Surface Wear and Retention Force of Zirconia and PEKK Implant-retained Crowns

Keywords

PEKK
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ABSTRACT

Purpose: The aim of this study was to evaluate the surface wear and retention force of telescopic attachments made of zirconia primary crowns and poly-ether- ketone -ketone (PEKK) secondary crowns for 2-implant retained mandibular complete overdentures. Materials and Methods: Ten healthy completely edentulous patients aged 55-60 years were selected for this study. Each patient received two implants in the mandibular canine regions. Maxillary conventional complete dentures were constructed against implant-retained mandibular overdentures for all patients. Zirconia- PEKK telescopic attachments were fabricated to retain the overdentures where primary copings were constructed of zirconia and secondary ones were constructed of PEKK. Retention force and surface wear were evaluated at the time of overdenture insertion (T0), and after 6 months of overdenture use (T6). Results: The results revealed less wear of zirconia copings compared to PEKK ones at T0 and T6. However, both materials showed insignificant wear after 6 months of overdenture use. A significant increase in retention force was observed after 6 months of overdenture use. Conclusion: Within limitations of this study, PEKK may be considered a promising alternative material for telescopic secondary crowns construction combined to zirconia primary ones, regarding the wear resistance and the satisfactory retention forces.

INTRODUCTION

It is well established that overdentures assisted with two inter-foraminal implants is the treatment of choice that can solve the problems of lower complete dentures lacking adequate retention, stability, and support. This is especially true after a long period of wearing the dentures with subsequent ridge resorption.[1-3] Different implant attachment systems can be used in these cases like bars, ball & socket, locator, magnets, and telescopic crowns.[4] Telescopic non-rigid attachments showed 10 years of clinical success in severely resorbed edentulous mandibles. This concept might offer benefits in terms of cleaning, handling, and long-term satisfaction. In addition, telescopic attachment is indicated over bar attachment in cases that have a pointed (V-shaped) jaw otherwise tongue space interference occurs, or in cases that showed wide inter implant distance or implants that are diagonally distributed. Telescopic attachments can provide good stability due to the resistance of their vertical walls to lateral forces.[3]

Telescopic crowns give their retention force from the frictional relationship between the primary and secondary crowns. Over time of use, tribological changes occur in the form of wear and galvanic corrosion, especially between metallic primary and secondary crowns which lead to loss of the retention forces, that considered a major problem of double crown systems.[5] In this regard, it was concluded that the materials used for double-crown systems show a significant effect on their retention.[6,7]

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Clinicians and manufacturers are looking for less expensive, more esthetic, and biocompatible alternatives that can give comparable accuracy and long-term retention for double-crown retained overdentures. Non-metallic alternative materials for double-crowns include zirconia, and poly-aryl-ether-ketone (PAEK) in the form of poly-ether-ether-ketone (PEEK) or poly-ether-ketone-ketone (PEKK).[8] Zirconia is a non-corrosive material, its color seems like the color of teeth, and it has excellent biocompatibility, wear resistance, and unique mechanical properties.[6] It has been verified as a suitable material for primary telescopic crown construction and has presented itself as a substitute for gold alloys.[9] Emera[10] concluded that all-zirconia double crown systems can be considered a biologically promoting telescopic attachment.

PAEK high-performance polymers used for telescopic crown construction showed superior results and maintenance of retention forces for a longer time,[11-13] and solved the problem of metal show through the overdenture in metallic secondary crowns.[14] The structure of PEEK polymer offers exceptional physical properties, biocompatibility, and chemical resistance. It was reported that PEEK is an appropriate material for the fabrication of telescopic attachments.[15,16]

Several studies evaluated implant telescopic overdenture made of zirconia primary crowns combined with PEEK secondary crowns and concluded satisfactory clinical and radiographic results in addition to acceptable retention forces.[13,17] However, the latest study evaluated the wear of all-zirconia, all-PEEK, and zirconia-PEEK telescopic attachments by assessing surface changes of both copings using a Scanning Electron Microscope (SEM). The highest wear values were correlated to the zirconia-PEEK group, mainly in secondary copings.[18]

PEKK (Pekkton®ivory) was introduced more recently and it stands at the apex of the PAEK family, it has high wear resistance and high compressive, flexural, and tensile strength. It is 80% higher in compressive strength than PEEK, and it has better long-term fatigue properties than unreinforced PEEK.[11] As well its mechanical strength, exceptional biocompatibility, shock-absorbing capability, and the variable fabrication techniques including milling and pressing make PEKK an attractive dental material for telescopic dentures.[19-23]

Kotthaus *et al.*,[11] lately evaluated the retention forces of PEKK secondary crowns when combined with primary crowns fabricated from four different dental alloys. They concluded that after 10,000 wear cycles, all the tested telescopic attachments reached an acceptable force for overdenture retention. In addition, they found that zirconia primary crowns showed the smallest amount of wear compared to PEKK and the gold and non-precious metal alloys.

The introduction of zirconium dioxide (zirconia) and PEKK (polyether-ketone-ketone) as tooth-colored biocompatible materials in the field of prosthodontics, with their superior physical properties and the ongoing development of CAD/CAM technology, has led to the manufacturing of metal-free telescopic attachment using these novel materials. However, limited data are available concerning the serviceability of this evolved telescopic attachment. The aim of this study was to clinically evaluate zirconia-PEKK telescopic attachment for two-implant retained mandibular complete overdenture regarding surface wear and retention force.

The initial null hypothesis was that there would be no difference in surface wear of primary and secondary telescopic crowns across different follow-up periods. The second null hypothesis was that there would be no difference in the overdenture retention force through time.

MATERIALS AND METHODS

Ten healthy completely edentulous male patients with an average age of 55-60 years were carefully chosen for this study. The inclusion criteria of the patients were the satisfactory bone quantity and quality of mandibular residual alveolar ridge as confirmed by cone beam CT, sufficient restorative space to accommodate the telescopic attachment, and normal maxilla-mandibular relation (Angle's class I). Exclusion criteria involved local inflammation and systemic diseases that restrict surgical procedures, bone metabolic disorders, history of parafunctional habits, and radiotherapy to the head and neck region

The research protocol was approved by the ethical committee of the faculty of dentistry, Mansoura University (Code NO. is 13010222)

PRE-SURGICAL PROCEDURES

Each participant received conventional complete dentures, following a lingualized occlusion scheme. A 3D surgical guide for implant placement was fabricated according to the dual-scan technique in the following steps:

1. Extraoral scanning of the prepared mandibular denture with radiopaque markers (that are used as reference points).
2. Intraoral scanning while the patient was wearing the dentures and closing in centric relation.
3. Both scans were combined for obtaining a 3D software image. The bone sites planned for implant placement were evaluated and measured for adequate thickness and height. A universal surgical kit with consecutive drill diameter sleeves and horizontal indicators was provided with the surgical guide.

SURGICAL AND PROSTHETIC PROCEDURES

The 3D printed implant placement guide was fixed intraorally for the drilling and insertion of two implants (3.5 mm diameter and 12 mm length) (Dentium Superline, Dentium, Co. Ltd., Korea) that were inserted in the mandibular canine area bilaterally.

After 3 months period of osseointegration, the cover screws were unscrewed and replaced by healing abutments for additional two weeks for peri-implant gingival healing. After that, two staged fixture-level open tray impression technique was done using a mandibular acrylic resin custom tray with two holes corresponding to each implant site as follows:

- The first stage impression was made with a medium body rubber base for recording residual alveolar ridges.
- Two Long Fixture level transfer copings were fixed to the implants and then splinted with light-cured flowable composite.
- The second stage impression was done using the light body rubber base material (Speedex, Coltene/WhaledentInc, Cuyahoga Falls, OH, USA) by injection around the splinted transfer copings to record the peri-implant soft tissues.
- Finally, the implants' analogs were fixed to the transfer copings before impression pouring. Then the implants' abutments (Dentium Superline, Dentium, Co. Ltd., Korea) were attached to implant analogs on the master cast.

CONSTRUCTION OF CAD-CAM RESILIENT TELESCOPIC ATTACHMENT

A. Primary Telescopic Crown:

The master model was scanned to obtain the 3D virtual image. Software designing of the primary copings was done while the same parameters were maintained for all patients regarding 5 mm height, vertical apical two-thirds, and 4˚ occlusal one-third tapering. An occlusal hole was designed corresponding to the implant abutment screw. The software design was transmitted to the milling machine (Sheraeco_scan3 Germany) for the milling of primary crowns from semi-sintered zirconia blocks.

B. Secondary Telescopic Crown:

Intraoral try-in of primary copings was done followed by returning them to the master cast to be scanned. The parameters of the secondary copings software design were parallel walls, 0.5 mm as a minimal thickness, and 0.3 mm occlusal space between primary and secondary copings. Proximal projections were applied to the design of secondary copings to improve their mechanical retention to the overdenture fitting surface as suggested by Emera[11] *(Figure 1a*). Finally, data were transported to the CAM program to mill PEKK (Pekkton® ivory, Cendres + Métaux SA, Biel/Bienne, Switzerland) secondary crowns.

FABRICATION OF MANDIBULAR OVERDENTURE

- Duplication of the master cast was done after indexing in the land area while the secondary telescopic crowns were attached to the primary ones.
- The produced duplicate cast with secondary copings in stone.
- Polished and occlusal surfaces of the conventional mandibular denture were duplicated using a silicone index (Coltoflax; ColteneAG, Altstatten, Switzerland). While the denture was seated on the master cast without telescopic attachment.
- Identical artificial teeth were placed in their corresponding rooms in the silicon mold and the index was relocated over the duplicate master cast.
- Molten base plate wax was poured to fill the mold cavity then the conventional flasking procedures were performed.
- Duplicate denture with relief space corresponding to the telescopic attachment was produced and ready for the intra-oral pickup step.

SECONDARY CROWNS PICK-UP PROCEDURES

Cementation of primary crowns to the implant abutments was done concerning isolation measures against excess cement. Venting holes were opened through the lingual flanges of mandibular overdenture. Secondary crowns were located over primary ones with respect to the accurate path of insertion *(Figure 1b*). An adequate amount of autopolymerizing acrylic resin (Acrostone cold cure, Egypt) was applied to the overdenture fitting surface corresponding to the location of secondary crowns. Intraoral pick-up of secondary crowns was done under light biting force. Diamond bur was used to remove the excess acrylic resin material that escaped through the venting holes.

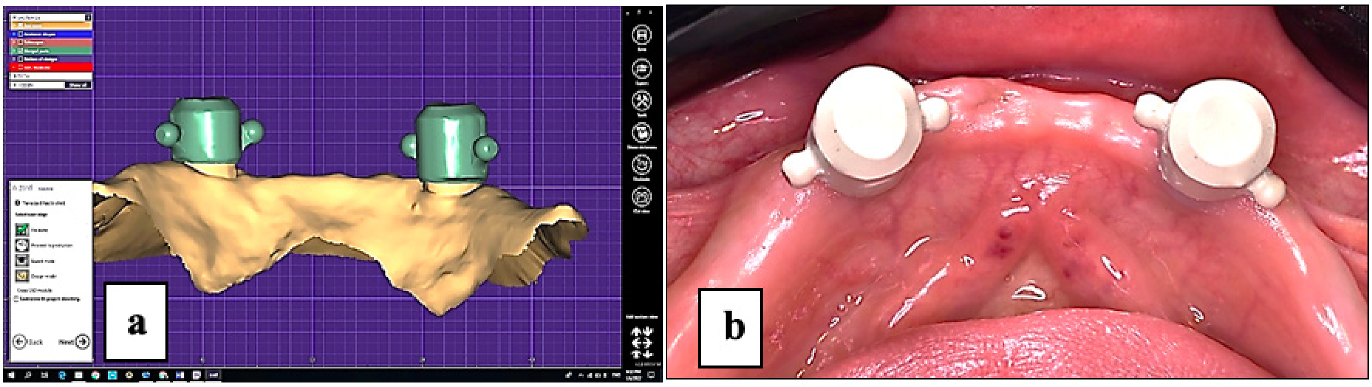

Figure 1: a) Final software design of PEKK secondary crowns, b) Accurately positioned secondary crowns over primary ones for pickup procedures.

EVALUATION

Surface Wear Evaluation:

A scanning electron microscope (SEM) was used to evaluate the surface topography changes of primary and secondary crowns. Analysis was performed at the time of secondary copings pickup (T_0) and after 6 months of overdenture use (T_6) for both copings.

Before scanning, primary copings, and implant abutments were unscrewed from the fixture as one unit through the pre-designed occlusal hole. coating with gold/palladium using a Hummer VI deposition system for about 1.0-1.5 minutes of sputtering was done to the primary and secondary copings to be detected by the SEM. *(Figure 2a,b)* Samples were studied using an electron microscope (JOEL-JSM-6510LV) at 14X, 150X magnification power *(Figure 3a,b)*. For standardization, scanning was done every time while the samples were fixed to the 30° tilted mounting table of the SEM. Evaluation of surface changes (wear) was done by using Computer Assisted digital image analysis (Digital morphometric study).

Computer Assisted Digital Image Analysis (Digital Morphometric Study)

SEM images were captured for the surfaces under (X14) magnification and saved in JPG format. The resulting images were analyzed on Intel® Core I3® based computer using Video Test Morphology® software (Russia) with a specific built-in routine for image statistics.[18] A 3D histogram was constructed depending on pixel data (including pixel intensity on a gray scale from 0 (black) to 255 (white) from which a complete pixel statistic was obtained *(Figure 3c,d,e,f)*.

Mean pixel intensity was calculated which is directly proportional to surface roughness. All results were exported as XLS.

Retention Measurements:

For measuring the retention force of overdenture clinically, a device developed by Hussein and Elsyad[25] was used at the following intervals:

- At the time of overdenture insertion. (T0)
- Six months after overdenture insertion. (T6)

Measuring Device:

The used device allowed measurement of retention force in Newton in the vertical direction perpendicular to the patient's occlusal plan by using a forcemeter device which was attached to the device.

The overdenture was modified by attaching four hooks at the buccal flange in the canine and first molar areas using auto-polymerized acrylic resin at the same height. After seating the mandibular overdenture in the patient's mouth. The patient was inquired to fit his chin on the chin support of the device with the mandibular occlusal plane maintained parallel to the floor. The hooks were engaged intra-orally to the fork of the force meter at the pull end *(Figure 4a,b)*. By activating the pulling action of the device, the force gauge measures the retention force of the mandibular overdenture. Five readings were recorded, and the mean was calculated.

STATISTICAL ANALYSIS

Data were tabulated, coded, and then analyzed using the computer program Statistical Package for the Social Sciences (SPSS) version.[25] Data were normally distributed as detected by the Shapiro–Wilk test. Paired sample test was used to compare means of pixel intensity and retention values at T0 and T6.

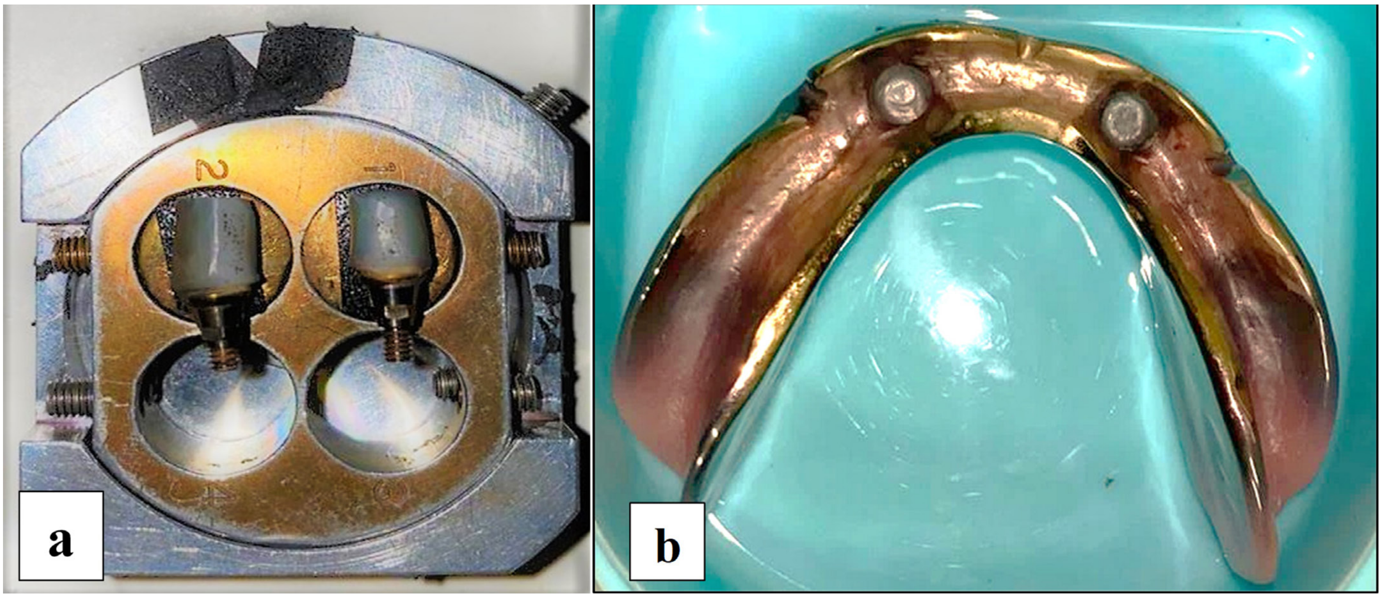

Figure 2: Primary copings (a) and secondary copings (b) after coating with gold.

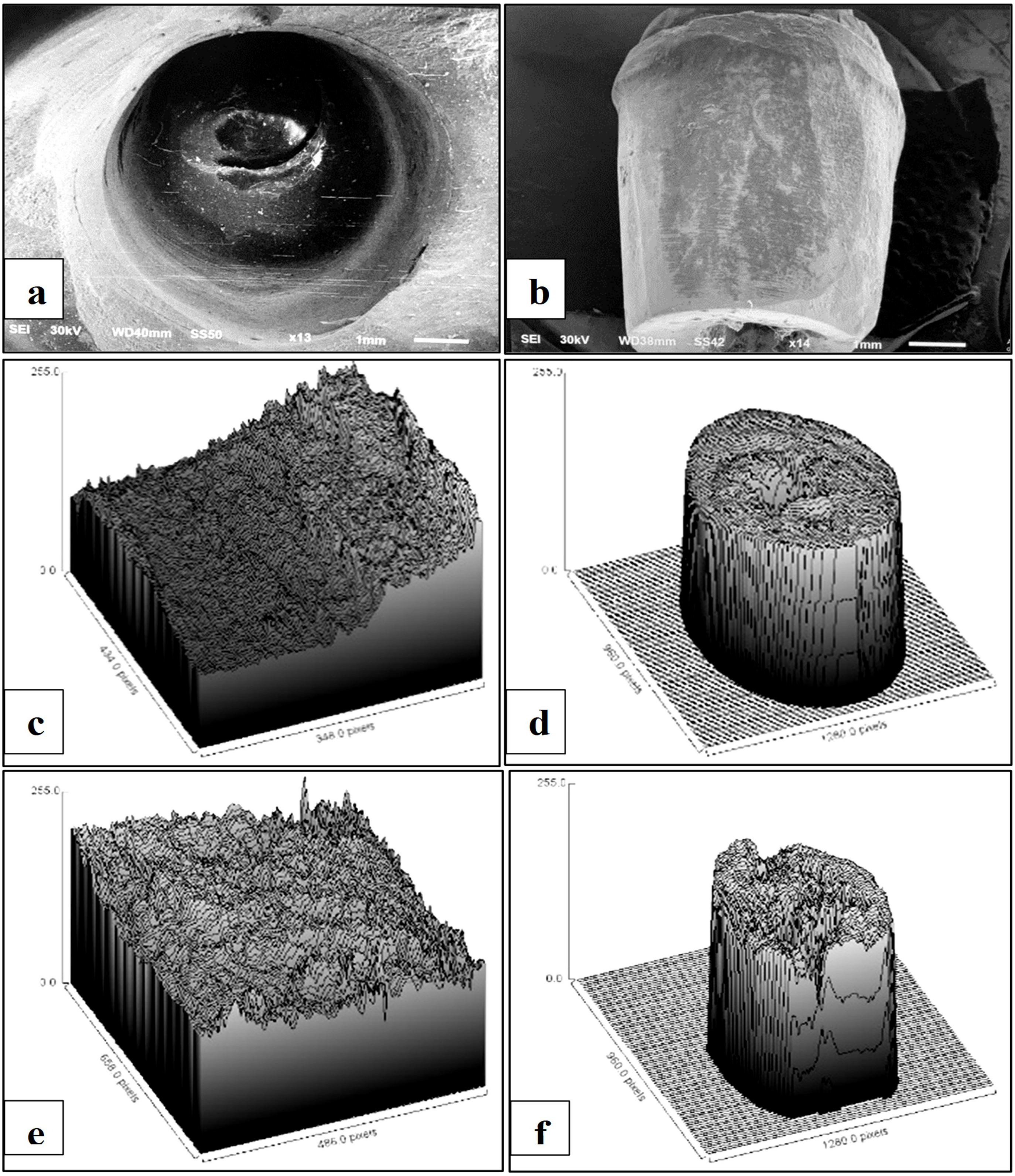

Figure 3: Primary copings (a) and secondary copings (b) under SEM at (14 X). Primary copings (c) and secondary copings (d) under SEM at (14 X) at (T0) showed a smooth, finely grained surface. Primary copings (e) and secondary copings (f) under SEM at (14 X) at (T6) showed minor surface irregularities, scratch lines along the path of insertion/removal, and localized deformation.

RESULTS

Table 1 and Figure 5 shows the mean pixel intensity of zirconia primary copings and PEKK secondary copings at the time of overdenture insertion (T0) and after 6 months of overdenture use. The results revealed less wear (less mean pixel intensity) of zirconia copings compared to PEKK ones at both T0 and T6 evaluation periods. However, both materials showed insignificant wear after 6 months of overdenture use where the P value was 0.847 for zirconia primary copings and 0.415 for PEKK secondary copings.

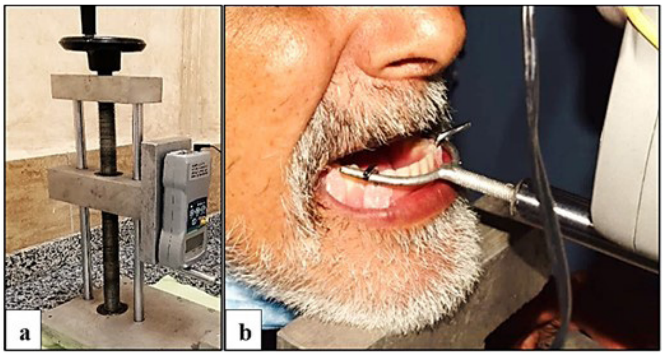

Figure 4: Measuring maxillary denture retention: a) Digital forcemeter fixed to the measuring device. b) The patient rested his chin on the chin support of the device.

Table 1. Mean pixel intensity of zirconia primary copings and PEKK secondary copings at (T0) and (T6).

	T0 (M ± SD)	T6 (M ± SD)	Paired T-test (P value)
zirconia primary copings	89.6 ± 6.48	95.5 ± 15.82	0.847
PEKK secondary copings	179.85 ± 10.16	186.61 ± 16.88	0.415

M: Mean SD: Standard Deviation

The retention force of zirconia-PEKK telescopic attachment at the time of overdenture insertion and after 6 months of overdenture use is presented in Table 2. A significant increase in retention force was observed after 6 months of overdenture use (P value is 0.012).

DISCUSSION

The introduction of new high-performance tooth-colored materials in the last years has decreased the use of metals in the construction of a dental prostheses. Moreover, the presence of computer-aided designing and the accuracy of milling and printing machines has encouraged the use of these new materials in the construction of small components like attachments.[26]

Several materials and materials combinations were used to fabricate telescopic attachments as precious and non-precious metal alloys, zirconia, and PEEK.[14] Recently, PEKK was introduced as a new member of the poly-aryl-ether-ketone (PAEK) family with improved physical and mechanical properties that made it to be in the summit of high-performance polymers. The development of PEKK inspired researchers to evaluate it in the construction of different prosthetic parts of dental prostheses and attachments.[27] Consequently, this study aimed to clinically evaluate zirconia-PEKK telescopic attachments.

In this study, a resilient design of telescopic attachment was used rather than a rigid one to decrease stresses transmitted to the two implants.[3,4] resilient telescopic concept was applied by designing a 4° occlusal convergence angle. Nakagawa *et al.*,[28] investigated the effect of taper on the retention force of double crowns made of a zirconia/alumina nanocomposite stabilized with cerium oxide (Ce-TZP/A). The studied taper angles were 2°, 4°, and 6°. They concluded that the taper had a significant effect on retentive force and settling. Where 4° taper was the most appropriate for retention force production.

The results of the present study showed that after six months of using zirconia-PEKK telescopic attachment, the digital morphometric surface analysis to electron microscopic surface imaging of the zirconia primary copings revealed a non-significant difference (P= 0.847), thus the initial null hypothesis is accepted. This finding agrees with previous studies that demonstrated the low abrasive and wear potential of zirconia, even when set in function against a similar material just as hard with the same material properties.[6] Also, PEKK secondary coping internal surface showed non-significant wear values (P=0.415) which may be related to the improved PEKK physical and mechanical properties. PEKK has a second ketone group which increases polarity and backbone rigidity and causes an increase in the melting temperature and glass transition, the extra ketone group in PEKK has improved the physical properties of the material compared to PEEK.[27]

Moreover, an *in vitro* study by Kotthaus *et al.*,[11] evaluated PEKK secondary coping against primary copings made from different materials: gold alloy, non-precious metal alloy, zirconia, and PEKK. They concluded that zirconia primary crowns showed the least wear in comparison to other types of materials used after completing 10,000 insertion and removal cycles, which conforms with the result of the present study regarding the low wear values of zirconia primary crowns.

Telescopic attachment retention force is affected by several factors including the angle of occlusal convergence, precision of fit, abutment height, and material of construction.[17] Zirconia -PEKK telescopic attachment in the present study showed a mean initial retention force of 13.40 N at the beginning of the study and increased to 15.3 N after six months of overdenture use, which is above the reported satisfactory retention force. A clinical study assessed the association between patient satisfaction and retention force values and concluded that approximately 10 N of the retention force was efficient.[29]

The second null hypothesis is rejected where a significant increase in retention force was observed after 6 months of overdenture use. The observed increase in retention force is in line with what was reported in the *in vitro* study made by Kotthaus *et al.*,[11] who noticed that all zirconia- PEKK telescopic attachments demonstrated an increase in the retention force over the course of 10,000 wear cycles. This increase was highly obvious during the first 2000 cycles before continuing stable for the subsequent 8000 cycles of joining and separation. The authors explained this increase by the wedge effect caused by

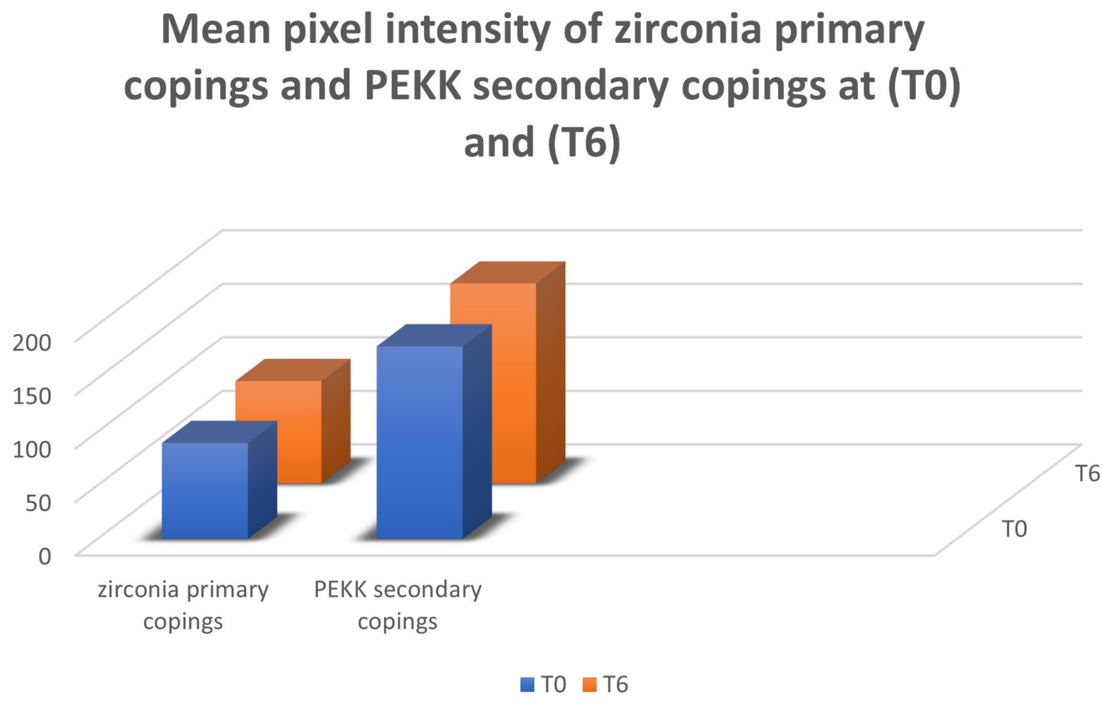

Figure 5: Mean pixel intensity of zirconia primary copings and PEKK secondary copings at the time of overdenture insertion (T0) and after 6 months of overdenture use.

Table 2. Retention force of zirconia-PEKK telescopic attachment at (T0) and (T6).

	T0 (M ± SD)	T6 (M ± SD)	Paired T-test (P value)
Retention force	13.4 ± 1.64 N	15.30 ± 1.05 N	0.012*

M: Mean SD: Standard deviation
*: significant where P ≤ 0.05 N: Newton

the settling of the secondary crowns, which affects the retentive force. Additionally, a recent clinical study evaluated the dislodging force of double crown-retained removable partial dentures (RPDs) made from PEKK and PEEK with zirconia primary copings. They concluded that, after clinical functional use, double crown-retained RPDs made from PEEK exhibited a minimal increase in dislodging force, while those made of PEKK showed a significant increase in dislodging force.[30]

RECOMMENDATIONS

Further investigations are recommended with an increased sample size and a longer evaluation period.

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