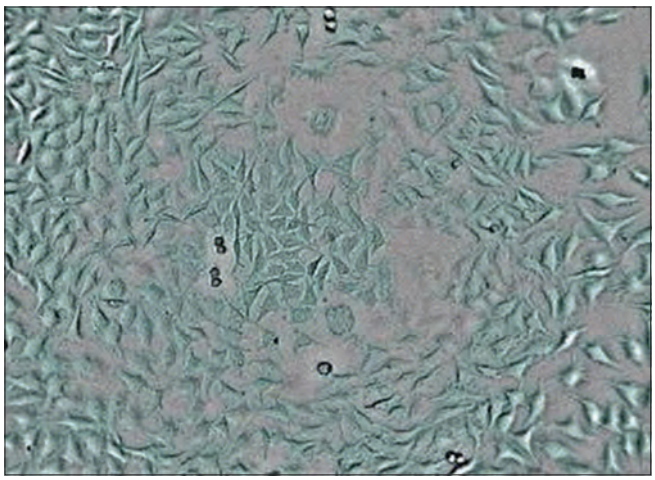

Figure 12: On 3rd day of the assay

Mitotic phosphoprotein which was a marker for the mitosis period was used to distinguish between the G2 and M phases of the cell cycle using the fluorescence intensity of the PI channels the cells in G2/M phase (17.9%) group further separated as G2 phase (16.4%) and M phase (1.64%), respectively. BN arrested the cell cycle at the initial M phase which was authenticated by the forward scatter and percentage of PI staining.

For more information refer to the flow cytometer graphs:

As BN did not hamper the G1 phase and G2 phase of the cell cycle. It can be concluded that BN-coated discs showed better cell differentiation properties.

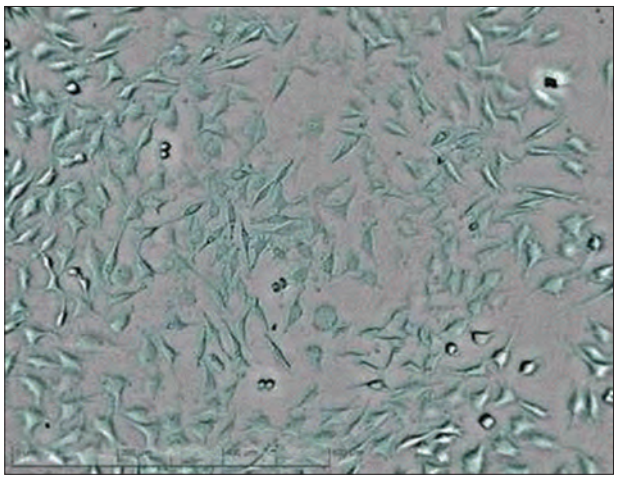

Figure 11: Microscopic image to hrs

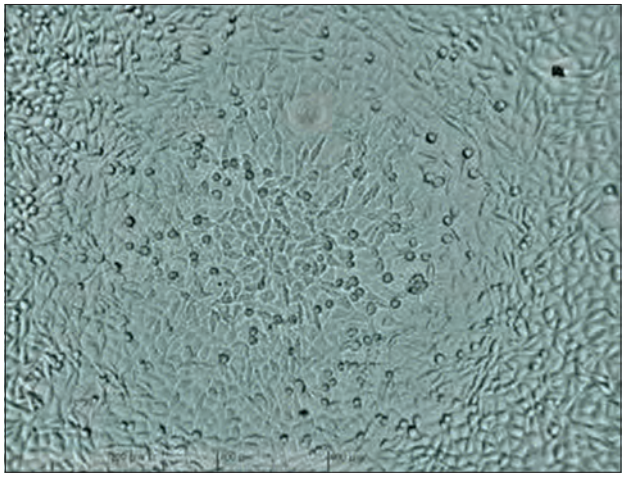

Figure 13: Between the 3rd and 7th day

DAPI assay

As shown in above Figure 16, normal intact nuclear morphology was observed in uncoated discs. However, abbreviated nuclei were detected on treatment with coated discs. The characteristic changes, particularly in the nucleus were observed through nuclear staining with the fluorescent dye DAPI. As shown in Figure 16, the intact nuclear morphology was witnessed in uncoated discs. However, the disturbed nuclear morphology with fragmentation was

observed in coated discs indicative of the initiation of the cell differentiation.

DISCUSSION

Integral to dental therapy is the use of Ti as an implant material. The development of commercially pure Ti (cpTi) and some of its alloys for the production of dental prostheses and oral implants was primarily motivated by the high cost of noble alloys and the potential biological dangers of base metal alloys.[9]

While it has been used in dentistry for more than 50 years, cpTi still has room for improvement in terms of both the material and the methods used to manufacture it, maybe to prevent future mechanical or biological issues. In a rare instances, insufficient osseointegration and insufficient new bone apposition might cause clinical failure of implants.[9]

In general, patients often have to wait for three to 6 months for the final prosthesis. And To reduce the waiting period for successful osseointegration to take place several treatment modalities have been introduced. These include modifications of implant surface design and coating the implant surface with bioactive films such as – aluminum oxide and HA crystals to make this implant surfaces osteoinductive. Further to enhance the clinical success of implant surface etching (Sandblasted, large grit, acid-etched implant surface implants,[6] aluminum oxide-blasted implants,[10] calcium phosphate[10] etc.,) various soft and hard tissue augmentation techniques, and the use of growth hormones and inducer solutions have been proposed.

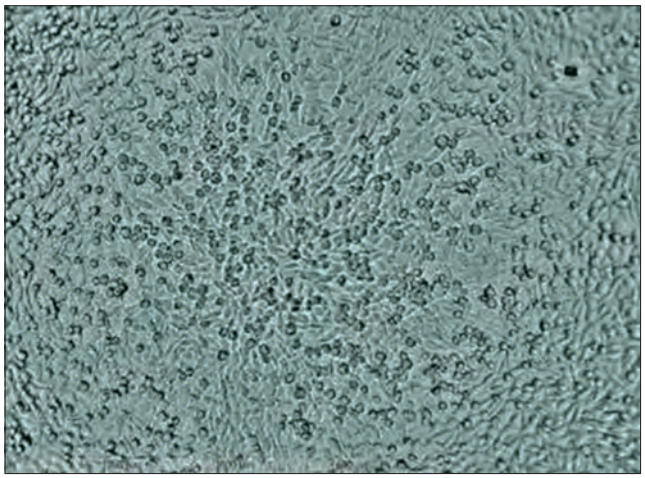

Figure 14: On the 7th day of the MTT assay. MTT: 3-(4, 5-dimethyl thiazolyl-2)-2, 5-diphenyltetrazolium bromide

Many unique engineering properties of hBN include solid lubricants for high-temperature bearings, mold release agents, ultra-high pressure transmission agents, dielectrics for radar antennas and windows, neutron absorbers and shields for nuclear reactors, etc., Because of its superior mechanical and biological properties, it has also been researched for use in dental cement, medicine, and cosmetics and has been proposed to be used for dental implant coatings.[7]

A man-made substance called hBN has a layered crystal structure with strong covalent bonds between atoms but weak Van der Waals interactions between layers. Similar to graphite, hBN has a hexagonal crystal structure that is sometimes referred to as "white graphite."[6]

Hakki *et al*. in 2012 and Ozmeric *et al*. in 2019 in their animal study stated that BN in nano-structure form can be used for surface modification of Ti alloy disks.[8] Additionally, BN can be used for bio-applications, and once the clinical uses are established, various strategies can be used to modify the BN nanostructures for those purposes. These include imaging, drug delivery, an antibacterial effect, and the stimulation of osteogenic cell growth and differentiation, among others.[11]

Çakal *et al*. in a 2019 study, the various other methods of coating BN on the surface of Ti such as RF-magnetron sputtering, physical vapour deposition, chemical vapour deposition and spin coating method.[10]

In the present research spin coating was used to apply a uniform layer of hBN over the Ti disc. This method of

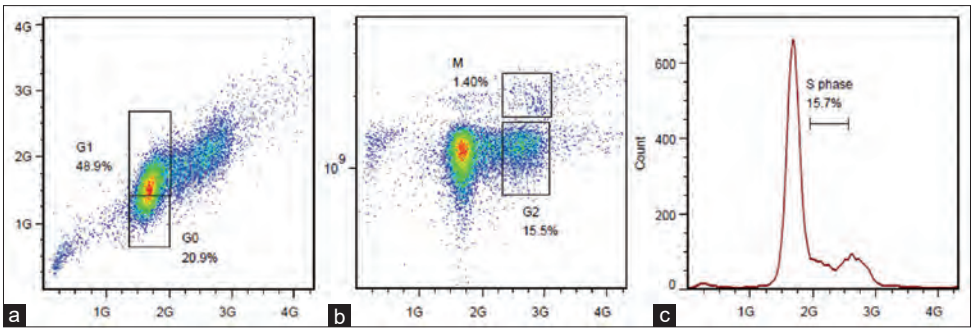

Figure 15: Flow cytometer graphs (a-c) to analyze the cell morphology and cell count at various stages of the cell cycle

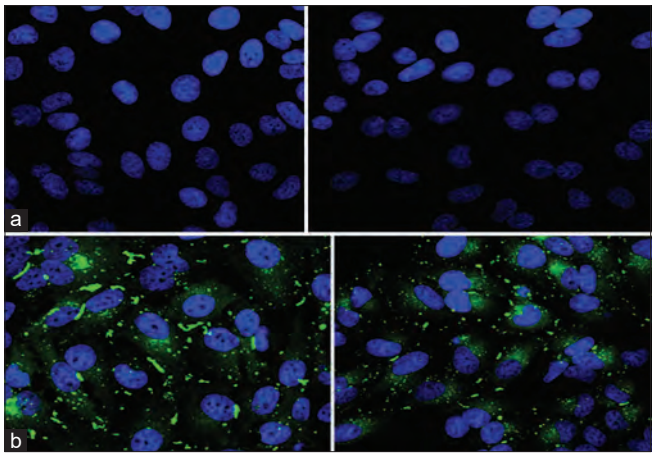

Figure 16: Morphological assessment of coated discs treated with UMR 106 cells through confocal microscopy. Nuclei were stained with DAPI and observed under a confocal microscope in comparison to the uncoated discs. (a) Control, (b) coated. UMR 106: Cell line name/code, DAPI: 4',6-diamidino-2-phenylindole, is a fluorescent stain

coating is a successful method by S. Heeravathi and Christy. In their study, they showed that Spin coating can produce the desired (microlevel to nano level) thickness by varying the spinning speed and other parameters. Hence it can be implemented in micro and nano-coating processes.[12]

In the present *in vitro* study, cell culture of UMR-106 (rat bone cell line) is done on the Ti discs which are taken as the control group and Ti coated with BN discs, which is the experimental group in the laboratory and basic parameters of cell growth such as cell adhesion, cell differentiation, and cell proliferation are comparatively evaluated at 3 and 7 days interval.

Initially, both groups showed positive results for cell growth. However, during the evaluation of cell adhesion, a significant number of cells are found adhered to the BN-coated Ti surface and cell differentiation assay tests revealed that BN-coated discs did not hamper the cell cycle at the G1 and G2 phase of the cell cycle. Further in the proliferation assay or MTT assay tests, coated discs showed mild cell inhibition activity at 3 and 7 days intervals, as compared to the standard drug 5 FU.

To further assess the response of hBN on living cells, DAPI assay was performed and fragmented nuclear morphology of cells was observed with BN-coated discs as compared to the intact nuclear morphology with uncoated discs, which was indicative of the initiation of cell differentiation. Hence, the BN coat does not have any cytotoxic effects on the living cells and tissues.

From the above results, it can be concluded that the BN-coated Ti surface showed a superior osteogenic cell growth property over the uncoated Ti disc surface.

The limitations of this study are that statistical analysis is not possible for this descriptive study.

Hence, it can be concluded that for the success of implant treatment, a good surface modification and required roughness are a prime requirements.

CONCLUSIONS

Based on the results obtained in this *in vitro* study, implant surfaces treated with BN coating showed positive results for cell adhesion, cell differentiation and cell proliferation. BN coating upon the Ti discs did not hamper the cell cycle process and showed positive results for cell expression at G1 and G2 phases. Hence, we can conclude that BN coating on Ti dental implants can be a boon to implant dentistry in providing a better bone-to-implant interface.

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Nil.

Conflicts of interest
There are no conflicts of interest.

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Research

Obturators: A proposed classification and its associated techniques

Ranjoy Hazra, Ayush Srivastava, Dinesh Kumar

Department of Prosthodontics and Crown and Bridge, Army Dental Center (Research and Referral), New Delhi, India

Abstract

Statement of Problem: Multiple classifications exist for maxillectomy defects. However, none of the existing classifications describes the defects as favorable or unfavorable from the prosthodontist's standpoint. The most common problem with prosthetic treatment in such patients is in getting adequate retention, stability, and support. The size and location of the defect usually influence the amount of impairment and difficulty in prosthetic rehabilitation.

Proposed Classification: A series of cases has been studied, and a newer type of maxillary defect is seen with a better presurgical involvement of the prosthodontist. This type of defects is not present in any of the existing classification; hence, a modification is proposed, and its requisite cast partial framework design is also given. Another treatment-based classification is also proposed for easy treatment planning in these cases. A case series of maxillectomy patients with varying types of defects rehabilitated with obturators with different designs, modes of retention, and fabrication procedure in accordance to the newer classification is described.

Discussion: Surgical intervention creates communication among the oral cavity, nasal cavity, and maxillary sinus. The obturator prosthesis is commonly used as an effective means for rehabilitating such cases. There is a plethora of classifications available for maxillectomy defects though none of them takes existing dentition into consideration. While remaining dentition and various other favorable and unfavorable factors decide on the final prognosis of the prosthesis. Hence, a newer classification was planned with keeping in mind newer treatment modalities.

Conclusions: Prosthodontic rehabilitation with obturator prosthesis design and manufactured by various principles and techniques restores the missing structures and acts as a barrier between the communication among the various cavities and definitely improving their quality of life. Considering the complexities of maxillary anatomy, the various permutations of the maxillectomy defect, the current trends in surgical management with presurgical prosthodontic planning, and various prosthodontic treatment options available, it is imperative that a more objective modification of the current classification described in this article is warranted for and could be more operator friendly in finalizing and communicating of the treatment plan.

Keywords: Classification, obturator, treatment planning

Address for correspondence: Dr. Ranjoy Hazra, Department of Prosthodontics and Crown and Bridge, Army Dental Center (Research and Referral), New Delhi - 110 010, India.
E-mail: rj.razr@gmail.com

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INTRODUCTION

Rehabilitation of maxillectomy patients can be challenging. The most common problem with prosthetic treatment in such patients is in getting adequate retention, stability, and support.[1] The size and location of the defect usually influence the amount of impairment and difficulty in prosthetic rehabilitation. Each patient and defect is unique in nature and has to be managed in a way best suited for it.[2] Thus, to successfully obturate the defect and reduce the discomfort of the various patients, a prosthodontist is supposed to be equipped with an array of design and techniques.[3]

There is a plethora of classifications available for maxillectomy defects, as described by Aggarwal *et al.* in 2015.[4] Each one has its own merit, like divided the defects according to their horizontal and vertical extensions, where the extension determined the treatment outcome. Bidra *et al.* did a systematic review of maxillectomy classification and found that only three out of 14 existing classifications evaluate existing dental status.[5] The existing dentition plays a paramount role in deciding the prognosis of the final functional outcome of the rehabilitation procedure. Hence, it cannot be ignored, as it has been in the existing classification systems. Hence, there is a need of a newer classification for maxillectomy defects in accordance with the newer surgical and prosthodontic protocols in place, which would help us in choosing the right treatment modality rather than concentrating on the anatomic limits of the defect.

PROPOSED CLASSIFICATION

A prosthetically driven classification is proposed, which could serve as a broad guideline of mode of rehabilitation of the patient.

As the earlier classifications and their proposed design were exclusively for cast partial framework, the need of the hour is to include newer treatment modalities available within the classification [Table 1].

Type I-minimally compromised situation

Adequate soft tissue and dentulous segment available after resection (of <50% of hard palate, alveolus, and one canine tooth), which can be used to gain retention, stability, and support for cast partial definitive obturator.

- Adequate bone volume present for the placement of endosseous implants.
- The presence of lateral scar band following split-thickness skin grafting.
- Implant placement is not mandatory but is an option if required.

Forty-nine of the total cases (73%) fell in this category.

One such case is of a 32-year-old serving soldier with a right Aramany's Class I maxillary defect which was rehabilitated with a cast partial obturator with an altered cast technique. After surveying, tripodal design with an I bar was planned, and teeth preparation was accordingly done; a Cast partial denture (CPD) framework was fabricated, which was used to make the defect impression, and an altered cast was prepared [Figure 1]. Following which conventional steps were followed, and hollowing of the bulb was done with alum.

Type II-moderately compromised situation

Inadequate soft tissue and dentulous segment available after resection, which can be used to derive retention, stability, and support for cast partial definitive obturator.

- Adequate bone volume (Division A/Division B) present for the placement of endosseous implants.
- The cases where soft tissue closure has been achieved/attempted following resection obliterating vestibule/defect.
- Implant placement is mandatory in these types of cases.

Twelve of the total cases (18%) fell in this category.

Table 1: Treatment categorization distribution

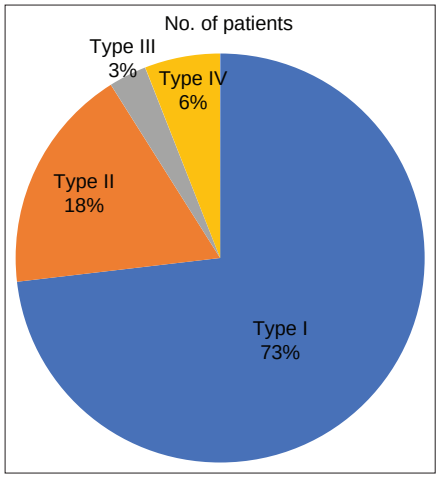


Figure 1: CPD framework fabrication for a Type I case. CPD: Cast partial denture

One such case is of a 75-year-old edentulous retired soldier who has undergone left total maxillectomy and an attempted free fibular reconstruction and soft-tissue grafting and was rehabilitated with an implant-supported obturator. The bone graft was completely resorbed following extensive chemoradiation, leaving no vestibule on the left edentulous upper jaw. A diagnostic conventional upper and lower conventional complete denture was fabricated, which was used for prosthetic-driven treatment planning. The same dentures were used as a template during detailed cone-beam computed tomography analysis. The dentures were converted into Laney-Poitras surgical guide during the placement of three implants in the right upper jaw and two implants in the lower bilateral canine region [Figure 2]. An open-tray impression of the maxillary arch was made to fabricate a cast with implant analogs over which a bar framework was designed and casted in cobalt-chrome alloy [Figure 3]. In the lower arch, stud abutments were screwed. Following which conventional denture fabrication steps were followed after blocking out the framework and abutments intraorally. The finished prosthesis, thus fabricated, was attached with clip assembly and metal o-ring housing, respectively, with self-cure acrylic.

Type III-severely compromised situation

Inadequate soft tissue and dentulous segment available after resection, which can be used to derive retention, stability, and support for cast partial definitive obturator.

- Inadequate bone volume present for the placement of endosseous implants.
- Preprosthetic surgery is essential to develop a favorable soft tissue contour and/or bone grafting to increase bone volume.
- Implant placement is mandatory in these types of cases following preprosthetic surgery with/without complex surgical techniques like pterygoid/zygomatic implant/patient-specific implant placement.

Two of the total cases (3%) fell in this category.

Type IV-severe systemically compromised situation/any contraindication to definitive therapy

Altered systemic conditions of the patient like high chances of recurrence and resurgery of the patient, the inability of the patient to attend longer/multiple appointments for definitive therapy, severe trismus, systemic condition not conducive to any surgical trauma, or in cases who are allergic to metals.

- Long-term acrylic interim obturators or flexi obturators can be planned in these types of cases.

Four of the total cases (6%) fell in this category.

One such case is of a 56-year-old wife of a retired soldier with a left Aramany's Class IV maxillary defect who was rehabilitated with a flexi obturator. The patient had a known history of allergy to metals; hence, a long-term interim obturator was planned with a new-generation polyamide-based thermoplastic material. A dual impression was made, and bite registration was

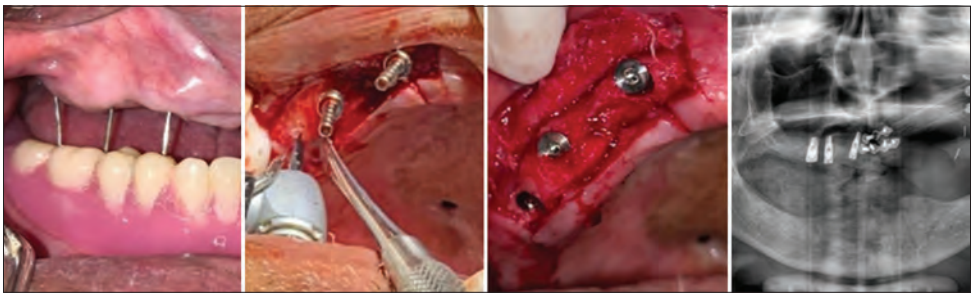


Figure 2: Implant placement for a Type II case

Figure 3: Implant supported bar framework in a Type II case

done, following which conventional teeth arrangement and wax-up was done [Figure 4]. The flexi obturator was processed in a special cartridge furnace and injection system at a temperature of 300°C after adequate spruing [Figure 5].

Note: If with a Class I/Class II/Class III maxillary defect, there is an associated defect of the resection of the lips, nose, cheek, outer skin, and soft palate; the class will be subclassified as "A" and "B."

Subgroup A: The second prosthesis or the extension of the original prosthesis to rehabilitate the associated defect increases or at least does not affect adversely the treatment outcome of the original prosthesis.

Subgroup B: The second prosthesis or the extension of the original prosthesis to rehabilitate the associated defect is going to affect adversely the treatment outcome of the original prosthesis. A compromised treatment plan depending on the primary treatment objectives or a totally separate prosthesis has to be catered for.

Furthermore, those cases where the second prosthesis itself has a poor prognosis irrespective of the original prosthesis.

The complete classification is summarized in Table 2.

All three classifications involving dentate status in maxillectomy cases given by Aramany, Okay, and Rodriguez do not take into consideration the cases where postresection dental segments are preserved both anteriorly and posteriorly to the resected area without crossing the midline.[6-8]

It can be a modification of Aramany's Class II defect with posterior dentulous segment available for support and retention.[6]

Alternatively, it can be a modification of Okay's Class IB/II defect with posterior dentulous segment available for support and retention.[7]

These types of cases have become increasingly common with better presurgical prosthodontic planning to save any possible posterior dentulous segment during resection. The importance of conservative surgical management in nonaggressive lesions has been understood by the operating surgeon, and the vital role a nonresected posterior dentulous segment plays in improving the final prognosis of functional rehabilitation of the patient. This modification will invariably have the best prosthodontic prognosis, and the clinician can immediately expect a better functional outcome.

Sixty-seven maxillectomy cases were seen in our department from May 2019 to January 2022, and three of them had retained posterior edentulous segment (4%) [Table 3].

These cases can be managed both with tripodal and quadrilateral designs during cast partial denture framework fabrication [Table 4].

One of those three cases is of a 39-year-old serving soldier with Aramany's left Class II maxillary defect with a modification who was rehabilitated with a cast partial obturator with a hollow bulb technique. After surveying, tripodal design with a circumferential clasp assembly on the 1st premolar and 1st molar on the nonaffected side and a cast circumferential embrasure clap on the molars of the affected side. A cingulum rest indirect retainer was planned on the central incisor, and any direct retainer on it was avoided to enhance esthetics and reduce excessive metal display [Figure 6]. Teeth preparation was accordingly done; a CPD framework was fabricated which was used to make the defect impression, and a pick up impression was made. Following which conventional steps were followed, and hollowing of the bulb was done with a salt bag.

DISCUSSION

From a prosthodontic perspective, unilateral defects are simpler to manage than bilateral defects due to the increased surface area for retention and support and the reduced volume of tissues to be replaced by the prosthesis. However, the presence of implants and the number and

Figure 4: Flexi obturator fabrication for a Type IV case

Figure 5: Flexi obturator placement in a Type IV case

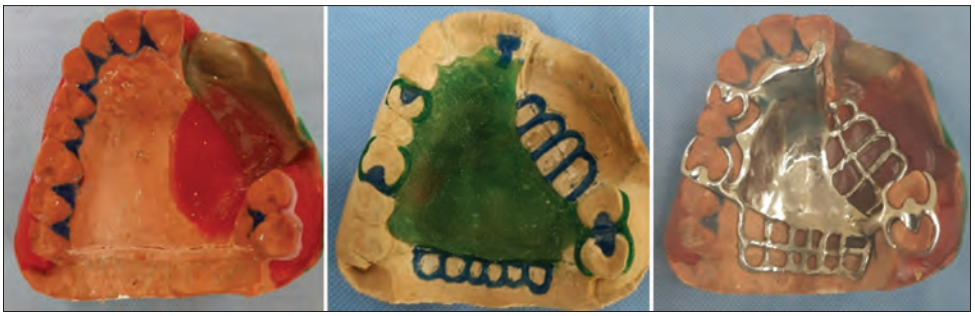


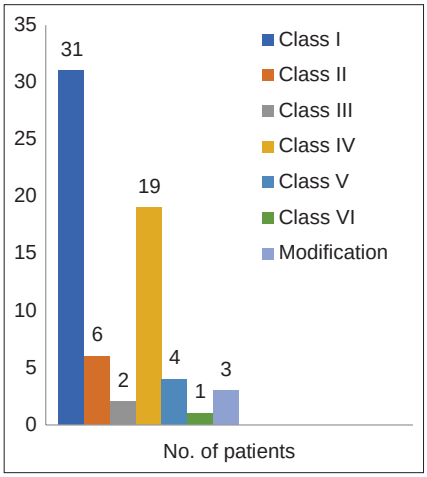
Figure 6: CPD framework fabrication for a modification of Class II defect with a tripodal design. CPD: Cast partial denture

Table 2: Proposed classification

Proposed classification	
Type I-Minimally compromised situation	Adequate soft tissue and dentulous segment available after resection (of<50% of hard palate, alveolus, and one canine tooth), which can be used to gain retention, stability, and support for cast partial definitive obturator Adequate bone volume present for the placement of endosseous implants The presence of lateral scar band following split thickness skin grafting Implant placement is not mandatory, but is an option if required
Type II-Moderately compromised situation	Inadequate soft tissue and dentulous segment available after resection, which can be used to derive retention, stability, and support for cast partial definitive obturator Adequate bone volume (Division A/Division B) present for the placement of endosseous implants The cases where soft tissue closure has been achieved/attempted following resection obliterating vestibule/defect Implant placement is mandatory in these types of cases
Type III-Severely compromised situation	Inadequate soft tissue and dentulous segment available after resection, which can be used to derive retention, stability, and support for cast partial definitive obturator Inadequate bone volume present for the placement of endosseous implants Preprosthetic surgery is essential to develop favorable soft tissue contour and/or bone grafting to increase bone volume Implant placement is mandatory in these types of cases following preprosthetic surgery with/without complex surgical techniques like pterygoid/zygomatic implant/PSI placement
Type IV-Severe systemically compromised situation/ any contraindication to definitive therapy	Altered systemic condition of the patient like high chances of recurrence and resurgery of the patient, inability of the patient to attend longer/multiple appointments for definitive therapy, severe trismus, systemic condition not conducive to any surgical trauma, or in cases who are allergic to metals Long-term acrylic interim obturators or flexi obturators can be planned in these types of cases
All types are subdivided into two, if there is an associated defect	
Subgroup A	The second prosthesis or the extension of the original prosthesis to rehabilitate the associated defect increases or at least does not affect adversely the treatment outcome of the original prosthesis
Subgroup B	The second prosthesis or the extension of the original prosthesis to rehabilitate the associated defect is going to affect adversely the treatment outcome of the original prosthesis

PSI: Patient-specific implant

Table 3: Distribution of cases

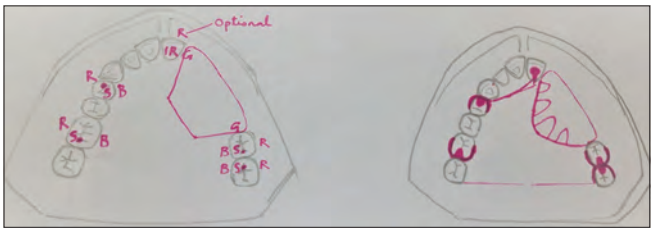


quality of remaining teeth are important prognostic factors to be considered. Previous authors have discussed biomechanical considerations for the prosthodontic rehabilitation of various unilateral and bilateral defects.

Prosthodontic management of an isolated defect is simpler when sufficient teeth or implants exist both anteriorly and posteriorly for adequate retention and support of the prosthesis. These cases could be managed with both tripodal and quadrilateral designs during cast framework fabrication.[9] It is important to note that if a maxillectomy defect crosses the midline and involves the loss of even a single tooth socket on the contralateral maxilla, these defects should be described as bilateral defects. This is because the biomechanics of the resultant defect is altered due to the change in the fulcrum line, which can affect the prosthodontic treatment outcomes.

Although flexi obturator has not been tried widely, this could be a practical alternative in cases with specific

Table 4: CPD design: Tripodal/ quadrilateral



S: Support, R: Retention, B: Bracing, G: Guiding plane, IR: Indirect retention, CPD: Cast partial denture

indications like metal allergy and with smaller defects as it is flexible, dimensionally stable, lightweight, and provides high fatigue endurance along with excellent wear resistance.[10-12] The material is slightly translucent and matches with the tissue.[13]

CONCLUSIONS

It is practically impossible to achieve a universal acceptance of a single classification system that satisfies surgical and prosthodontic requirements. Considering the complexities of maxillary anatomy, the various permutations of the maxillectomy defect, the current trends in surgical management with presurgical prosthodontic planning, and various prosthodontic treatment options available, it is imperative that a modification of the current classification described in this article is warranted for and could be more operator friendly and more objective in nature. This classification can be used as an aid to treatment planning and would help predict the prognosis of prosthodontic rehabilitation.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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Case Report

Completely digitally fabricated custom functional finger prosthesis

Anuraj Vijayan, Vishwas Bhatia[1], Saksham Arora, Shubham Gupta

Department of Prosthodontics, I.T.S. Dental College, Hospital and Research Centre, Greater Noida, Uttar Pradesh,
[1]Director, Signature Dental 32 Clinics, Delhi, India

Abstract

The loss of a finger in any capacity as a result of trauma has a significant influence on the patient's everyday life, as well as their psychological and physical health. Multiple conventional techniques have been reported in the literature, mostly offering psychological and cosmetic benefits to such individuals. However, there is a paucity of literature for functional finger prosthesis. This case report describes rehabilitation of an amputated index finger using an innovative digital workflow, thereby making it impression-free, cast-free, accurate, less time-consuming, and above all functionally viable. Digital technology was used for designing, and fabrication of this prosthesis was done using three-dimensional (3-D) printing. When compared to traditional prostheses, this 3-D–printed prosthesis was functional, allowing the patient to conduct everyday activities and providing the patient's confidence a psychological boost.

Keywords: Finger prosthesis, maxillofacial prosthesis, rehabilitation, silicone elastomers

Address for correspondence: Dr. Anuraj Vijayan, Department of Prosthodontics, I.T.S. Dental College, Hospital and Research Centre, Greater Noida, Uttar Pradesh, India.
E-mail: anurajvjn9@gmail.com
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INTRODUCTION

The most prevalent kind of partial hand amputations includes complete and partial finger amputations, with trauma being the most common cause, as well as congenital abnormalities or absence. Prosthetic rehabilitation of the amputated finger has been shown to help psychosocial characteristics of a patient by providing reduced hypersensitivity and increased strength in grip.[1] Despite the fact that these prostheses give psychological and esthetic benefits, they generally lack the functioning of a normal finger.

Fabrication of a traditional prosthesis is extremely time-consuming and complex as it requires customization and sculpting to fit each individual.[2] All of these issues can be avoided with the use of computer-aided design (CAD)/computer-aided manufacturing and rapid prototyping technologies. Additive manufacturing technologies can either be used as adjuncts or can have a completely digital workflow.[3]

When compared to traditional approaches, these technologies drastically shorten the time needed to design and fabricate such prostheses.[4] In the literature,

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improved accuracy and efficiency of socket fabrication have been documented using CAD combined with standard tessellation language (STL) files and additive manufacturing.[1] A combination of these technologies can also be used for remote manufacturing of prosthesis if the necessary designs and measurements are obtained.[5]

Although there are a few accounts of functional prosthesis in the literature, there is no literature on characterized functioning three-dimensional (3-D)–printed finger prosthetics, to the best of the authors' knowledge. This case report describes the usage of a novel innovative cast-free 3-D–printed prosthesis to replace a traumatically severed finger, as well as the fabrication procedure.

CASE REPORT

A 65-year-old male patient was referred to the department of prosthodontics, with a chief complaint of a partially missing index finger in his right hand. Case history revealed that the patient had lost the distal and middle phalanges, at the proximal interphalangeal joint, 2 years back, due to an acquired traumatic injury. The finger was severed after it became entangled in machinery during work and was never reattached due to a delay in treatment. On inspection, it was observed that wound healing appeared to be complete with no signs of infection or inflammation in the surrounding tissues [Figure 1]. The patient had no prior experience with a prosthesis for the same. After evaluation, the patient was explained about the option of a 3-D–printed functional finger prosthesis and the patient consented for the same.

This cast-free procedure requires specific measurements of the finger stump to be made. The residual stump, in this case, was 44 mm (mm) in length and had a diameter of 25 mm, which was used to design the finger socket of the prosthesis. This finger socket is responsible for the retention of the prosthesis on the stump. Measurements of the opposite index finger were taken for customization of the middle (26 mm) and distal (24 mm) components of the prosthesis [Figure 2]. Measurement of linkage length is critical because it is this component that acts as an anchoring point and initiates the motion of other components. These dimensions were then utilized to alter the stock CAD (Knick's Prosthetic Finger version 3.5.5) [Figure 3].[6] The stock CAD consists of eight total components, namely, knuckle plugs (4 in number), finger socket, tip knuckle, tip cover, middle bumper, middle segment, base knuckle, and wrist linkage [Figure 4]. An open-source software OpenSCAD system (http://www.openscad.org) was used to customize these individual components, based on patient's measurements, following which digital models were rendered and files of customized components were exported in STL format. After this, the customized data set was sent to the laboratory, where it was prepared for final 3-D printing using software (Chitubox v1.4.0; Shenzhen CBD Technology Co. Ltd.; China). The final printing was done using a photopolymer resin (Phrozen TR300 Ultra-High Temp Resin, Phrozen, Hsinchu, Taiwan) and a Digital Light Processing 3-D Printer (Phrozen Shuffle, Phrozen, Hsinchu, Taiwan). Additional components included elastic cords (2 mm in diameter) and nylon string (2 mm in diameter). These individual components were then assembled, according to the designers' instructions [Figure 5].[7]

The prosthesis was then evaluated for fit and function. Demonstration of various movements the prosthesis could simulate was given to the patient [Figure 6], following which characterization of the prosthesis was done.

Covering the complete prosthesis with a silicone over-sleeve for esthetics would have restricted mobility and impaired the prosthetic's functioning. Hence, this type of prosthesis is best paired with sectional silicone sleeves. It was decided to fabricate silicone sleeves (Silicone A-2186 Platinum Silicone Elastomers, Factor II, Lakeside, USA) for nonfunctional components, i.e., middle segment and the tip cover. The sleeves were fabricated using 1.5 mm thick wax sheets adapted to above-mentioned components. These sheets were then flasked using type II gypsum product (Kaldent, Kalabhai Pvt. Ltd., Mumbai, India) and mold was created using lost-wax technique. The silicone base material was then mixed with catalyst in a ratio of 10:1 by weight and thixotropic agent (Factor II) was also added to thicken the mixture. Intrinsic staining (KT-699, Silicone

Figure 1: Prerehabilitation photographs, dorsal view (a), palmar view (b), and close up of the finger stump (c)

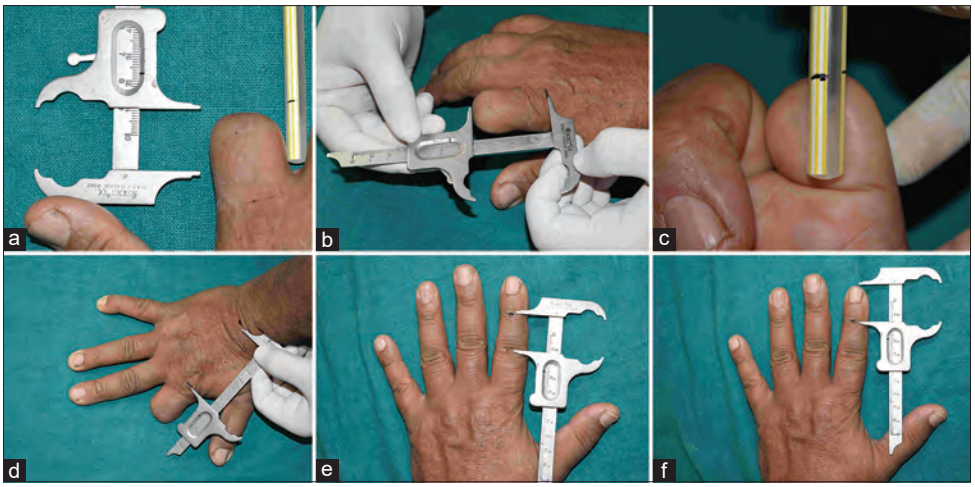

Figure 2: Measurements of the finger stump (a-c). Measurement of linkage length (d), middle (e), and distal phalanx (f)

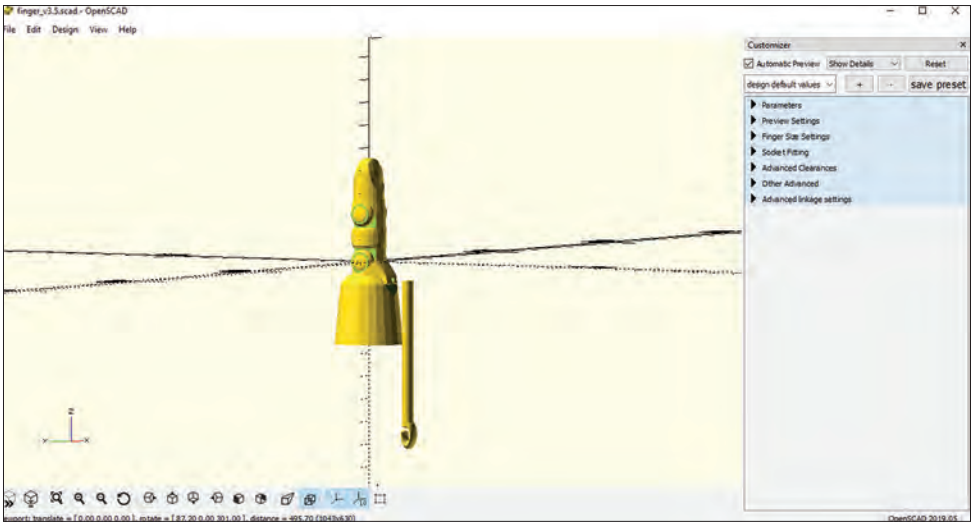

Figure 3: Stock CAD Model (Knick's Prosthetic Finger version 3.5.5)

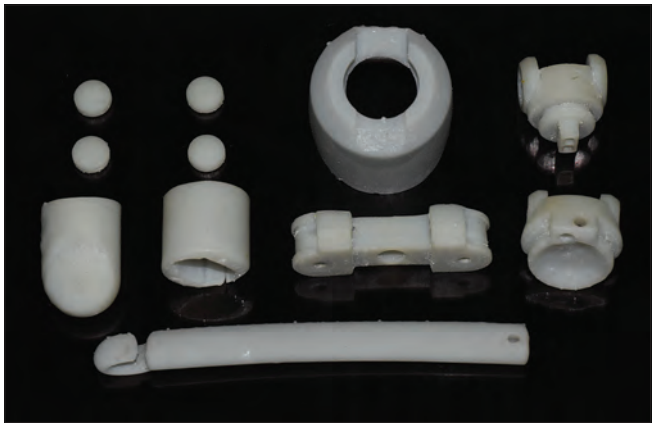

Figure 4: Three-dimensional–printed components. (From left to right) Top row: Two pairs of knuckle plugs, finger socket, and tip knuckle. Middle row: Tip cover, middle bumper, middle segment, and base knuckle. Bottom row: Linkage

Coloring Kit, Factor II, Lakeside, USA) of silicone was done to match the patient's skin color. Shade matching was done to match the shade of the adjacent middle finger and thumb. This colored silicone was packed into the mold in layers and the flask was closed.

Following this, the silicone was then processed at 100°C for 30 min according to the manufacturer's instructions. After processing, the silicone sleeves were retrieved and adapted to the corresponding components. A custom nail was fabricated and fixed in position using cyanoacrylate adhesive (Fevi-Kwik, Pidilite Industries, Mumbai, India). To provide components that were not covered in silicone with a more appealing appearance, characterization was done with color-matched acrylic paints (Kokuyo Camlin Industrial Ltd., Mumbai, India).

The final characterized prosthesis was then placed over the patient's stump, and the linkage was attached to a bracelet that was fastened around the patient's wrist [Figure 7] along

with instructions to practice flexion of the wrist while trying to hold onto an object. Furthermore, the patient was instructed to remove the prosthesis during bedtime so that it does not get damaged during sleep. On the 3rd day of follow-up, the patient reported having been satisfied with the esthetics along with no difficulties in operating and controlling the finger. The patient was instructed to report to the department for monthly follow-ups or in case of damage to the prosthesis or stump.

DISCUSSION

Dexterous people suffer tremendously in terms of esthetics and usefulness when a limb is lost. Rehabilitation gets easier when just the distal phalanx is affected, and near-normal functioning can be restored with a suitable prosthesis.[8] However, it has been revealed in surveys, that 30%–50% of upper limb amputees do not use their prosthesis regularly due to poor esthetics, low functioning, and controllability.[9] This is where a functional prosthesis can help. The patient can then satisfactorily perform daily life activities such as holding a pen and picking up objects with ease.

To the best of the authors' knowledge, a total of three functional finger prostheses have been reported in the literature.[1,10] First of which was reported by Pattanaik and Pattanaik, who incorporated a pliable hairpin into modified conventional silicone finger prosthesis. However, the functioning in their prosthesis was restricted to only two fixed positions, opened or closed position, with the patient having to adjust the pin manually. Furthermore, fabrication of the same is technique sensitive.[10] Young *et al*., conducted a case study comparing commercially available finger prosthesis (MCP-Driver™ finger prosthesis, NAKED Prosthetics Inc., Olympia, WA, USA) and a locally 3-D–printed finger prosthesis (LPF). They compared both the prostheses on various parameters such as gross manual dexterity, satisfaction, and upper extremity functional status. It was observed that patient satisfaction was greater with LPF, whereas gross manual dexterity and upper extremity functional status were closely matched. The design of LPF fabricated by the author was quite similar to the prosthesis described in this case report, except for the joint between the middle and distal segments of the prosthesis, which was fixed at 30° downward angulation.[1]

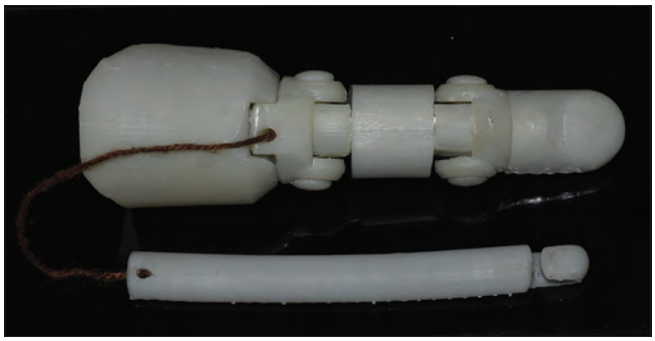

Figure 5: Assembled finger prosthesis

The approach described in this case report uses digital technologies to create customized finger prostheses without the need for an impression. Thus, the process is much more rapid when compared to the conventional method. Because of hinges that act between the tip knuckle and the middle segment, as well as the middle segment and the base knuckle, the functional prosthesis presented in this case study provides full functioning, identical to an anatomical finger. Hence, the range of motion achieved by this prosthesis is much greater when compared to LPF.

However, no prosthesis is completely perfect and limitations of the prosthesis described in this case report lie in the esthetics. Since restoring functionality is the prime objective of this prosthesis, a complete silicone over-sleeve cannot be fabricated, as it was found to hinder smooth functioning of the prosthesis. Hence, a decision to process silicone in sections was taken. Newer, thinner sheath materials will provide a scope for further enhancement in this regard.

To activate the finger, the patient has to move their finger stump in a downward direction and or flex their wrist, which would result in flexion of the finger prosthesis. Relaxation of the wrist results in the prosthesis attaining an extension position. This particular prosthesis has a tension-driven

Figure 6: Trial of prosthesis (a). Demonstrations of movement (b) and prosthesis function (c)

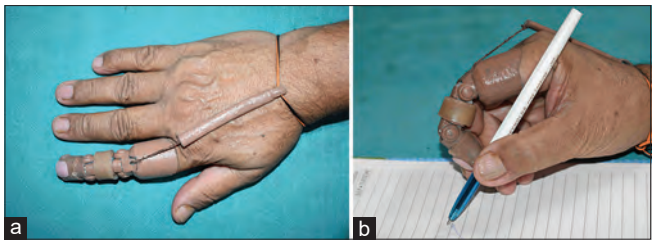

Figure 7: Final prosthesis fit after customization of three-dimensional–printed components and silicone sheath application (a). Customized three-dimensional–printed prosthesis in function (b)

voluntary closing mechanism, which is activated upon flexion of the stump and/or the wrist. The movement is activated when the thread attached to the linkage detects a tug. Now, since the linkage is anchored to a bracelet tied to the wrist, it transmits pulling forces to the string attachment and sets the prosthesis into motion. Initially, the string attached to linkage tugs onto the tip knuckle, which rotates to almost 30°, after which the base knuckle also gets activated. Base knuckle gets activated because the force vector through the prosthesis changes from a vertical to a more angled one. After the above-mentioned stage, continued pull on the string owing to movement of the stump and/or wrist will result in increased rotation in both knuckles. As a result, the prosthesis is now rendered functional. Because of opposing tension generated by elastics positioned between the tip knuckle and middle segment, as well as the base knuckle and middle segment, when tension from the string is removed by relaxing the stump and the wrist, the prosthesis returns to its original position, thus completing the full cycle.

CONCLUSION

Functional disability caused by loss of finger can be overcome by this prosthesis to a large extent as this prosthesis can replicate flexion and extension like an anatomical finger. It provides the patient with psychological and functional advantages. Another advantage is the time saved in making an impression and casts for the same. This functional prosthesis can only be used in patients with missing middle phalanx. If the middle phalanx is present this prosthesis cannot be fabricated. However, in conducive cases, this prosthesis can be very helpful.

Acknowledgment

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Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient has given his consent for his images and other clinical information to be reported in the journal. The patient understands that his name and initials will not be published and due efforts will be made to conceal identity, but anonymity cannot be guaranteed.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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Brief Communication

Magnetic resonance imaging investigations in patients with metallic dental prosthesis: "The associated dilemma for medical fraternity and the dentist's role"

Ritika Bhambhani, Santanu Sen Roy[1], Shubha Joshi[2]

Departments of Prosthodontics and [1]Public Health Dentistry, Gurunank Institute of Dental Sciences and Research, Kolkata, West Bengal, [2]Department of Prosthodontics, Krishna Institute of Medical Sciences, Karad, Maharashtra, India

Abstract

Background: Interdisciplinary referrals for dental examination in hospital setups are common before radiotherapy, kidney transplants, or magnetic resonance imaging (MRI). The patients who walk in could be random patients with metallic or porcelain-fused-to-metal prostheses done elsewhere but might require an opinion before the MRI. This leaves quite a responsibility on the consulting dentist to green signal the procedure. There is a lack of evidence in the literature, to confirm the absence of any untoward consequence during such MRI, which might leave the dentist in dilemma. Dental materials' magnetic behavior raises concern regarding whether they are 100% nonferromagnetic; furthermore, the examining dentist might be unaware of the metal used (Co-Cr, Ni-Cr, or trace elements). Clinicians may also come across full-mouth rehabilitated patients with multiple crown–bridge prostheses or metallic superstructure for implant prostheses. Research in the area leaves many unanswered questions because most studies have evaluated artifacts during MRI and are *in vitro*. Titanium is considered to be safe due to its paramagnetic behavior, whereas the literature does not rule out the probability of dislodgment of other porcelain fused to metal (PFM) prostheses. Due to less reported literature there exists dilemma to ascertain MRI in these patients. An online Google Search, PubMed, and gray literature portray the ambiguity associated with metal and PFM crowns and their magnetic behavior during MRI. Most studies were associated with the artifacts caused during MRI and methods of reducing them under *in vitro* situations. The concern for dislodgment has also been expressed in a few reports.

Technique: Certain steps of a pre-MRI checkup and an innovative technique have been discussed to assure patient safety during the MRI.

Conclusion: The technique explained is inexpensive and a quick aid that can be executed before the investigation.

Clinical and Research Implications: There is a need to study and understand the magnetic behavior of Co-Cr and Ni-Cr crowns in the presence of various MRI strengths.

Keywords: Artifact, diamagnetic, dislodgment of a dental crown, ferromagnetic, metal crowns and magnetic resonance imaging, paramagnetic

Address for correspondence: Dr. Ritika Bhambhani, Department of Prosthodontics, Gurunank Institute of Dental Sciences and Research, Kolkata - 700 114, West Bengal, India.
E-mail: ritikabhambhani@yahoo.co.uk

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INTRODUCTION

Materials used in dental practice have varied magnetic susceptibility, in the magnetic field of magnetic resonance imaging (MRI). Porcelain-fused metal and metallic prostheses (Ni-Cr and Co-Cr with trace elements such as Mo and Be) have proven clinical success over many decades but are sometimes a concern in a situation where an individual needs to get an MRI for diagnosis and disease follow-up. The paraphernalia of MRI works by creating strong magnetism and high radiofrequency pulses, magnetizing all substances to some degree under the magnetic field.[1,2] Depending on their magnetic susceptibility, all dental materials can be classified into three main categories [Table 1].[1-6]

The main concerns that can occur during the MRI of a patient with a dental prosthesis could be artifact creation, heat production, and/or risk of displacement. Due to the differences in the field strength at the interface of dental materials and the adjacent tissue, there occurs a signal loss producing some artifacts or a black image. This might not have any underlying anatomical or pathological cause, but it reduces the image's readability.[3] Dislodgment or displacement can cause life-threatening accidents and could become the reason for the denial of the MRI. Artifact creation on the diagnostic image and its severity would depend on the composition, shape, and position of the prosthesis along with the location of the tissues of interest. The loss of legibility could be more in head-and-neck MRI or when imaging paranasal sinuses, in the presence of metallic prostheses. The more the distance between an appliance or externally implanted device and the desired location to be imaged, the lower the distortion. The artifact is more in an area of 10 cm around the object concerned.[7] Diamagnetic substances cause minimal artifacts. Precious metals like gold–palladium alloy are more conducive and cause less heterogeneity of the radiofrequency field; on the contrary, stainless steel (SS) is less conducive and may render the image undiagnostic.[8] Pure titanium alloy would produce mild artifacts compared to Cr-Co and Ni-Cr alloys.[9]

Table 1: Dental materials based on their magnetic permeability properties

Type	Magnetic property	Examples
Diamagnetic	Magnetic susceptibility or χ=0 relatively inert objects in an external magnetic field	Precious metal alloys (Au, Pt, Ag, Ir, and Pd), titanium alloys, and amalgam
Paramagnetic	χ>0	Base metal alloys
Ferromagnetic	χ>>1	Some composites containing ferric oxide

Klinke *et al*. designed and reported an *in vitro* study on various filling, prosthetic, and orthodontic materials; 13 out of 44 commonly used dental materials were found to produce artifacts in MRI contrary to 41 out of 44 in computed tomography (CT). The authors concluded the metal-based restoration materials to have a stronger influence on CT compared to artifacts in MRI.[10] Coloring agents used in composites contain some elements such as ytterbium trifluoride and lanthanum oxide which were found to be the cause of artifacts in both MRI and CT. Technique variations such as the spin-echo and fat-suppression protocols, low magnetic field strength (1.5 Tesla vs. 3 Tesla), small field of view, and high-resolution matrix could be applied to lessen these artifacts.[11-14] Sumner *et al*. mention little-known effects of the preformed SS crowns but found SS crowns to become more magnetic when cold worked.[7] The decision to remove brackets/another prosthesis would depend on the composition and desired anatomic location to be imaged.[11] The quest for more MRI-compatible materials led to newer crown–bridge materials such as carbon fiber-reinforced epoxy resins and polyether ether ketone.[15] MRI strengths used in medical research settings range from 0.064 to 8 T. Materials preferred in such settings should be MRI safe/MRI compatible, where "safe" is the one which produces the least artifacts and has no risk of translational movement (measured by torque deflection angle test). Most of the concerned researches have utilized *in vitro* tests under 1.5 or 3 T. Higher Tesla settings have not been reported in collaboration with the effect on dental materials. A need for a waiting time period after the dental implant placement, before which MRI could be safely conducted needs to be evaluated and specified.[16] There is a mention about the possibility of extensive dental hardware or prosthesis being a reason for a patient's ineligibility for MRI, by Sinkiewicz. The author reported a patient where MRI had to be stopped due to a possible hazard resulting from a sensation (to the patient) of the crowns being pulled out. The crowns were reported to have a nickel content of 82% as evaluated later. There is a need for careful evaluation before MRI in situations with metal devices such as pacemakers and defibrillators, aneurysm clips, cochlear implants, insulin pumps, vascular stents, and artificial joints.[17] Altering the field strength or MRI technique would reduce artifacts, but in a rare scenario, an MRI scan might not be permissible due to the risk of device dislodgment (like aneurysm clips) or malfunction (as is possible in pacemakers). Bryll *et al*. conducted a study at 1.5 T observing artifacts but reported no dislocation.[18]

American standards of testing materials under magnetically induced deflection (ASTM F2052-06) elicit that if the external prosthesis or medical device gets exposed to a

magnetic field and shows deflection lesser than 45°, then the force is no greater than that imposed by the earth's gravitational field. However, deflection angles more than 90° with deflection forces of 0.03–0.3 N were found for some dental attachments (castable alloys/removable partial dentures) during 3 T MRI and could present risk. Even in the former, complete safety could be uncertain due to factors such as degradation of the luting cement and fatigue cycles.[2,19-21] The retention force of luting cement (48–150 N) was reported as strong enough to prevent prosthesis dislodgment. A deflection of 18° for the Co Cr alloys, 13.5° for Ni Cr, 5°–6.5° for the implant samples, and 90° or more for magnetic attachments, were recorded under magnetic fields produced by 7 T MR imager. No apparent translational attraction was reported but cautioned, especially when 7 T was used. Miyata *et al.* mentioned the need for the removal of the magnetic keepers and the cast magnetic alloy coping even under 3 T.[20,22,23]

Some heat changes have been reported in orthodontic cases but not with prosthetic crowns. The temperature rise has been considered insufficient to cause any damage to periodontal tissues. If most of the artifacts can be reduced by certain technical considerations, then in such a situation, any displacement could still remain a concern, especially in a random patient when one is unsure of metal content/percentages. The magnetic field force could result in a passive displacement, a projectile incident or injury or discomfort to the patient during the procedure. The risk involved affects the decision of the radiologists while preparing the MRI. A dental checkup before the MRI would need the dentists' decision on further proceedings. The removal of multiple prosthetic units could be time-consuming, also a financial burden for the patient, and a loss of credibility of the age-old materials used in practice.

The technique proposed here is to negate this fear of dislodgment during the MRI by holding the prostheses or dental components in place. Some authors have mentioned the use of a mouthpiece as a spacer for avoiding backscatter and other prototypes of field correcting devices.[24,25] The MRI safe splint is an innovative technique and is helpful to assure safety during the MRI, it can be advised and fabricated during the pre MRI dental examination.

TECHNIQUE

A pre-MRI dental examination should include an evaluation of the prosthesis material, retention, location, and the number of units involved. Removable partial dentures can be removed, but the concern exists with the prosthesis of cast alloys and orthodontic brackets. The material composition (zirconia, composites, or PFM crowns) is noted and so are details of the crowns with faulty margins or poor retention. If so they can be removed before MRI and refabricated later; keeping the patient informed. However, if the decision to retain the crowns is made, then the following device could help to further negate the fear of displacement. A discussion with the MRI technician would be helpful, and it would let them know the location of prosthesis present.

MAGNETIC RESONANCE IMAGING SAFETY GUARD

A closed mouth technique is used to make a putty addition silicone impression, recording both the upper and lower arches in one record. Once set, the convenience of reinserting is confirmed, if the need arises any overextended margin or extensions into deep undercuts can be trimmed. The patient is taught to wear and remove it. A "↑" marking for "this way up" could make it easier for the patient to understand which way to wear and can be marked on the upper labial border of the guard. The patient is instructed to wear the guard and bite onto it while the MRI is done [Figure 1].

In the case of the orthodontic treatment, wax spacers can be used before molding the putty material. After the MRI is done, the crowns can be examined again for any loosening and the needful can be done. The putty impression would hold on to the prostheses within its intaglio surface, and while the patient bites onto the putty guard, there is no risk of dislodgment of any prosthetic unit. After the MRI is over, the putty guard is to be carefully removed and re-examined for any changes or loosened crowns.

DISCUSSION

The main aim of the technique is to avoid a time-consuming and invasive process of prostheses removal before the

Figure 1: Magnetic resonance imaging safety guard

MRI and at the same time make it safer for the patient. Reduction of artifacts by up to 78% could be achieved by various methods by the concerned staff of radiology. The advantages of using this guard are its easy fabrication, readily available materials, and simple and inexpensive procedure. It can be prepared immediately before the MRI procedure in a short period. It is quite an economical procedure as it requires no special equipment.

CONCLUSION (FUTURE IMPLICATIONS)

Protective splint aids the process of MRI for patients with metallic prosthesis/dental materials to nullify the risk of any displacement because artifacts can be minimized by other protocols. Furthermore, this technique would make the investigative procedure safer for the patient and the removal of multiple or long-span metallic prostheses could be avoided.

With the inception of dental MRI, there would be a shift of materials to MR-safe materials. The effect of the microstructure of dental alloys on magnetic properties is an area that has scope for interdisciplinary research. The use of metal ceramics is very common in most developing nations and hence this technique can aid in the safety concerns of the MRI.

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Conflicts of interest
There are no conflicts of interest.

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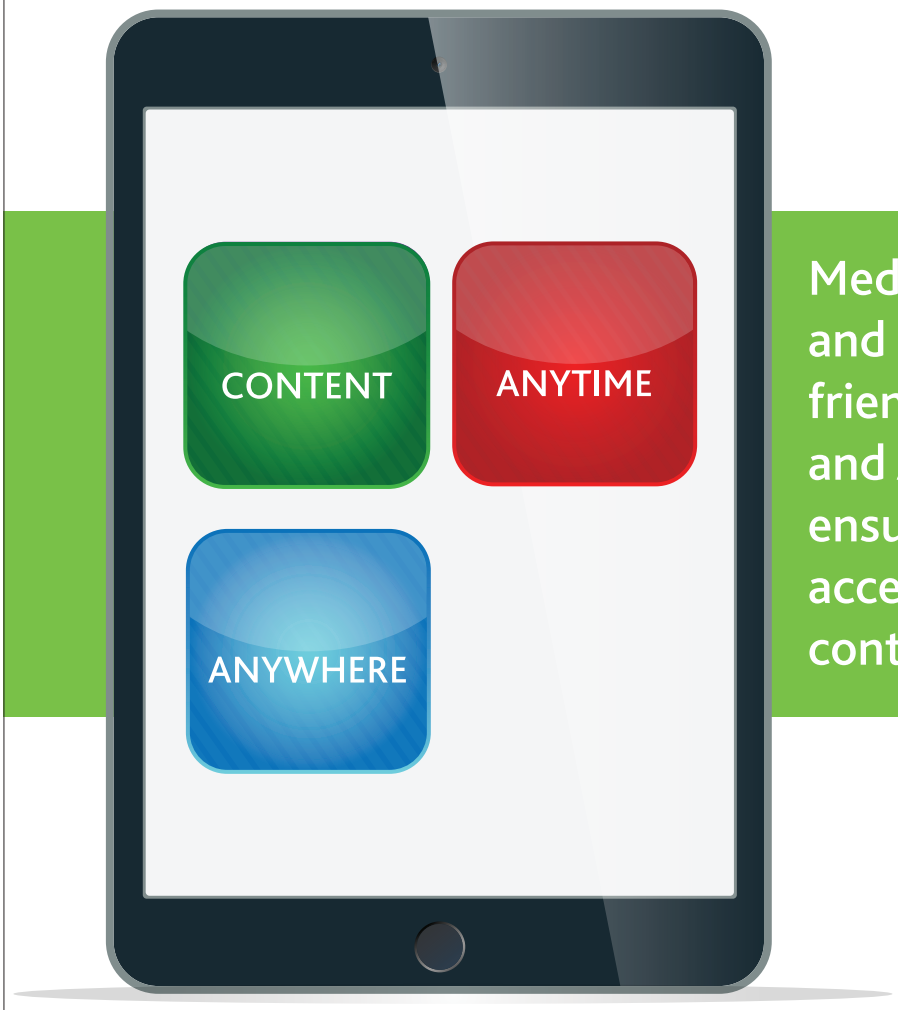

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