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Comparison of retentive force and wear pattern of Locator® and ADD-TOC attachments combined with CAD-CAM milled bar

Sung-Ki Chae[1,2a], Won-Tak Cho[1,3a], Jae-Won Choi[1], Eun-Bin Bae[1], Ji-Hyeon Bae[1,3], Gang-Ho Bae[1,3], Jung-Bo Huh[1,3*]

[1]Department of Prosthodontics, Dental Research Institute, Dental and Life Sciences Institute, Education and Research Team for Life Science on Dentistry, School of Dentistry, Pusan National University, Yangsan, Republic of Korea
[2]Research and Development Institute, Samwon D.M.P, Yangsan, Republic of Korea
[3]Research and Development Institute, PNUAdd Co., Ltd., Busan, Republic of Korea

ORCID

Sung-Ki Chae
https://orcid.org/0000-0001-6608-5797
Won-Tak Cho
https://orcid.org/0000-0003-2174-7333
Jae-Won Choi
https://orcid.org/0000-0001-6786-9251
Eun-Bin Bae
https://orcid.org/0000-0002-9524-3835
Ji-Hyeon Bae
https://orcid.org/0000-0003-3805-5229
Gang-Ho Bae
https://orcid.org/0000-0002-9287-6610
Jung-Bo Huh
https://orcid.org/0000-0001-7578-1989

PURPOSE. The purpose of this study was to investigate changes in retention and wear pattern of Locator® and ADD-TOC attachments on a digital milled bar by performing chewing simulation and repeated insertion/removal of prostheses in fully edentulous models. **MATERIALS AND METHODS.** Locator (Locator®; Zest Anchors Inc., Escondido, CA, USA) was selected as the control group and ADD-TOC (ADD-TOC; PNUAdd Co., Ltd., Busan, Republic of Korea) as the experimental group. A CAD-CAM milled bar was mounted on a master model and 3 threaded holes for connecting a bar attachment was formed using a tap. Locator and ADD-TOC attachments were then attached to the milled bar. Simulated mastication and repeated insertion/removal were performed over 400,000 cyclic loadings and 1,080 insertions/removals, respectively. Wear patterns on deformed attachment were investigated by field emission scanning electron microscopy. **RESULTS.** For the ADD-TOC attachments, chewing simulation and repeated insertion/removal resulted in a mean initial retentive force of 24.43 ± 4.89 N, which were significantly lower than that of the Locator attachment, 34.33 ± 8.25 N ($P < .05$). Amounts of retention loss relative to baseline for the Locator and ADD-TOC attachments were 21.74 ± 7.07 and 8.98 ± 5.76 N ($P < .05$). **CONCLUSION.** CAD-CAM milled bar with the ADD-TOC attachment had a lower initial retentive force than the Locator attachment. However, the ADD-TOC attachment might be suitable for long-term use as it showed less deformation and had a higher retentive force after simulated mastication and insertion/removal repetitions. [J Adv Prosthodont 2022;14:12-21]

KEYWORDS

Bar attachment; Digital milled bar; Implant supported overdenture; Zirconia prosthesis; Computer aided design and computer aided manufacturing (CAD-CAM)

Corresponding author
Jung-Bo Huh
Department of Prosthodontics, Institute of Translational Dental Sciences, School of Dentistry, Pusan National University, 20, Geumo-ro, Mulgeum-eup, Yangsan 50612, Republic of Korea
Tel +82-55-360-5133
E-mail neoplasia96@hanmail.net

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[a] These authors contributed equally to this work.

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INTRODUCTION

Implant-fixed prostheses or removable dentures have been used to restore oral function in edentulous or partially edentulous patients,[1] and recently, implant overdentures that can obtain additional stability are attracting attention.[2,3] Implant overdentures can satisfy the esthetic needs of patients and may be cost-effective treatment options when establishing treatment plans.[4] In addition, implant overdentures can be used with fewer implants when it is difficult to place multiple implants due to bone resorption, and they provide more stable retention and support than conventional dentures.[5] In order to enhance the retention and stability of implant overdentures, solitary or bar type attachments are commonly used.[6,7]

Solitary type attachments such as ball, magnet, and Locator attachments can be used even when intermaxillary space is insufficient. They can be easily inserted and removed, which is convenient for maintaining oral hygiene.[8] However, they are less stable than bar type attachments and require frequent visits for maintenance.[9] On the other hand, bar type attachments such as the Hader, Dolder, and milled bars require sufficient intermaxillary space (at least 15 mm), and the fabrication processes are complex.[10] The bar-clip attachment does have some disadvantages such as mucosal hyperplasia, hygiene problems, and the need for clip activation.[11-13] Nevertheless, bar type attachment can splint implants, provide stability by inhibiting displacing forces in the vertical and oblique directions, and disperse stresses on implants at the attachments.[14] Furthermore, implants provide more support and stability to bar attachments in this type of prosthesis than the edentulous alveolar ridge, which eliminates the need for denture base extension.[15]

Although the traditional milled bar is difficult to fabricate by casting or milling alone, computer aided design and computer aided manufacturing (CAD-CAM) milled bars can be easily fabricated and have emerged as cost-friendly alternatives to electrical discharge machining (EDM).[16-18] Unlike prefabricated bars, a custom-made bar can be milled with high precision to allow accurate adaptation of the milled bar by the denture metal framework, which provides stability and resistance against rotational and lateral loading.[18-20] Such milled bar-based implant overdentures exhibits firmness and sufficient stability, but it is difficult to obtain uniform and precise frictional fits, which may reduce retention after repeated insertions and removals. To address this issue, a method of obtaining additional retention using attachments was devised.[21] In an edentulous maxilla with low bone quantity and or quality, the use of Locator attachments with a bar enables splinting of adjacent implants, which disperses the stress otherwise exerted on one particular implant.[22] Locator-bar attachment systems can be classified as gold bar casting, laser welding, or drill and tapping systems based on how the metal patrix is fixed to the bar.[23] The drill and tapping method makes it easier to connect an attachment to the metal bar and to deal with situations in which an attachment replacement is required due to retention loss, since only the matrix part needs to be replaced, without having to re-fabricate the bar.[24]

However, studies have shown repeated insertion and removal can cause abrasion of the Locator matrix and that different water temperatures can cause deformation of Locator matrix nylon.[25] Recently, a new attachment called ADD-TOC, developed to supplement the limitations of the locator, was introduced. According to the manufacturer, ADD-TOC can be used for a long time without wear or deformation, due to the presence of the zirconia balls and shape memory alloy springs. Previous studies that investigated the retention of similar products with similar structures have reported that a matrix with zirconia balls and elastic springs presented no functional problems and exhibited less wear after mastication or repeated attachment insertions and removals, little retention loss, and the capacity for long-term use.[26-29] Multiple reports have been issued on implant overdentures using a bar with attachments.[30,31] One *in vitro* study investigated changes in retention and wear patterns of Locator and ADD-TOC connected to a jig after repeated insertion/removal cycles.[32] However, no previous study has performed clinical simulations on actual prostheses or examined retention loss and wear patterns of attachments after long-term use.

In this study, we investigated changes in retention and wear patterns of Locator® and ADD-TOC attach-

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ments on digitally milled bars by performing chewing simulation and repeatedly inserting and removing prostheses in fully edentulous models.

MATERIALS AND METHODS

Edentulous mandibular models with resorbed ridges were fabricated using acrylic resin (Orthodontic resin; Dentsply Caulk, Milford, DE, USA). A master model was constructed with implants (EF fixture 4.8 mm × 10 mm; Snucone Co., Daegu, Republic of Korea) inserted at sites of the first molar and canine of left and right edentulous mandible at an angle of 0°. Gingival gum (Coltène® Gi-Mask Automix; Coltène Whaledent AG, West Sussex, UK) was used to reproduce gingival elasticity during mastication in the edentulous residual alveolar ridge.

Three scan bodies (SC-SURO; Geomedi Co., Uiwang-si, Kyeonggi-do, Republic of Korea) and a laboratory scanner (FREEDOMHD; DOF, Seoul, Republic of Korea) were used on the resin models to design a milled bar for attachments. CAD-CAM milled bars were designed using CAD software (exocad DentalCAD; exocad GmbH, Darmstadt, Germany). Three threaded holes were formed using a tap on the CAD-CAM milled bar to connect the ADD-TOC and Locator; the threaded holes were ≥ 3 mm deep and 2 mm wide. The CAD-CAM milled bar width in the patrix area was ≥ 4 mm (Fig. 1).

Dental milling equipment (ARUM 5X-200; ARUM DENTISTRY Co., Ltd., Daejeon, Republic of Korea) was used to fabricate CAD-CAM milled bars, and a tap (Thread Mill M2.0; ARUM DENTISTRY Co., Ltd., Daejeon, Republic of Korea) was used to create the 3 threaded holes used to connect 3 attachments to the top of the CAD-CAM milled bar. The fabricated CAD-CAM milled bar was then fixed to the resin model using a torque wrench (TW; Snucon, Daegu, Republic of Korea) at a torque of 35 N·cm.

A CAD-CAM milled bar was installed in each resin model and scanned using a laboratory scanner. A zirconia-based removable prosthesis was designed using CAD software and then milled from zirconia blocks using a milling machine. Spaces for attachments were created inside zirconia removable prosthesis. Four holes for retention testing were created in the lower parts of the canine and second molar of the zirconia removable prostheses. The completed removable zirconia prostheses were sintered according to the manufacturer's instructions. Attachment matrices were secured to spaces inside prostheses using self-adhesive resin cement (G-CEM; GC, Tokyo, Japan).

For the control group, we used the Locator attachment, which is the most widely used CAD-CAM milled bar attachment system. In the experimental group, the ADD-TOC attachment (ADD-TOC; PNUAdd Co., Busan, Republic of Korea) was used; this attachment provides retention using a zirconia ball-nitinol spring assembly. The ADD-TOC attachment used was of the low type with a retentive force of 5 - 7 N. We refer to the Locator attachment group as the LB group and the ADD-TOC group as the AL group (Table 1, Fig. 2).

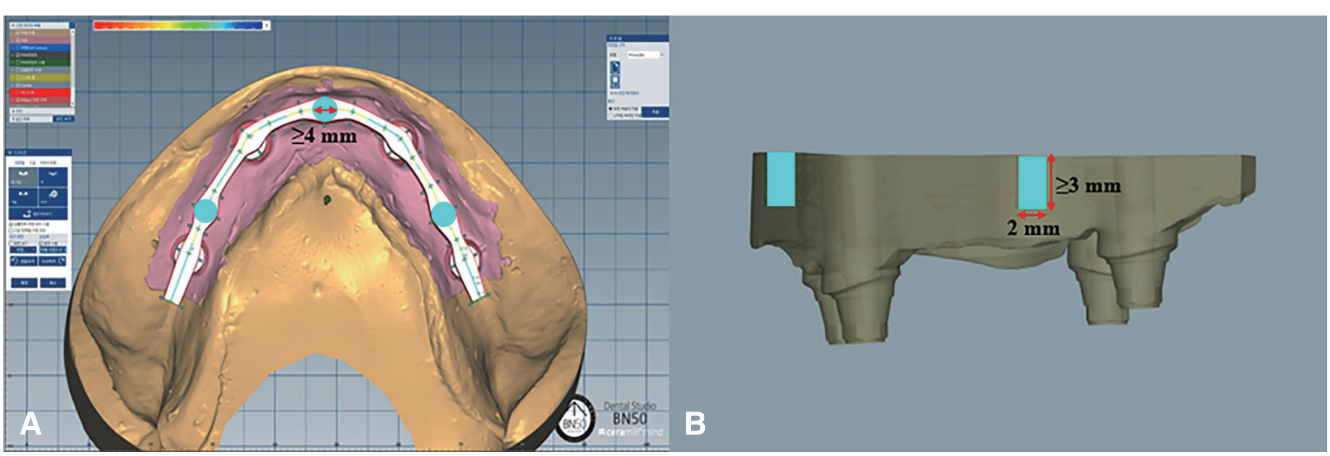

Fig. 1. Milled bar design for attachment mounting using CAD software. (A) Occlusal view, (B) Buccal view.

Table 1. Characteristics of the attachment systems evaluated in this study

Abbreviation	Material		Brand name	Manufacturer	n
	Matrix	Patrix			
LB	Nylon (Blue)	Titanium alloy (Ti-6Al-4V ELI alloy) with TiN coating	Locator®	ZEST Anchors Inc., Escondido, CA, USA	10
AL	Nitinol (Ni-Ti) Zirconia (ZrO_2)	Titanium alloy (Ti-6Al-4V ELI alloy)	ADD-TOC	PNUAdd Co., Busan, Republic of Korea	10

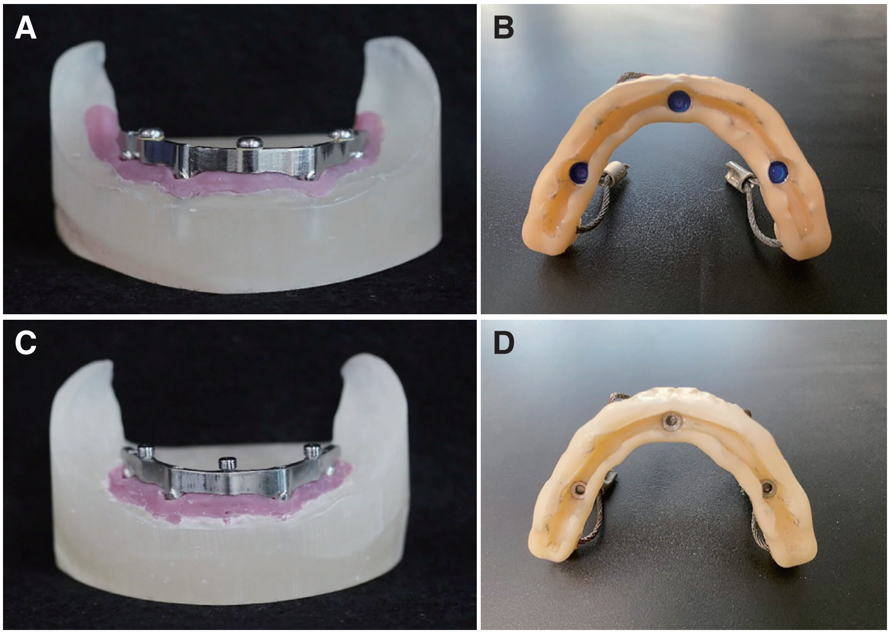

Fig. 2. Specimens with attachments manufactured using CAD-CAM system. (A) Milled bar model with Locator attachments, (B) Removable zirconia prosthesis with Locator attachments, (C) Milled bar model with ADD-TOC attachments, (D) Removable zirconia prosthesis with ADD-TOC attachments.

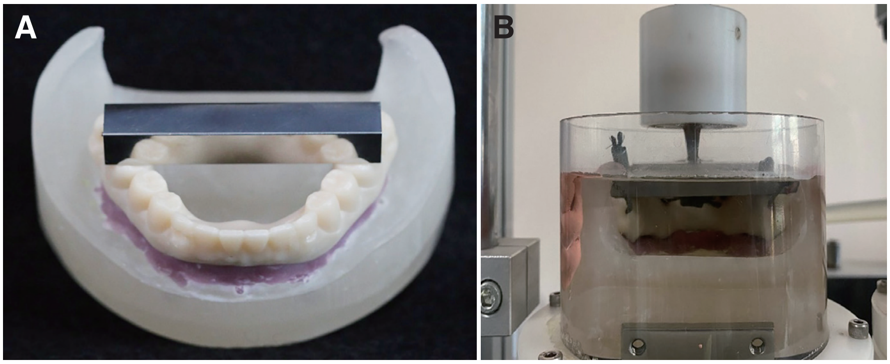

Fig. 3. Process to evaluate the change in retention of two attachments according to the accelerated aging test. (A) Removable zirconia prosthesis and a stainless steel bar, (B) Chewing simulator for repeated mastication and artificial aging.

Both attachments were connected to the 3 threaded holes at the top of their respective CAD-CAM milled bars at 35 N·cm (Fig. 3). A stainless bar (55 mm × 10 mm × 10 mm) was fixed to the first molar of the constructed zirconia removable prosthesis and chewing simulator (TW-T1000; TaewonTECH, Bucheon, Republic of Korea). Thermocycling was performed at 5 - 55°C and a dwell time of 60 s. A total of 400,000 loadings were performed using a vertical force of 70 N at a frequency of 1.6 Hz. Repeated insertion/removal were performed for a total of 1,080 chewing simulations (equivalent to 1.75 year; Fig. 4).[33]

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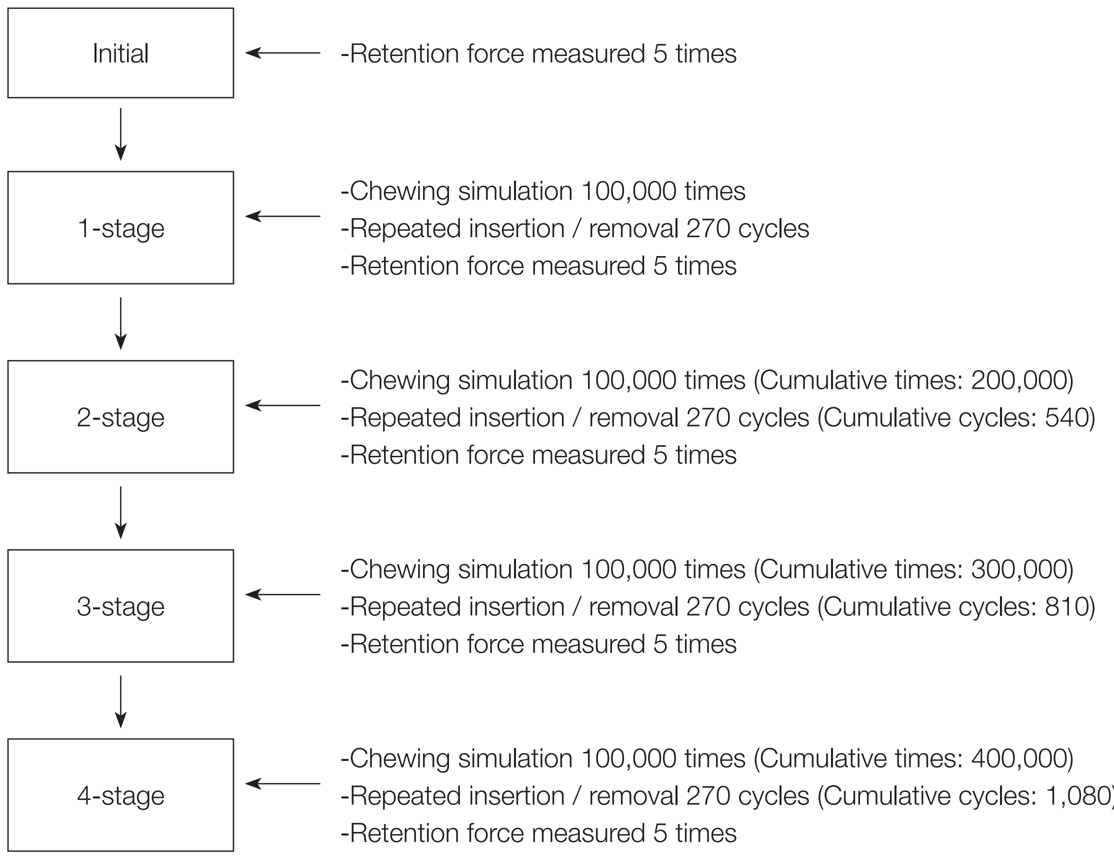

Fig. 4. Schematic diagram of the experimental procedure.

At each stage of the experimental procedure (refer to Fig. 5), 100,000 loadings and 270 cycles of insertion/removal were performed. To reproduce a clinical setting, 270 insertion/removal cycles were manually performed after 100,000 loadings. Retentive forces were measured using a universal testing machine (3345 Machine; Instron Inc., Carton, MA, USA) after repeated insertion/removal. The entire procedure was repeated four times to simulate 1.75 year in the clinical setting (1,080 insertion/removal cycles, 400,000 loadings). After simulating repeated chewing simulation and manual insertion/removal cycles, retention of the zirconia removable prosthesis was tested by connecting a wire to a hole in the prosthesis using the universal testing machine at a cross-head speed of 50 mm/min.[34]

The wear patterns of attachment components, patrices, and matrices were examined using a field emission scanning electron microscope (Gemini 500; Zeiss, Oberkochen, Germany) after chewing simulation.

The statistical analysis was performed using SPSS software (SPSS Ver. 25; SPSS Inc., Chicago, IL, USA). For each stage of the experiment, inter-group comparisons of normal data (as determined by the normality test) were conducted using the *t*-test. ANOVA (Analysis of variance) was used for intra-group comparisons at different stages in the LB group and the Kruskal-Wallis test or the Mann-Whitney test with the Scheffe post hoc test were used in the AL group. The significances of changes in retention were determined using the independent *t*-test. Statistical significance was accepted for P values < .05 using a 95% confidence interval.

RESULTS

The results of retention testing in the LB and AL groups are shown in Figure 5 and Table 2. Initial testing revealed significantly different mean retentions in the two study groups of 34.37 ± 8.06 and 25.51 ± 5.70 N, respectively. However, after stage 1, no significant intergroup difference was observed (18.72 ± 7.92 and 18.34 ± 7.98 N, respectively) (P > .05). In the LB group, mean retentions in stages 1 to 3 were 18.96 ± 7.20 N, 15.93 ± 6.17 N, and 15.94 ± 4.76 N, respectively (no significant difference was evident (P > .05)), but after stage 4, mean retention fell significantly to 12.64 ± 3.29 N. In the AL group, corresponding values were 20.63 ± 6.47 N, 19.32 ± 4.60 N, and 20.16 ± 6.18 N at stage 1 - 3, which were also not significantly different, but after stage 4, mean retention fell significantly to 16.53 ± 3.04 N.

As shown in the Figure 6, the LB group showed significant retention loss of 44.84% from baseline at stage 1 (P < .05), while the AL group showed no significant retention loss (P > .05). In the LB group, percentage reductions in retention relative to baseline were 44.84%, 53.65%, and 53.61% at stages 1 to 3, respectively, and 63.24% at stage 4. In the AL group, corresponding percentage reductions were 19.12%, 24.26%, 20.99%, and 35.20%, respectively (Table 3).

Figure 7 shows changes in the surface morphologies

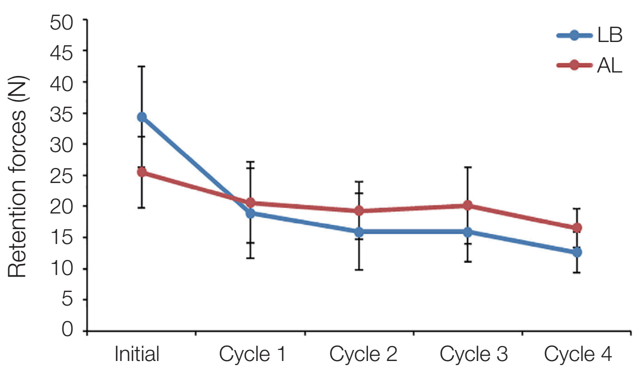

Fig. 5. Retention forces (N) in each attachment. LB: Locator, AL: ADD-TOC.

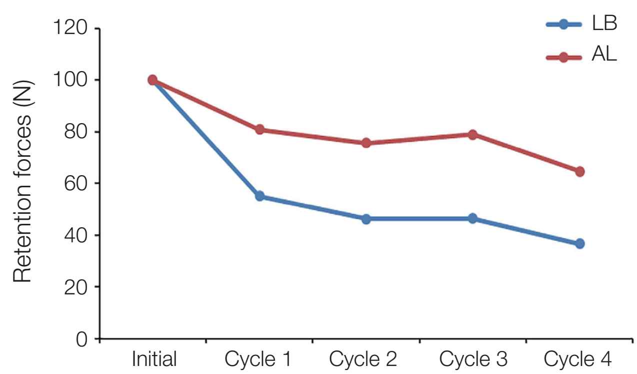

Fig. 6. Cumulative change (%) in retentive forces during each stage. LB: Locator, AL: ADD-TOC.

Table 2. Mean changes in retentive forces (N)

Group	Initial	Stage 1	Stage 2	Stage 3	Stage 4	*P* value
LB	34.37 ± 8.06	18.96 ± 7.20	15.93 ± 6.17	15.94 ± 4.76	12.64 ± 3.29	< .001
AL	25.51 ± 5.70	20.63 ± 6.47	19.32 ± 4.60	20.16 ± 6.18	16.53 ± 3.04	< .001
P value	< .001	.193	.004	.020	< .001	

LB: Locator, AL: ADD-TOC.

Table 3. Retentive force loss (N) and change (%) after each stage

Group		Stage 1	Stage 2	Stage 3	Stage 4	*P* value**
LB	Mean ± SD (N)	$15.73 \pm 6.56^{A,a}$	$18.44 \pm 5.88^{A,b}$	18.43 ± 5.91^{Ab}	21.74 ± 7.07^{Ac}	.001
	Change (%)	44.84	53.65	53.61	63.24	
AL	Mean ± SD (N)	$4.88 \pm 7.25^{B,a}$	$5.94 \pm 5.49^{B,a}$	$5.21 \pm 6.35^{B,a}$	$8.98 \pm 5.76^{B,a}$	.080
	Change (%)	19.12	24.26	20.99	35.20	
P value*		< .001	< .001	< .001	< .001	

*Values were calculated using the Mann-Whitney test. **Values were calculated using the Kruskal-Wallis test and post-hoc Mann-Whitney U test. Different uppercase letters in columns and different lowercase letters in rows indicate significant differences (P < .05).
LB: Locator, AL: ADD-TOC.

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of patrix and matrix after chewing simulation and repeated insertion/removal cycles. In the LB group, debris was observed in the nylon inserts of matrix created by breakage and tearing of the Locator (Fig. 7C). In addition, patrix surfaces were scratched by repeated insertion and removal (Fig. 7D). In the AL group, the matrix retained the spherical zirconia shape (Fig. 7G), whereas the patrix surface had abrasions caused by insertion and removal (Fig. 7H).

DISCUSSION

Implant overdentures have been in the spotlight as a more efficient treatment option than the conventional complete denture option for edentulous patients, in which stability and retention are difficult to obtain.[34] Implant overdentures may be classified as solitary and bar types.[6,7] Solitary type attachments, such as ball, magnet, and Locator attachments, have the advantage that they can be easily inserted and removed and installed even in small intermaxillary spaces,[8] but they have poorer stability than bar type attachments such as Hader, Dolder, and milled bars and require more frequent clinic visits for maintenance.[9] On the other hand, bar type attachments require sufficient intermaxillary space and are costly, due to the complex nature of the fabrication procedure.[10] Nevertheless, the splinting effect of bar type

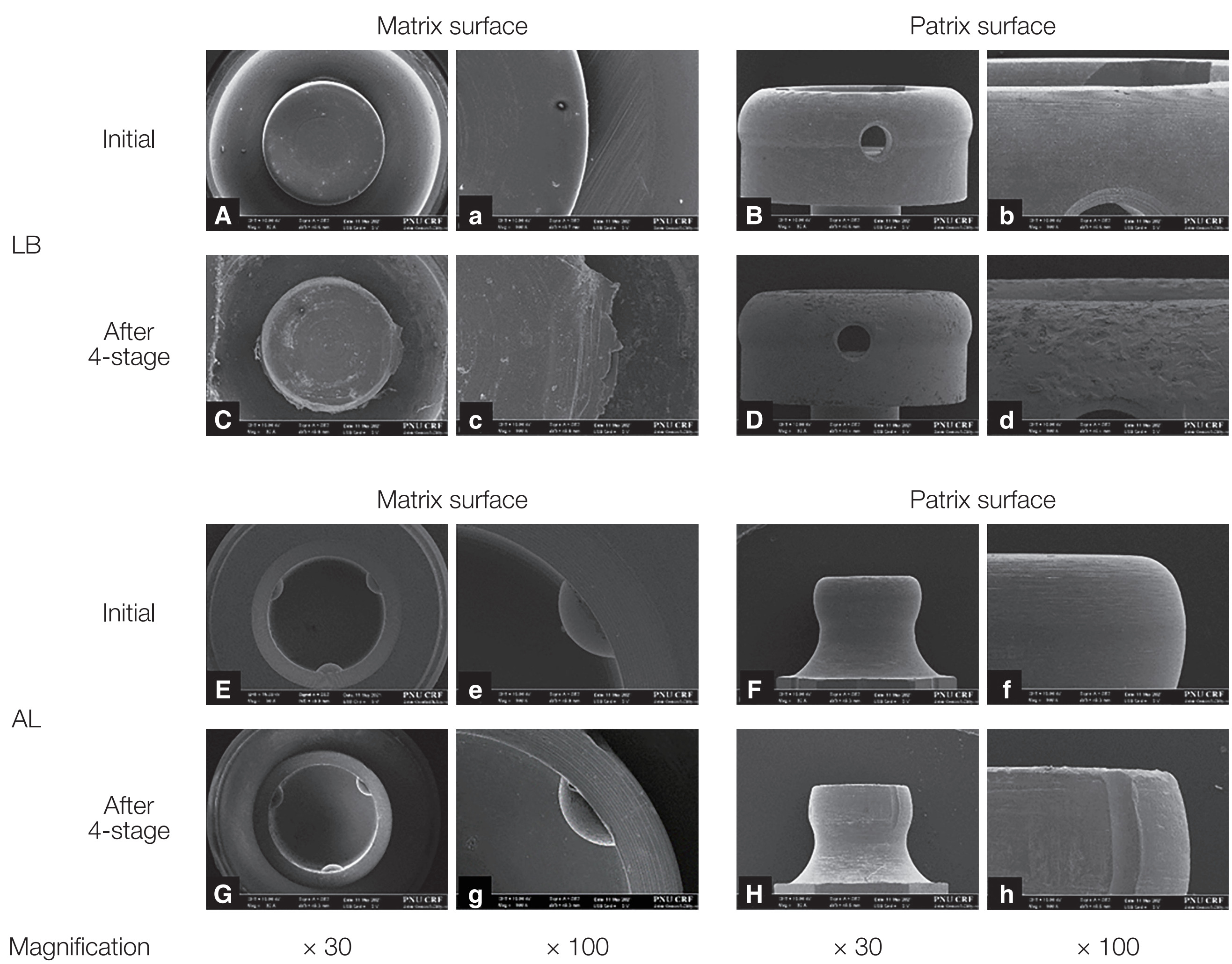

Fig. 7. Field emission scanning electron microscope images of attachments after simulated mastication and repeated insertion/removal. LB: Locator, AL: ADD-TOC.

attachments can provide stability and resistance to lateral and rotational loading and can disperse stresses exerted on implants.[14]

Unlike prefabricated bars, milled bars can be milled accurately to produce guide planes that allow accurate adaptation of the denture base and provide stability against rotational and lateral forces.[18-20] However, it is difficult to achieve uniform, precise frictional fits, and retention loss may occur after repeated insertion/removal cycles, and thus, methods that uses an attachment to obtain retention was introduced.[21]

Many studies have been conducted on the use of locator attachments and have reported that when used with a bar, splinting can dissipate stresses on certain implants.[21,22] There are four methods of fixing attachment to bar; that is, gold bar casting, laser welding, drilling, and tapping.[23] Of these, drilling and tapping provide a straightforward means of connecting attachments to titanium bars and of replacing the matrix part in cases of retention.[24] However, a previous study on the Locator system reported that repeated insertion and removal and differences in water temperature can cause retention loss due to wear or deformation of the matrix.[25] To solve this problem, a new matrix was introduced that achieves retention using a zirconia ball-nitinol spring structure, which has been reported to exhibit no wear and minimal retention loss after long-term use.[26-29]

In the present study, the reason for using the Locator blue insert as the control was that the retention forces (5 - 7 N) achieved using ADD-TOC and Locator blue inserts with CAD-CAM milled bars were similar (both measured at 6.7 N).[32] Both were subjected to retention testing before and after repeated insertion/removal testing. To prevent fracture or deformation of removable prostheses during insertion/removal and chewing simulation experiments, we used the most commonly studied yttrium-stabilized tetragonal zirconia polycrystal (TZP) zirconia removable prosthesis.[34]

It has been reported that the initial retention of a bar attachment using 5 clips is about 27 N and that this reduces to ~ 9.2 N after 540 insertion/removal cycles.[35] Pigozzo *et al*.[36] reported that a retention force of 5 - 7 N is required for overdenture stability and several *in vivo* studies have demonstrated that stud attachments provide retention forces of 7 to 31 N.[37] In the present study, mean initial retentions in the LB and AL groups were 34.37 ± 8.06 N and 25.51 ± 5.70 N, and final retentions were 12.64 ± 3.29 N and 16.53 ± 3.04 N, respectively, which is consistent with previously reported initial and final retention results for bar/Locator attachments.[32] The LB group showed 63.24% retention loss over the experiment, which was attributed to marked wear and deformation in the nylon matrix after repeated insertion/removals and mastication testing. In contrast, in the AL group, the 3 zirconia balls mounted on a nitinol spring exhibited a retention loss of 35.20%. Locator nylon inserts of LB group are made of unreinforced polyamide 66 resin for injection molding. Unreinforced polyamide 66 resin will affect its performance upon exposure to moisture and temperature changes.[38] Due to its high affinity for water molecules, water diffuses into the polyamide chains, causing reductions in flexural strength, tensile strength and stiffness.[38,39] As a result of this study, it is considered that the holding force decreased due to the weakening of the mechanical properties. Conversely, the AL group is made of zirconia balls and nitinol springs, so it has excellent corrosion resistance against temperature and moisture.[40] Instead, a connector manufactured of titanium grade 4 resulted in reduced retention force due to wear of titanium connector by zirconia balls.

We simulated repeated insertion/removal of implant overdentures and mastication testing by mimicking clinical settings, but in the actual oral environment, various factors such as saliva, plaque, abnormal behavior, and the use of denture cleaner can affect retention.[26] Moreover, changes in retention and attachment can be influenced by the descriptor, number of implants, connection type of implants, and functional locations of attachments as well as the number of implants and angles and distances between implants.[26,41] Therefore, we suggest future studies be conducted to identify the factors that can influence overdenture retention and wear patterns under different conditions.

CONCLUSION

In this study, the ADD-TOC attachments used in conjunction with a CAD-CAM milled bar initially had lower initial retentions than the commonly used Locator attachments. However, after repeated cyclic loadings and insertion/removal cycles, we observed wear on patrix surfaces in the LB group. In the AL group, though patrix surfaces showed signs of wear, matrices retained their initial morphology. In terms of retention loss, the AL group consistently showed better results than the LB group. Nevertheless, both products provided sufficient retention for clinical applications.

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