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AN IN VITRO RESEARCH EXAMINED THE RETENTION OF METALLIC AND NON-METALLIC DOUBLE CROWN RETAINED MANDIBULAR OVERDENTURES ON IMPLANTS

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Abstract
Purpose: To evaluate the change in the retention of novel metallic and non-metallic combinations for double-crown-retained mandibular overdentures on implants.

Methods: Cylindrical bases were used to insert four implants arranged in an arch, with 10 mm inter-implant spacing anteriorly, and 35 mm posteriorly. Five groups (n = 8 each) of different materials combinations were tested for retention: zirconia abutments/PEEK framework (ZP), PEEK abutments/ PEEK framework (PP), titanium abutments/PEEK framework (TP), titanium abutments/CoCr framework (TC), and titanium abutments/gold copings/cobalt-chromium framework as the control group (TG). The abutment retention height was 4 mm with 1° convergence angle.

Results: The initial median retention of all groups ranged from 10.0 to 33.3 N. After 10,000 insertion/separation cycles, the median retention ranged from 10.3 to 35.0 N. The change in the retention after 10,000 cycles was not statistically significant within groups ZP and TG. For groups PP and TP, there was a slight increase in retention with partial significance. The retention of group TC showed fluctuation with a partially significant decrease in retention.

Conclusions: The use of novel metallic and non-metallic combinations in the construction of double-crown-retained mandibular overdentures on implants resulted in acceptable levels of retention and might be recommended for clinical application.

Keywords: Double-crown-retained mandibular overdentures; PEEK frameworks; Retention; Wear.

INTRODUCTION

For prosthetic rehabilitation, recent studies advise using double-crown-retained removable prostheses with natural teeth and/or implants [1]. Double-crown attachments have the advantage of offering sufficient stability and retention with good mastication and better phonetics. Notwithstanding these benefits, making double-crown-retained detachable prostheses is time-consuming, expensive, and technically challenging. Additionally, there is a chance that retention will deteriorate over time because to the mechanical wear of the abutments and copings [2–6].

Different crown tapers, heights, materials, and friction between the axial walls of the inner and outer crowns all affect how well double-crown-kept prostheses are retained [7–10]. The retention, however, may deteriorate over time as a result of wear amongst the materials [8]—which may be an abrasive or adhesive wear [11].

Double-crown wear is a typical issue that may require the replacement of the prosthesis [12, 13]. The most appropriate material to employ in the construction of double-crown restorations has been deemed to be gold alloys [14]. This is explained by the fact that gold has a low coefficient of wear, which contributes for the prosthesis's ability to maintain sufficient long-term retention [7, 15]. Tests in the laboratory revealed that an electroplated system had a stronger retention force than a cast one [12, 16]. Unfortunately, the therapeutic usage of gold is steadily reducing as a result of the sharp increase in price. Gold's biocompatibility could also make it difficult for it to combine with other metals in the mouth cavity [17].

Table 1-Different material combinations of the study groups.

Type	**Test groups**				**Control group**
	Group ZP $N = 8$	Group PP $N = 8$	Group TP $N = 8$	Group TC $N = 8$	Group TG $N = 8$
Abutment material	Zirconia	PEEK	Ti alloy	Ti alloy	Ti alloy
Outer coping material	PEEK	PEEK	PEEK	CoCr	Gold electroforming/bonded to CoCr framework
N: number of specimens.					

Practitioners and manufactures are looking for less expensive, more aesthetically pleasing, and biocompatible replacements that can offer double-crown-retained overdentures with equivalent accuracy and long-term retention. Zirconia is a non-corrosive substance that is more biocompatible than gold and has a colour that is similar to that of teeth. Engels et al. came to the conclusion that the materials utilised for double crown systems show a considerable influence on their retention in this regard [18]. In comparison to combinations of gold/gold and titanium/titanium, electroplated secondary copings on zirconium main crowns demonstrated improved prosthesis retention and reduced wear [19, 20]. Zirconia/electroplated double-crown retained removable prostheses had a similar 3-year survival rate to cast cobalt-chromium/electroplated double-crown retained removable prostheses in a clinical investigation [21]. A semi-crystalline thermoplastic polymer with good mechanical properties is polyetheretherketone (PEEK). The chemical structure of poly-aromatic ketones provides; stability at high temperatures exceeding 300 °C, easy processing, high stiffness, and chemical stability. PEEK is also radiation-resistant and compatible with a variety of reinforcing materials, including glass and carbon fibres. For patients who are allergic to titanium, PEEK-based dental polymers may offer an alternate choice for a unique range of metal-free crowns and implant abutments [22]. When compared to zirconia or titanium abutments, PEEK implant abutments showed equal to lower values of biofilm development [23]. Therefore, the construction of the abutments and the framework of the double-crown-retained overdentures may benefit from the use of thermoplastic materials [24]. Alternative components for double-crowns include various metals and titanium as well as base metal alloys. Nevertheless, there is a demand for non-metallic substitutes due to known sensitivities to some of these metals. Some patients showed sensitivity to nickel and to a lesser extent also to cobalt [25]. Although titanium is a bio- compatible metal, it may cause inflammatory reactions

in approx- imately 0.6% of patients [26, 27].
Zirconia, polyoxymethelyene (POM), polyetheretherketone (PEEK), and polyetherketoneketone (PEKK) are non-metallic substitutes. However, there is no evidence accessible [28] about the retention durability of these substitute materials for double crowns. To find the ideal restorative material combination for double-crown-retained overdentures on implants, the effects of various material combinations, as well as the number of insertion/removal cycles, were evaluated in the current study. The null hypothesis of the research was that neither the number of insertion/separation cycles nor the various combinations of the examined elements would have an impact on the retention of the substances being studied.

METHODOLOGY

The investigation was conducted using cylinder bases manufactured of polyvinylchloride (PVC) material (Richter, Kiel, Germany) at the Department of Prosthodontics, Crown & Bridge, School of Dental Sciences, Sharda University, Greater Noida. Four 12 mm long implants were positioned parallel to one another in an arch, replicating the clinical situation of repairing an edentulous mandible, with an anterior inter-implant spacing of 10 mm and a posterior arch width of 35 mm. The distance between the anterior and posterior implants' fulcrum lines was 10 mm. The sites that had been developed simulated the mandibular inter-foraminal region at the first premolar and lateral incisor locations. The lateral incisor implants had a diameter of 3.5 mm, while the premolar implants had a diameter of 4 mm. to ensure that all implant positions are uniform for all specimens, a metal template was constructed. The implants were attached to the PVC bases using a BisGMA based temporary crown and bridge material (Luxa Temp, DMG, Hamburg, Germany). Retentive holes were pre- pared within the PVC bases using a round bur before inserting the BisGMA. The retentive holes were made in different angled levels to maintain the stability of the implants within the PVC bases during the test.

2.1. Study groups

Five different groups of eight specimens each were constructed (Table 1). Group ZP; zirconia abutments (KATANA Zirconia, HT High Translucent, Kuraray Noritake Dental, Tokyo, Japan, LOT DMZHE)/PEEK framework (Bio HPP for2press, Bredent, Senden, Ger- many, LOT 439061). Group PP; PEEK abutments (bre CAM. Bio HPP, Bredent, LOT 439876)/PEEK framework. Group TP; titanium al- loy abutments (SKY prefab titanium, Bredent, LOT 445342)/PEEK framework. Group TC; titanium alloy abutments/CoCr alloy frame- work (Tizian Blank NEM 98 mm, Schütz Dental GmbH, Rosbach, Germany). Control group TG; the abutments were constructed from titanium alloy and the outer copings were electroformed with pure gold copings (Gramm GES Electroforming System, GAMMAT optimo2, Gramm Technik, Ditzingen-Heimerdingen, Germany) and bonded to cast CoCr framework (WIRONIUM, Bego, Bremen, Ger- many).

The abutments (main copings) were developed and built using CAD software (Dental Designer-Premium 2013, 3Shape, Copenhagen, Denmark) and a CAM system (Zenotec select hybrid, Wieland Dental + Technik, Pforzheim, Germany) to standardise their dimensions. The abutments have conical crowns with a 1degree taper. The finish line's width was 0.8 mm, and the abutments' length was 7 mm with a retention height of 4 mm. They were then machined from zirconia, grade 5 titanium alloy, and PEEK materials. Additionally, the zirconia abutments were sintered in accordance with the guidelines provided by the manufacturer.

2.2. Fabrication of the abutments

After being precisely aligned with the implants, the milled titanium alloy abutments were tightened with a torque of 25 Ncm. Ti-bases (SKY uni. fit CAD abutment incl. screw, Bredent, LOT 443385) were placed on the implants in the proper alignment and fastened with a torque of 25 Ncm. Following using a primer layer to condition both the zirconia and the titanium, MKZ-Primer (Bredent, LOT

201160), a dual-cure composite adhesive cement, was used to adhere the zirconia and PEEK abutments to the Ti- bases in accordance with the directions provided by the manufacturer. Utilising the PEEK-specific primer (Vi- sio.link, Bredent, LOT 154931), the PEEK abutments were condition.

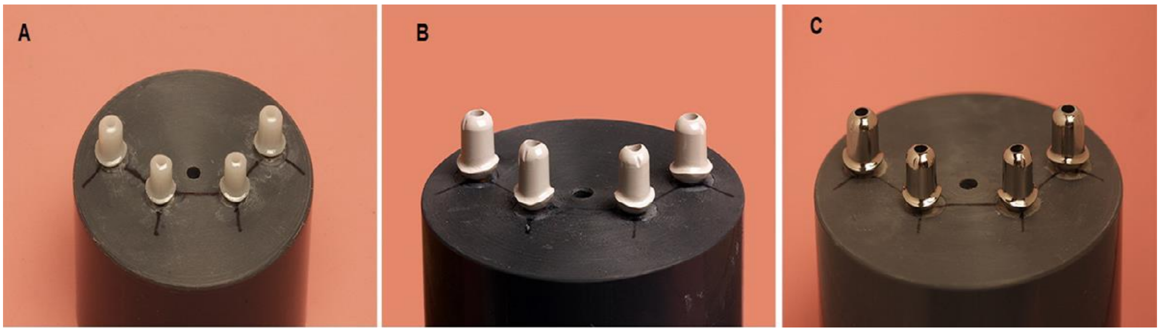

Fig. 1. Finished and polished abutments; A: Zirconia, B: PEEK, C: Titanium

Fig. 2. Steps of construction and testing of the PEEK frameworks; A: The wax pattern fixed in the investment mold; B: Pouring of the investment material before placement into the furnace; C: The mold containing the melted BioHPP in the pressing unit; D: The remaining investment material removed by air-abrasion; E: The specimen fixed and tested for retention in the chewing simulator.

Fabrication of the secondary crowns

The experimental groups' secondary PEEK copings were directly waxed over the abutments to form a framework with a thickness of 0.8 mm. Sprues 2.5 mm in diameter were utilised to join the central sections of the coping. To enable fixation in the testing machine (Sprue channel, Bredent), sprues of 4 mm diameter were employed to link the top of the copings to a loop at the meeting centre point of the top sprues (Fig. 2 A). Then, in accordance with the manufacturer's instructions, the ceramic reinforced PEEK (Bio HPP, Bredent) was invested and injected into the waxed frameworks using the For2Pressmachine (Bredent). The residual investment material was removed by air-abrasion with the devested pressed frameworks with 110 µm alu- mina particles at 2.5 bar pressure. Thereafter, the frameworks were adapted to their corresponding abutment-model and finished using cross-cut burs (Fig. 2 D). To make sure that the baseline retention values of the eight samples in each group would be reasonably near to one another, the retention of the PEEK frames for each testing group was measured using an all-purpose testing machine (Zwick Z010, Zwick GmbH, Ulm, Germany). Similar to the PEEK frameworks, the CoCr frameworks (Tizian Blank NEM 98 mm, Mani Schütz Dental) were created utilising CAD/CAM technology. A haptic scanner (Renishaw Scanner DS 10, Schütz Dental GmbH) was used to scan the abutments (Fig. 3).

Fig. 3. CoCr framework.

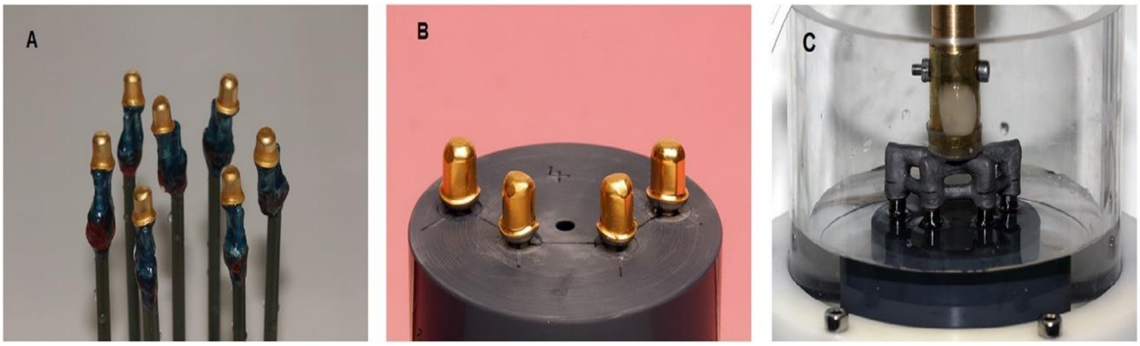

Fig. 4. Some steps of constructing and testing of TG group specimens; A: The titanium abutments with gold copings on rods after the electroforming process; B: The titanium abutments with gold copings on the PVC base; C: A specimen of TG group with the CoCr framework tested by the chewing simulator.

To withstand the electroformed gold copings, the cast CoCr frameworks (Wironium) were constructed in accordance with the same design as the PEEK frameworks. To provide a passive fit and to make room for the adhesive luting resin, a 0.1 mm space was allowed among the frames and the copings. Following the manufacturer's directions, the secondary copings were attached to the framework using DTK-adhesive after being condition- ed with a 1:1 mixture of MKZ Primer and activator (MKZ EM-Activator, Bredent, LOT 201161). While the CoCr frameworks were subjected to air abrasion with 110 m alumina particles at 2.5 bar pressure before being prepared using the MKZ Primer.

Measurement of the retention force

Each specimen underwent 10,000 insertion/separation cycles in the chewing simulator equipment (SD Mechatronik, Feldkirchen-Westerham, Germany), which is equivalent to about 10 years of removing and re-putting in the denture three times each day. In order to imitate the damp intraoral circumstances and remove wear remnants from the friction area, the specimens were submerged in deionized water during the test (20 °C 2 °C). In the current study, an axial load of 98 N was applied at a speed of 7 mm/sec to guarantee that the overdentures frameworks were completely seated on the matching abutment prototypes. The dislodging force's orientation was changed to run parallel to the path of insertion. The maximum retention force value was recorded for each separation cycle, using force transducers (Typ U9C, Hottinger Baldwin Messtechnik, Darmstadt, Germany) and the recording software (DIAdem, GFS Systemtechnik, Aachen, Germany). The data was tabulated and statistically analyzed after 0, 100, 200, 300, 400, 500, 1000, 2000, 3000, 5000, 8000, 10,000 cycles and the retention of the specimens were analyzed. For each interval, five surrounding measurements were used to calculate the mean value, which represented the mean retention at the corresponding interval.

Statistical analysis

Medians and means with standard deviations (SD) were used to report the results. The Shapiro-Wilk test was used to check whether the data had a normal distribution. To compare the median retention values at various cycles within each test group, the non-parametric Friedman test and Dunn-Bonferroni post-hoc test were used. The equality of variances among the test groups was evaluated using the Lev-ene test. Additionally, to evaluate the retention forces across the test groups at various cycles, one-way ANOVA and a Games-Howell post-hoc test were employed. The threshold for statistical relevance was set at p 0.05. IBM SPSS Statistics for Windows, Version 22.0 (IBM Corp. Armonk, NY, USA), was used to conduct the statistical analyses.

Results

Table 2 displays the retention values across all test groups at various time points. All groups' initial median retention varied from 10.0 to 33.3 N. The median retention varied from 10.3 to 35.0 N after 10,00,000 insertion/separation cycles. For 95% of comparisons within the tested groups at various cycles intervals, the Shapiro-Wilk tests revealed no deviation from the assumption of normality. Only three out of sixty comparisons, or 5%, were not evenly distributed. The Friedman test revealed that among the ZP and TG groups, the change in retention forces after 10,00,000 insertion/separation cycles was not statistically significant ($p > 0.05$). However, there was a minor initial improvement in retention within groups PP and TP, which was partially due to significant at the first 10 0 0 cycles ($p \leq 0.05$). Only within group TC, the retention showed fluctuation at the beginning, followed by partially significant continuous decrease of retention. Fig. 5 shows how the retention of all groups changed during 10,00,000 insertion/separation cycles. Dunn-Bonferroni post-hoc analysis of pairwise comparisons demonstrated a substantial increase in retention for group PP at the 10, 20, 30, and 80 cycle points. At 500 and 10 0 0 cycles, there was a sizable rise for group TP. There was a distinction within group TC between the retention decreasing at both 80 0 0 and 10,0 0 cycles and the retention increasing at 20 0 and 10 0 cycles.

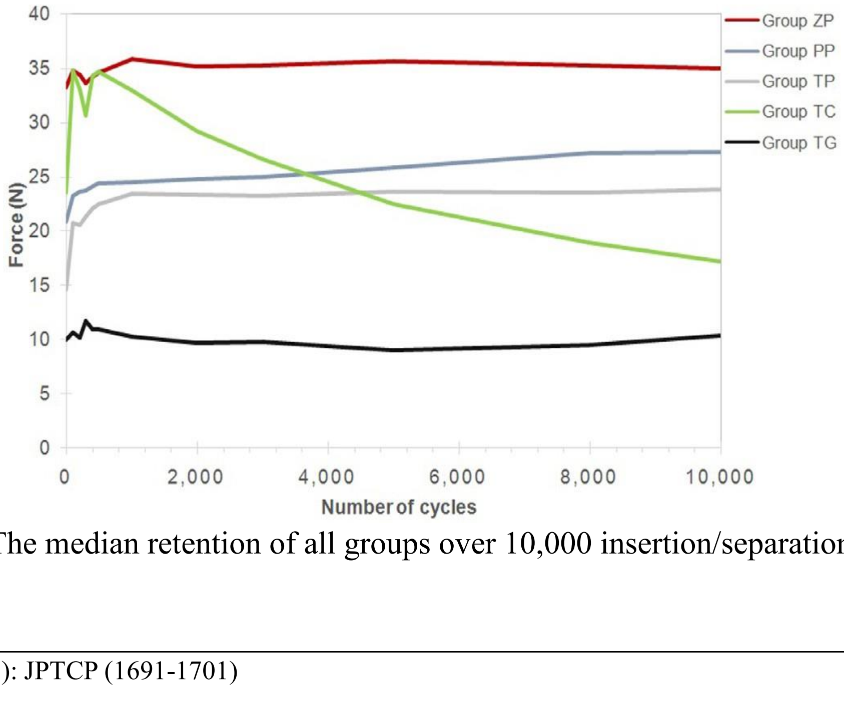

Fig. 5. The median retention of all groups over 10,000 insertion/separation cycles.

Table 2 -Median, mean, and standard deviation of prosthesis retention in Newton after different insertion separation cycles for all groups. Statistically different medians ($p \leq 0.05$) are indicated by different lower-case letters (within a column for the same group according to the Dunn-Bonferroni post-hoc test) or by different upper-case letters (within a row for the same number of cycles according to the Games-Howell post-hoc test).

Cycles	ZP	PP		TP		TC		TG
	Median Mean (±SD)	**median**	**Mean (±SD)**	**median**	**Mean (±SD)**	**median**	**Mean (±SD)**	**Median Mean(±SD)**
0	33.3 33.1	20.8	21.5	14.6	14.5	23.5	24.4	10.0 11.0
	a, A (6.7)	b, B	(4.1)	c, B	(5.7)	ab, AB	(10.0)	a, B (8.4)
100	34.8 34.3	23.3	24.6	20.7	22.1	34.8	32.3	10.6 10.9
	a, A (6.1)	ab, B	(5.2)	bc, BC	(6.7)	ab, AB	(12.0)	a, C (8.0)
200	34.4 33.7	23.6	25.2	20.5	22.8	33.0	36.3	10.2 10.7
	a, A (4.5)	ab, B	(5.0)	abc, B	(7.0)	a, AB	(11.7)	a, C (8.3)
300	33.7 33.2	23.7	25.6	21.3	23.5	30.6	37.5	11.7 10.8
	a, A (4.1)	ab, B	(5.1)	abc, B	(6.7)	a, AB	(16.1)	a, C (8.0)
400	34.2 33.5	24.1	25.8	22	24.0	34.3	37.3	10.9 10.6
	a, A (4.0)	ab, B	(5.0)	abc, B	(6.7)	a, AB	(14.3)	a, C (8.0)
500	34.6 34.0	24.4	25.4	22.4	24.3	34.7	37.9	10.9 10.5
	a, A (3.9)	ab, B	(3.7)	ab, B	(6.7)	a, AB	(13.8)	a, C (8.1)
1000	35.9 34.6	24.5	26.2	23.4	26.4	33	35.7	10.3 10.5
	a, A (4.1)	a, B	(4.8)	ab, B	(5.9)	a, AB	(13.5)	a, C (8.4)
2000	35.1 35.6	24.8	26.6	23.4	25.2	29.2	32.3	9.7 10.4
	a, A (6.1)	a, B	(5.2)	ab, B	(6.5)	ab, AB	(11.2)	a, C (8.8)
3000	35.3 35.8	24.9	26.7	23.2	25.3	26.6	29.7	9.7 10.6
	a, A (7.1)	a, AB	(5.2)	ab, B	(6.4)	ab, AB	(11.1)	a, C (8.8)
5000	35.6 35.9	25.8	26.2	23.6	25.4	22.5	25.8	9.0 10.7
	a, A (7.4)	ab, B	(4.0)	ab, AB	(6.3)	ab, ABC	(10.8)	a, C (8.9)
8000	35.2\ 35.3	27.2	26.6	23.5	25.3	18.9	21.2	9.4 11.3
	a, A (6.4)	a, B	(3.1)	ab, B	(6.0)	b, ABC	(10.7)	a, C (9.5)
10,000	35.0 35.2	27.3	26.6	23.8	25.5	17.2	19.7	10.3 11.6
	a, A (6.1)	ab, B	(3.6)	a, B	(5.9)	b, BC	(8.9)	a, C (9.6)

At various measuring cycles, the Levene test revealed heterogeneity in the variances among the test groups. When comparing all test groups at various cycles, the one-way ANOVA test revealed significant variations in the retention force (Table 2 summarises the findings of the non-parametric Games-Howell post-hoc test). As a result, group ZP's median retention force was much higher than those of groups PP, TP, and TG. Among groups PP and TP, there was no statistically significant difference. Except for when compared to group TC at high cycle numbers and to groupings PP and TP at first, group TG exhibited significantly worse retention than the other groups. In contrast to the other groups, except for group TG at the low number of cycles, group TC displayed substantial variation.

Discussion

The clinical scenario of a double-crown-retained overdenture on four implants was modelled in the present investigation. The majority of laboratory investigations have examined the retention of various double crown systems using just one retainer while measuring various parameters [9, 19, 29-31]. Nevertheless, 4 implants are typically advised as a minimum number of implants for a double-crown-retained overdenture in order to ensure longitudinal and stable retention [32]. The testing machine's pulloff direction was perpendicular since the secondary crowns were set up parallel to it. Preload of 98 N and pull off speed of 7 mm/sec were chosen as an agreement between values taken from well-known clinical testing and potential technical conditions. The reported chewing force and maximal bite force in patients with implant-supported overdentures was 50 N and 144 N, respectively [33]. In order to further examine the impact of the taper and space settings of tapered double-crowns on retention and settling, two sets of the load, 50 and 100 N, were used [34]. We chose the preload applied to the outer framework in the current investigation based on the cumulative reported data. Similar studies [3, 12, 19] shown a relationship between prosthesis removal speed and retention because of the hydraulic system of the electroplated conical crown. A speed of 7 mm/sec was determined based on both our initial pilot investigation and their findings. Additionally, it has been demonstrated that an almost constant level of retention force was obtained after 50 0 0 cycles of insertion and separation [4] and that 10,0 0 0 cycles are optimal for major changes in retention to occur. To replicate the moist intraoral circumstances, the specimens were submerged in water at room temperature. Additionally, the moist conditions made sure that worn items outside of the friction area were removed [16, 18, 19, and 37]. Additionally, a medium was needed between the primary and secondary crowns during the electroforming technique to aid in constructing hydraulic adhesion there [29]. To ensure the necessary solidity of the electroformed secondary crowns, they were attached to a supporting metal framework secondary crowns [18]. The abutments in the current inquiry were created and completed with a 1°taper. The maximum retention was attained with a 1degree taper in a recent study that looked at taper of 0 degrees, 1degrees, and 2 degrees [38]. In addition, establishing good retention of double crowns requires a very delicate and exact process that depends on a number of factors, including milling speed, cutter wear, polishing techniques, casting technique, and manner of setting the retention force [3, 39]. The production and finishing processes in the current investigation were as uniform as possible. Additionally, the PEEK frameworks were evaluated using a universal testing apparatus to guarantee that the beginning retention values of each eight specimens of each test group. According to reports, there is a direct link between patient happiness and the prosthesis' retention [13]. The peak load, or maximum dislodging force, needs to be precisely monitored in order to assess how well the implant attachments are retained. It stands for the overdenture's resistance to being taken out of the abutments. In various therapeutic settings, choosing the right type of prosthesis is influenced by peak load. The degree of wear over the attachments' lifetime also serves a fundamental purpose in ensuring retention over time [40]. In order to assess the change in retention over 10,0 0 0 insertion/separation cycles. and determine the prosthesis retention, which is the maximum force created before the complete separation of double-crown components. The retention was lower in the electroformed control group (TG) than in the other groups. The direct manufacture of gold crowns using the electroforming method established an ideal fitment, which could be attributed to the production process [16]. Similar to this, the electroforming procedure achieves an internally smooth coping surface and does not require any manual correction [12, 20].

The material was injected and invested during the production of the PEEK frameworks. After then, it became necessary to manually modify retention force in order to lessen stress on the abutments. However, compared to the TG group, the final prosthesis retention was higher. The preservation of the electroformed crowns in a research by Engels et al. was lower than that of the cast ones [18]. In addition, supplementary cast crowns with telescoping and conical) mainly ad- here through friction and wedging, whereas galvanic crowns basi- cally adhere by hydraulic adhesion [41]. It can be assumed that the variance in values is greatly influenced by production processes as well as material dependence [28]. An upward trend in the preload force of the double crowns with secondary cast crowns was observed to be correlated with a rise in the retention force. Nevertheless, for preloads among 10 and 300 N [20], this effect was not seen for the double crowns with electroformed secondary crowns. The disparity in retention force amongst the group serving as the control TG and the other test groups in the current investigation may be explained by all of these considerations.

Depending on whether the elevated sections of the material are abraded and levelled or other areas are broken off, the degree of wear may either increase or decrease as a result of the relative movement between the surfaces of the cop- ings. The retentive forces may then change, decreasing, remaining the same, or even increasing, depending on whether the surfaces at the worn tracks interlock or not. A gap might replace the tightly wedged contact as a result of more wear, which would also lower the retentive force. The behaviour of the retentive force may still be unpredictable even though the manually generated copings were built the effect of wear [20] by the same operator using the same techniques. The mean retention enhanced during 10,00,00 insertion and separation cycles in a prior study that examined various combinations of gold, titanium, and CoCr for both inner and outer crowns [7]. This rise was most likely brought on by a mechanical modification at the point where the inner and outer crowns meet. In none of the specimens was there a long-term decline in retention force brought on by metal abrasion. Consequently, the various physical properties and wear of the different materials, as well as the finishing of the primary crowns, building of the secondary crowns, and differences in material mechanical adaptation, could explain the observed minor increase in retention in groups PP and TP as well as the slight decrease observed in group TC, and the observed higher level of retention of group ZP in comparison to other groups.

When compared to zirconia, titanium, and electroformed gold materials, PEEK double crowns displayed encouraging outcomes. PEEK could be used effectively as the primary crown, the secondary crown, or both crowns. However, these findings should only be regarded as a preliminary analysis of the PEEK material when combined with authorised materials as CoCr, ZrO 2, and electroformed crowns [24]. The goal of this research and other studies that have just been published is to determine the amount of retention required to create a functional, reliable telescopic overdenture. Further laboratory and clinical tests, as well as monitoring patient satisfaction, are required in light of the optimistic findings from the current trial.

Conclusion

Within the limitations of this laboratory study, the use of metallic and non-metallic combinations in the construction of double-crown-retained mandibular overdentures resulted in acceptable and reliable levels of retention, which might be suitable for clinical application. Long-term clinical studies are required to support the use of PEEK for double crowns.

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