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RESEARCH AND EDUCATION

Retention and wear behaviors of two implant overdenture stud-type attachments at different implant angulations

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ABSTRACT

Statement of problem. Implant angulation should be considered when selecting an attachment. Some in vitro studies have investigated the relationship between implant angulation and changes in the retention force of the stud attachment, but few studies have evaluated the effect of cyclic loading and repeated cycles of insertion and removal on the stud attachment.

Purpose. The purpose of this in vitro study was to evaluate the effects of implant angulation on the retentive characteristics of overdentures with 2 different stud attachments, an experimental system and O-rings in red and orange, after cyclic loading and repeated insertion and removal cycles.

Material and methods. The canine region of a mandibular experimental model was fitted with 2 implant fixtures with 2 different stud attachment systems at implant angulations of 0, 15, or 30 degrees. A mastication simulator was used to simulate cyclic loading, and a universal testing machine was used to evaluate retentive force changes after repeated insertion and removal cycles. To simulate the numbers of mastication and insertion and removal cycles per annum, 400 000 cyclic loadings and 1080 insertion and removal cycles were performed. Wear patterns and attachment surface deformations were evaluated by scanning electron microscopy. Data were analyzed using the Kruskal-Wallis test, Mann-Whitney *U* test with Bonferroni correction (α=.05/3=.017), and the paired-sample Student *t* test (α=.05).

Results. When retentive forces before and after testing were compared, O-ring showed significant retention loss at all implant angulations (*P*<.001). In contrast, the experimental system showed little retention loss in the 0- and 15-degree models (*P*>.05), whereas the 30-degree model showed a significant increase in retentive force (*P*=.001). At all implant angulations, retention loss increased significantly for the orange O-ring, followed by the red O-ring, and the experimental system (*P*<.001). Scanning electron microscopy analysis showed more intense wear in the matrix than the patrix (abutment that matches to matrix) and more severe wear and deformation of the O-ring rubber matrix than of the experimental zirconia ball.

Conclusions. Upon completion of the experiment, wear and deformation were found for all attachment systems. Even when implants are not installed in parallel, the experimental system can be used without involving great loss of retention. (J Prosthet Dent 2016;■:■-■)

Patients with edentulism and substantial alveolar bone resorption experience discomfort if their dentures lack stability, retention, or support.[1] Implant-retained overdentures with attachments are a suitable option for these patients[2-4] and have been suggested as standard treatment options for improved retention and stability.[5,6]

Bar or stud attachments can be used with implant-retained overdentures.[7] The bar attachment splints the implants together, and the cross-sectional shape of the bar determines the degree of denture movement toward the residual ridge.[8] In addition, the bar attachment can be used when implants are not parallel.[9] However, its initial cost is high, the fabrication process involved is complicated, and sufficient vertical space is required for the attachment.[9]

The stud attachment is more affordable, and its production and oral hygiene management are less complicated. However, the retentive force may be limited on nonparallel implants.[10,11]

Retentive force is a key contributor to patient satisfaction.[12] According to Pigozzo et al,[13] 5 to 7 N should be adequate to stabilize overdentures, and Setz et al[14]

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Clinical Implications

The EZ lock may be considered for nonparallel implants, because it allows adjustment to the path of insertion and ensures adequate retentive force.

suggested a retentive force of 20 N is sufficient for a mandibular 2-implant-retained overdenture. However, with use and attachment component wear, loss of retention is inevitable.[7,15,16] Divergent implant angulations negatively influence retentive force and the longevity of attachment retention.[8,17] Nonparallel implants disrupt passive prosthesis insertion and promote early wear.[18] Stud attachments are available for implants with an interimplant divergence angle up to 10 degrees. However, a divergence angulation greater than 10 degrees results in excessive wear and ultimately retention loss.[19]

Among the stud attachments available, O-ring attachments have a straightforward design, excellent retentive force, easy maintenance, affordability, and variable retention capacity through the availability of various colored polymeric matrices. However, disadvantages include prosthesis complexity and wear caused by mastication, which ultimately result in retention loss and replacement every 6 to 9 months.[20]

A new attachment type has been introduced to address these disadvantages. It uses 3 zirconia balls and a titanium alloy spring within a matrix to provide lasting retentive capacity.[21] This attachment allows placement of the matrix parallel to the path of insertion, permitting its use for implants with an interimplant divergence of 40 degrees.[22] A number of studies have investigated retention changes in stud attachments in implant-retained overdentures,[12,23,24] but few have compared retention changes and wear patterns at different implant angulations or evaluated the efficacy of product designs intended to compensate for the limitations of O-ring.

The purpose of this in vitro study was to compare an experimental implant overdenture with the O-ring and stud attachment type at different implant angulations. The first null hypothesis was that implant angulation would not affect the retentive forces of each stud attachment or those of the mandibular overdenture attachment. The second null hypothesis was that the retentive forces of each stud attachment would remain undamaged after cyclic loading and repetitive cycles of insertion and removal.

MATERIAL AND METHODS

After an impression of an edentulous mandibular (N-2016-021-IIT) dental arch with severe bone resorption had been made by using a tray and silicone impression material (Imprint II VPS Impression Material; 3M ESPE), acrylic resin (Orthodontic resin; Dentsply Caulk) was used to fabricate a mandibular cast. A silicone-based soft tissue replicating material (Gi-Mask; Coltène/Whaledent Inc) was used to replicate the gingival elasticity of edentulous residual alveolar ridges during mastication. The thickness of the fabricated artificial gingiva was 4 mm,[25] and acrylic resin completed the definitive cast. Interimplant divergence angles of 0, 15, and 30 degrees were selected, and 2 holes with centers 22 mm apart were made in the mandibular canine region with a milling machine (Frasgerat F1; Degussa) and a 4.9-mm diameter drill.[26] Implants (EF fixture 4.8×10 mm; Snucone Co Ltd) were installed in the holes and fixed with acrylic resin. In the 0-degree models, 2 implants were installed in parallel and vertical to the model base. In the 15- and 30-degree models, the 2 implants were installed mesially at inclinations of 7.5 and 15 degrees from the vertical axis of the base in order to achieve interimplant divergence angles of 15 and 30 degrees, respectively.

In the present study, 2 stud attachments were chosen (Table 1): one was the O-ring (Dentis Co Ltd), which is commonly used clinically, and the other was the recently developed EZ lock (Samwon DMP Co). EZ lock is composed of a matrix and spherical patrix (abutment that matches to matrix), and the matrix contains 3 zirconia balls and a titanium spring. EZ lock attachments can be used for nonparallel implants because they adjust the matrix parallel to the path of insertion within the permitted range of angulations. The O-ring, which lacks rotational capability, has a rubber matrix and spherical patrix, and red or orange rubber inserts with different retention capacities are provided (Fig. 1). A total of 90 overdentures were fabricated: 10 overdentures for each selected interimplant divergence angle and 10 for each experimental matrix insert type.

A dental mastication simulator (R&D Inc) was chosen to perform the cyclic loading; a stainless steel bar 55×10×10 mm was placed in the first molar areas bilaterally. Then, a vertical force of 70 N, corresponding to the average masticatory force of the first molar, was applied at the center of the bar (Fig. 2A).[27] Specimens were exposed to 100 000 repeated cyclic loadings (the average number of mastications in 3 months) in 37°C deionized water to simulate the oral condition.[28] Upon completion of cyclic loading, a universal testing machine (Instron 3345; Instron Co) was used to install and remove dentures and to measure retentive force.

Briefly, a model assembled with an overdenture was fixed onto a surveyor table, and three 10-cm-long metallic straps were connected to the upper part of the universal testing machine.[29] The 3 chains were attached between the first molar and central incisor of the

Table 1. Specifications of tested attachment systems

Attachment System	Manufacturer	Material: Patrix	Material: Matrix	Matrix Insert	Retention Value (N)	n
EZ lock	Samwon DMP Co	Titanium alloy (Ti-6Al-4V) with TiN coating	Titanium alloy (Ti-6Al-4V ELI), Zirconia (ZrO2)	-	4.5	30
O-ring	Dentis Co Ltd	Titanium alloy	Polymeric	Red	4.0	30
				Orange	6.0	30

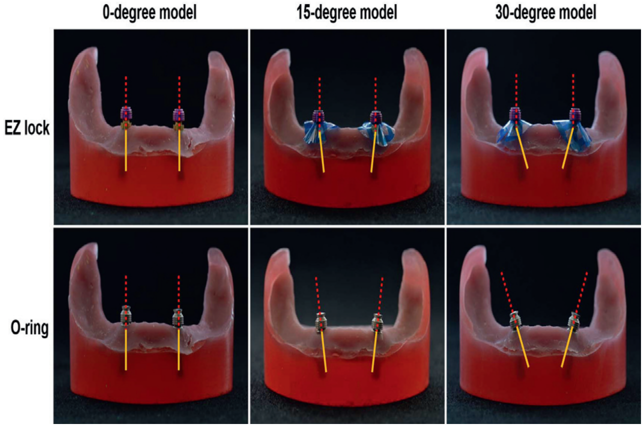

Figure 1. Mandibular experimental models and attachment systems. Solid line indicates implant angulation, and dotted line indicates attachment matrix angulation.

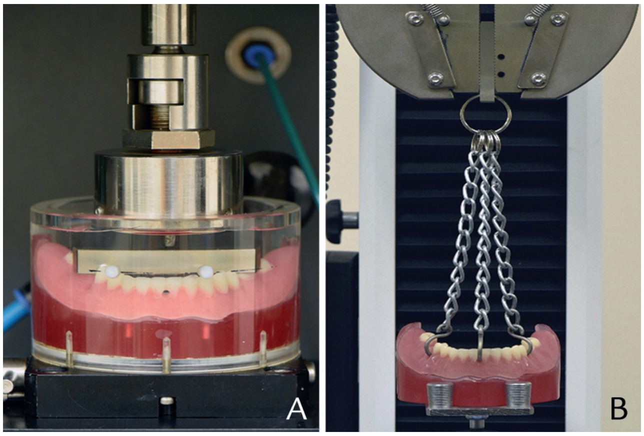

Figure 2. A, Simulation of 400 000 cyclic masticatory loadings of 70 N on overdentures. B, Overdenture setting for retentive testing using universal testing machine.

overdenture bilaterally, and adjustment of the position of the chains and the model exerted a purely vertical force to dislodge the denture (Fig. 2B). To withdraw the prosthesis, the cross-head speed was set at 50 mm/min to mimic the dislodging speed of a prosthesis from the residual alveolar ridge during mastication.[30] On the assumption that overdentures are installed and removed 3 times per day for hygienic reasons, 270 cycles of installation and removal were performed.[23] The process mentioned above was repeated 4 times, that is, 400 000 repeated loadings and 1080 installation-removal cycles to simulate the average number of mastication strokes and installation and removal cycles in 1 year.

After the experiment, wear and deformation patterns were observed by scanning electron microscopy (S-3500; Hitachi Ltd) at magnifications of ×25 and ×100.

Statistical software (SPSS Statistics v21; IBM Corp) was used for the statistical analysis, and the Shapiro-Wilk test and the Levene test were used to determine distribution normality and homogeneities of variances. The Kruskal-Wallis test and Mann-Whitney *U* test with Bonferroni correction were used to compare retentive forces for different implant angulations for the same attachment system and to compare the different attachment systems at the same angulations (α=.05/3=.017). In addition, retention losses were compared after the experimental process. For each attachment system, retentive forces were measured before and after the experiment and compared by using the paired-sample *t* test (α=.05).

Table 2. Means ±SD retentive forces (N) and retention losses (%) of each attachment system over time in 0-degree model

Time (mo)	Attachment System: EZ lock		O-ring (red)		O-ring (orange)		*P**
0	11.74	$\pm2.550^{aA}$	7.220	$\pm0.4500^{bA}$	9.530	$\pm0.3300^{aA}$	<.001
3	12.46	$\pm2.610^{a}$	5.730	$\pm0.7600^{b}$	6.160	$\pm0.5700^{b}$	<.001
6	12.26	$\pm1.530^{a}$	5.430	$\pm0.8300^{b}$	5.400	$\pm0.4600^{b}$	<.001
9	11.44	$\pm1.960^{a}$	5.160	$\pm0.7800^{b}$	5.030	$\pm0.2700^{b}$	<.001
12	11.44	$\pm1.590^{aA}$	4.880	$\pm1.040^{bB}$	4.350	$\pm0.1700^{bB}$	<.001
*P***	.443		<.001		<.001		
Retention loss	0.6500	$\pm10.70^{a}$	32.38	$\pm13.60^{b}$	54.26	$\pm2.820^{c}$	<.001

*Values were calculated using Kruskal-Wallis test. **Values were calculated using paired-sample *t* test, and retentive forces were compared between 0 and 12 months. Different lowercase letters in rows indicate significant differences (*P*<.05). Different uppercase letters in columns indicate significant differences (*P*<.05). Retention loss between 0 and 12 months are presented as percentages. Statistical significance (*P*<.05).

RESULTS

A significant decrease was noted in the retentive force of the O-ring at all implant angulations (*P*<.001). EZ lock in 0- and 15-degree models exhibited a constant retentive force (*P*=.443, *P*=.392, respectively), but EZ lock in 30-degree models demonstrated a significant increase in retention (*P*=.001) (Tables 2-4). At all implant angulations, the orange O-ring exhibited the greatest loss of retentive force, followed by the red O-ring and EZ lock (*P*<.001) (Tables 2-4). The initial retentive force of EZ lock tended to decline in response to increasing implant angulation (Fig. 3), but no significant differences were

Table 3. Means ±SD retentive forces (N) and retention losses (%) of each attachment system over time in 15-degree model

	Attachment System			
Time (mo)	**EZ lock**	**O-ring (red)**	**O-ring (orange)**	***P****
0	7.710 ±1.270^{aA}	7.850 ±0.5100^{aA}	11.15 ±1.100^{bA}	<.001
3	7.350 ±1.050^{a}	6.770 ±0.5000^{ab}	5.920 ±1.300^{b}	.044
6	7.280 ±0.4900^{a}	6.470 ±0.4000^{b}	4.450 ±1.200^{c}	<.001
9	7.240 ±0.4800^{a}	6.460 ±0.6500^{a}	3.980 ±0.8300^{b}	<.001
12	7.900 ±1.250^{aA}	6.290 ±0.7700^{bB}	3.880 ±0.8300^{cB}	<.001
*P***	.392	<.001	<.001	
Retention loss	-2.890 ±8.810^{a}	19.74 ±8.900^{b}	65.27 ±5.890^{c}	<.001

*Values were calculated using Kruskal-Wallis test. **Values were calculated using paired-sample *t* test and retentive forces were compared between 0 and 12 months. Different lowercase letters in rows indicate significant differences (*P*<.05). Different uppercase letters in columns indicate significant differences (*P*<.05). Retention loss between 0 and 12 months are presented as percentages. Statistical significance (*P*<.05).

Table 4. Means ±SD of retentive forces (N) and retention losses (%) of each attachment system over time in the 30-degree model

	Attachment System			
Time (mo)	**EZ lock**	**O-ring (red)**	**O-ring (orange)**	***P****
0	7.270 ±1.840^{aA}	8.140 ±0.1200^{aA}	9.220 ±0.6800^{bA}	.002
3	7.550 ±1.890^{a}	6.560 ±0.4400^{a}	4.850 ±0.7600^{b}	<.001
6	7.630 ±1.660^{a}	5.630 ±0.3200^{a}	4.430 ±0.5200^{b}	<.001
9	8.930 ±2.710^{a}	4.870 ±0.4300^{b}	4.320 ±0.4700^{c}	<.001
12	9.000 ±2.810^{aB}	4.250 ±0.1800^{bB}	3.900 ±0.2100^{bB}	<.001
*P***	.001	<.001	<.001	
Retention loss	-22.00 ±8.020^{a}	47.75 ±2.680^{b}	57.41 ±4.200^{c}	<.001

*Values were calculated using Kruskal-Wallis test. **Values were calculated using paired-sample *t* test and retentive forces were compared between 0 and 12 months. Different lowercase letters in rows indicate significant differences (*P*<.05). Different uppercase letters in columns indicate significant differences (*P*<.05). Retention loss between 0 and 12 months are presented as percentages. Statistical significance (*P*<.05).

observed between the 15- and 30-degree models (*P*=.971) (Table 5).

Red O-ring exhibited an increasing initial retentive force pattern as implant angulation increased (Tables 2-4), but no significant differences were observed between the 0- and 15- degree models (*P*=.043) (Table 5). O-ring demonstrated a constant loss in retentive force regardless of implant angulation and rubber insert and showed a marked decrease in retentive force during the first 3 months (Fig. 3). Compared with the other attachment systems, orange O-ring displayed the greatest retentive force decline at all implant angulations after repetitive loadings and seating and unseating cycles (*P*<.001) (Tables 2-4).

Attachment surfaces were observed by SEM after the experiment. The patrix demonstrated more noticeable wear than the matrix (Fig. 4). Compared with the zirconia balls of EZ lock (Fig. 4A, D, G), the rubber matrix of the O-ring (Fig. 4B, C, E, F, H, I) displayed obvious deformation and wear, which included torn and irregular surfaces. Unlike the patrix of EZ lock (Fig. 4J, M, P), the patrix of the O-ring (Fig. 4K, L, N, O, Q, R) showed obvious wear behavior at all implant angulations, and the 30-degree models of both the O-ring patrix (Fig. 4Q, R) and the EZ lock patrix (Fig. 4P) revealed a neck wear pattern.

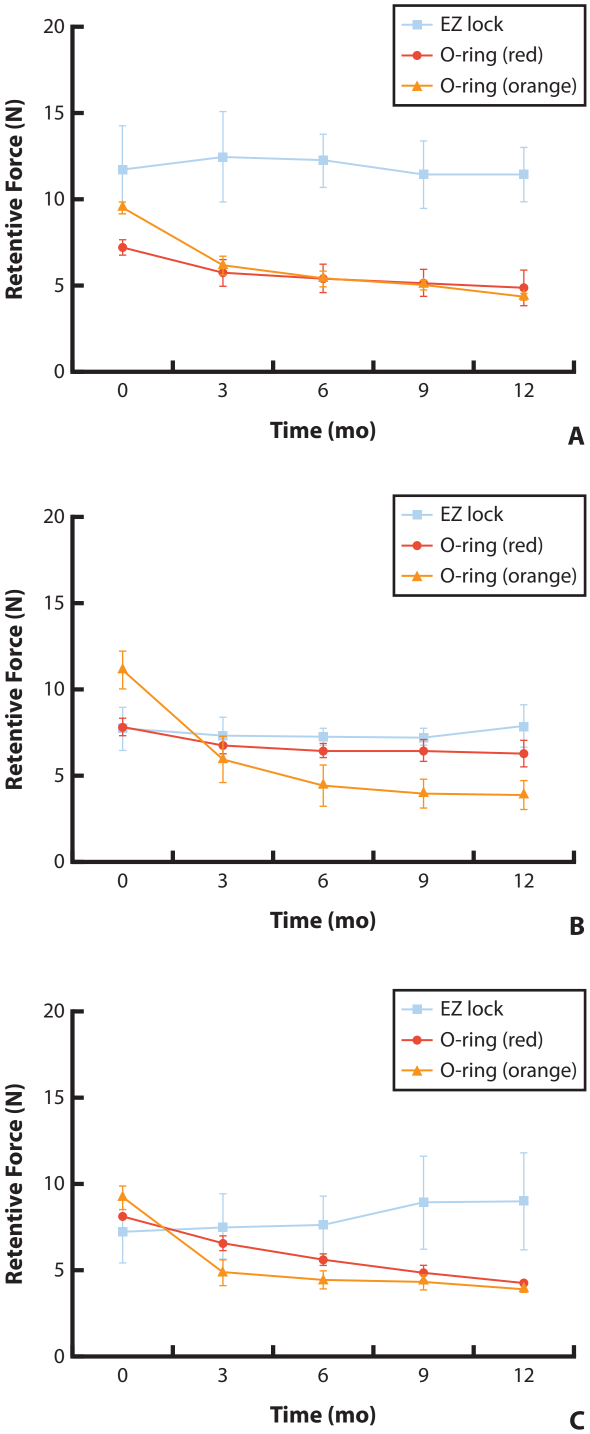

Figure 3. Retentive force change over time for each attachment system. A, 0-degree model. B, 15-degree model. C, 30-degree model. EZ lock achieved relatively constant retentive forces, although attachments in although attachments in 30-degree model showed increase in retention. However, O-ring exhibited obvious reduction in retention.

DISCUSSION

Determining the attachment type for implant-retained overdentures requires consideration of cost effectiveness,

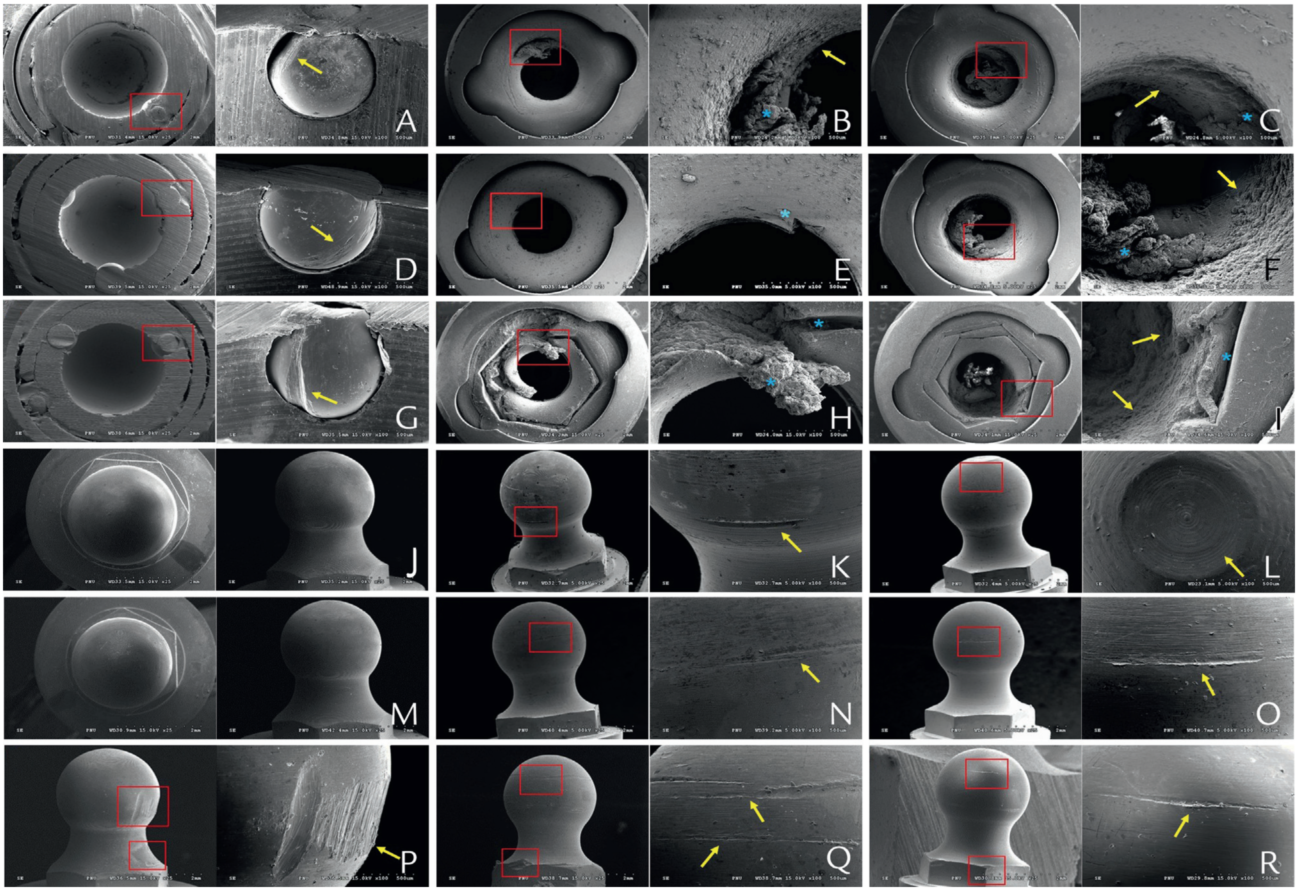

Figure 4. Scanning electron microscope images (original magnifications ×25, ×100) of matrix and patrix surfaces after testing of different attachment systems in 0-, 15-, and 30-degree models. 1st and 4th rows indicate 0-degree models, the 2nd and 5th rows the 15-degree models, and the 3rd and 6th rows the 30-degree models. Letters A to I display matrices, and letters J to R display patrices. Arrows indicate light wear and deformed areas. *Severe wear area with sloughing material.

Table 5. Multiple comparisons of Mann-Whitney U test with Bonferroni correction results

		EZ Lock			O-ring (red)			O-ring (orange)		
Time (mo)	**Model (degrees)**	**0 Degrees**	**15 Degrees**	**30 Degrees**	**0 Degrees**	**15 Degrees**	**30 Degrees**	**0 Degrees**	**15 Degrees**	**30 Degrees**
0	0		**	**		-	***		**	-
	15	**		-	-		***	**		**
	30	**	-		***	***		-	**	
12	0		***	-		*	-		-	**
	15	***		-	*		***	-		-
	30	-	-		-	***		**	-	
Retention loss	0		-	**		-	***		***	-
	15	-		**	-		***	***		***
	30	**	**		***	***		-	***	

*$P<.05$. **$P<.01$. ***$P<.001$.

acceptable retention, soft tissue discomfort, amount of bone available, oral hygiene, patient's expectation and social status, relationship between maxilla and mandible, opposing jaw condition, and interimplant distance.[7] Different views exist regarding the proper amount of denture retention. Some in vivo studies have reported that a stud attachment possesses vertical displacement forces of 7 to 31 N,[6,10] and thus, in the present study, 7 N was chosen for the permitted level of retention that allows maintenance of overdentures in the clinical situation.

Attachment retention loss is the most common complication of implant overdentures,[16] and nonparallel implants have a major negative impact on retentive force maintenance because this interferes with the path of prosthesis insertion and withdrawal and ultimately causes premature wear.[18] In the clinical setting, parallel

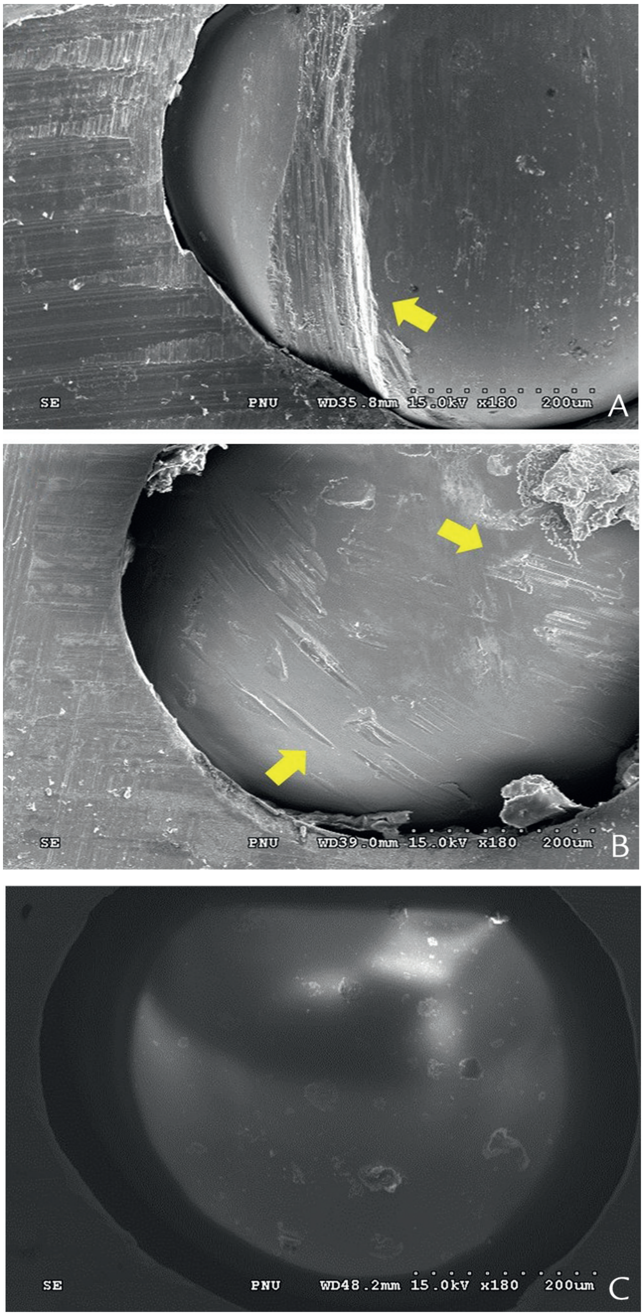

Figure 5. Three zirconia balls of EZ lock matrix after testing in 30-degree model (original magnification ×180). A and B, Wear observed on ball surfaces. C, No sign of wear observed. Arrows indicate regions of complete surface wear.

implant insertion can be complicated or unfeasible because of poor bone quality or anatomic conformation. Also, despite the use of a surgical guide for implant orientation, the final position of an implant can be altered because of the clinician's skill, patient cooperation, bone morphology, or guide stability.[31] Some clinicians favor an angled abutment or a bar to compensate for implant angulation when the stud attachment is inappropriate because of the nonparallel implant, but this has disadvantages in terms of cost, manufacturing process, and prosthesis maintenance.[18]

In the present study, 2 types of stud attachments, EZ lock and O-ring, were compared. The limited use of a conventional stud attachment for nonparallel implant angulation is redeemed by EZ lock, which enables divergent implant angulations of up to 40 degrees. O-ring is recommended for parallel and nonparallel implants as its highly elastic rubber component does not impede prosthesis seating or removal. Based on a previous study of the effect of implant angulation on stud attachment retention,[22] maximum divergent implant angulation was set at 30 degrees.

Occlusal force leads to denture rotation around the attachment on resorbed alveolar ridges[32] and ultimately causes retention loss because of matrix wear and contortion.[7] One study of the relationship between stud attachment retention and mastication loading reported that mastication deforms the attachment and that retentive force subsequently tapers.[33] Regardless of attachment system, the need to maintain the prosthesis during the first year is higher than in other periods[7]; therefore, this study conducted 400 000 cyclic loadings and 1080 insertion and removal cycles, equivalent to 1 year, to evaluate the retentive force changes of overdentures and consequent wear patterns of attachments.

In the present study, EZ lock provided constant retention at all implant angulations, even after the experiment. This can be explained by several factors. Unlike polymeric structures such as the rubber of O-ring, the zirconia balls of EZ lock resist wear better, and the resilient titanium alloy spring delivers steady support during denture function.[21] In addition, EZ lock can function properly without sacrificing retentive capacity even when implants are nonparallel since its matrix is capable of 3-dimensional rotation around the spherical patrix in order to arrange the matrix in parallel to the path of insertion.[22]

However, as implant angulation was increased to 30 degrees, initial retentive force tended to diminish. This phenomenon was possibly due to the incomplete seating of EZ lock at insertion. SEM images of the EZ lock matrix showed 2 of the 3 zirconia balls had scratch marks and showed apparent wear (Fig. 5A, B), whereas the third showed no evidence of wear (Fig. 5C). Patrices in 0- and 15-degree models did not display observable wear (Fig. 4J, M), but the 30-degree model exhibited apparent unilateral wear (Fig. 4P). This observation suggests that the complete insertion of the matrix is difficult when implant angulation increases and that a portion of the zirconia balls is involved in retaining the denture. Additionally, a focused force seems to be responsible for patrix wear. Moreover, such surface changes of the retentive component enhance irregularity and, ultimately, increase retentive force due to micromechanical friction.[24,34]

The retentive capacity of O-ring is influenced by the elasticity of the rubber ring, undercut conformation of the retainer, and frictional resistance between them, and thus, regardless of implant angulation, retention tends to gradually decline during repeated loading and insertion/withdrawal cycles. Wear, deformation, and degeneration can result in loss of retentive force, and the present study shows that wear-induced increases in ring diameter directly affect loss of retention (Fig. 4B, C, E, F, H, I).[35,36] In addition, matrices that cannot tolerate rotation cause unequal undercut, addressing a potential source of incomplete installation, premature wear, and retention loss.[22] Both the matrix and patrix of O-ring revealed a distinct wear pattern (Fig. 4K, L, N, O, Q, and R). This observation may have been the consequence of a chemical reaction by direct metal attack of free radicals from rubber during the wear process.[37] The rubber insert of the orange O-ring demonstrated greater initial retentive force and retention loss than that of the red O-ring. This observation is partially explained by the fact that during the experiment, the orange insert better resisted vertical dislodging forces than the red insert. Scanning electron microscopy images also indicated more substantial wear and distortion of the orange insert (Fig. 4C, F, I) than of the red insert (Fig. 4B, E, H). Another possibility is that the red insert had more freedom to rotate than the orange insert.[38] However, the correlations between freedom of rotation and wear and retention loss have not been established, and thus, additional studies are necessary.

A problematic feature of implant overdenture attachment is retention loss due to wear over time. Wear is a complex process that involves adhesion, abrasion, surface fatigue, and corrosion.[15] In the present study, average annual frequencies of recurrent loadings and of insertions and withdrawals were chosen to replicate clinical wear patterns of attachment systems. As compared with the metal components of the patrix, the rubber matrix displayed more significant wear and deformity. Titanium nitride coatings enhanced the rigidity of the patrix surface and wear resistance. Therefore, such coatings might be responsible for the sporadic wear and deformation of the patrix in EZ lock.[39] The experimental results of this study are subject to minor errors associated with the manufacturing process and experimental errors, which include suitability of the denture and model, parallelism of the implant and model base, modification in attachment assembly onto the denture, height differences between the 3 chains and the denture, and different denture positions in the universal testing machine. Nevertheless, given these limitations, EZ lock appeared to provide satisfactory retention capacity for overdentures at all implant angulations after 1 year, whereas O-ring was found to need attachment replacement or renewal because of time-related retention loss.

Several factors such as salivary components, temperature, parafunctional oral habits, dental plaque, use of denture sanitizer, and food debris and a number of implant factors such as interimplant distance and marginal sealing of dentures can affect retentive force. Therefore, further studies should be undertaken to investigate the influence of intraoral factors, numbers of implants, implant position, and interimplant distance on overdenture retention capacity and wear.

CONCLUSIONS

Considering the limitations of this in vitro study, the following conclusions were drawn:

1. Regardless of implant angulation, EZ lock was found to wear in the contact area between the zirconia ball matrix and the spherical patrix and to maintain initial retention after repeat loading and insertion and removal cycles.
2. For O-ring, these conditions led to extensive wear of the rubber matrix and titanium patrix and steady retention release.
3. The experimental findings indicate EZ lock is a functional treatment option for nonparallel implant angulation in the clinical setting.

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