Original Article

Retention Force and Wear Characteristic of Ball and O-ring Attachment of RetenDent Mini-implant Overdenture System

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Abstract

The purpose of this experimental study was to evaluate wear characteristics and retention force of the RetenDent mini-implant overdenture system (Chulalongkorn product) after the insertion-removal fatigue test. One-piece mini-implants attachment system for overdenture, Osstem MS denture® type implant (OSSTEM, Germany GmbH), and RetenDent mini-implant were tested. All samples were subjected to repeated insertion and removal fatigue cycles by a universal testing machine (E1000, INSTRON Instrument, England). Subjected fatigue cycles were 5500 with 1.00Hz frequency to mimic a 5-year insertion and removal three times per day. The retention force was measured by separating the O-ring from the abutment and recorded with the universal tester (EZ-SX, SHIMADZU, Japan). The retention force was measured six times, at baseline and the end of 1100, 2200, 3300, 4400, and 5500 cycles. These represent each year of use. After fatiguing, the mini-implant ball abutments were examined with a stereomicroscope (SZ61 OLYMPUS, Japan). The result showed a mean retention force of 6.65±0.24N for the RetenDent group and 6.84±0.24N for the Osstem group, which were not statistically different. The two attachment systems had no significant effect on retention force. However, the fatigue cycles alone and the interaction between the attachment system and fatigue cycles had significant effects on retention force. The retention of the RetenDent group was significantly higher at baseline (10.96±1.78N) and after 1,100 cycles (8.73±1.23N) compared to the Osstem group (6.50±0.88N and 6.66±1.27N). There was no statistical difference at 2200 cycles. The retention of the Osstem group became significantly higher after 3300, 4400, and 5500 cycles (6.86±1.07N, 7.06±0.997N, 6.997±1.02N) compared to the RetenDent group (5.04±1.19N, 4.49±1.26N, 3.88±1.44N). In conclusion, the RetenDent and the MS denture® mini-implant attachment system provided a similar retention force at higher than the minimum recommended for overdenture. There was no wear on the ball abutment of both groups under the stereomicroscope after 5,500 fatigue cycles.

Keywords: Attachment, Ball, Fatigue, Mini implant, O-ring, Overdenture, Retention force, Wear

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Introduction

The Thai community had been steadily transitioning to an elderly society. As reported in 2017, the Thai elderly population was 11 million from a total of 65.5 million Thais. This was approximately 17 % of the total population, ranking second among all ASEAN member countries and projected to be more than 26.6 % of the total population in 2030.[1,2] A survey taken in 2017 in Thailand had shown that only 23 % of the elderly population were wearing a denture.[1] This left 8.47 million elders with untreated edentulism.

Complete edentulism and tooth loss have been correlated to a multitude of systemic comorbid conditions. Also, patients with edentulism are at risk of reduced nutritional intake and increased risk of obesity.[3] In Thailand, the royal complete denture project had shown positive impacts on the quality of life of older Thai people and their oral health.[4] Prosthetic options for patients presented with complete edentulous ridge include a conventional complete denture, implant-supported prosthesis, and implant-retained prosthesis. These options differ in terms of cost, maintenance, denture stability and retention, and patient satisfaction toward the denture. Interestingly, some patients have had difficulty adapting to conventional dentures, even with proper tissue support and good denture quality.[5,6] On the other hand, implant-retained or implant-supported prostheses lessen the requirement of patient's muscular control development for denture adaptation. Thus, positively affecting their quality of life.[7-9] Implant-retained prosthesis such as implant-overdenture is a great alternative with a relatively lower cost compared to an implant-supported fixed denture.[10] Several studies have reported the advantages of implant-overdenture over conventional tissue-borne complete denture. These include better retention particularly in the edentulous mandible, good functional ability, and less ridge resorption rate.[7,8,11] In terms of patient-based analysis, implant-overdentures give better patient satisfaction with a predictable outcome.[9,12] Furthermore, the McGill consensus in 2002 suggested that two-implant overdenture is the first choice of treatment for the edentulous mandible.[13]

There have been uses of mini-implants to support the overdenture as an alternative to standard diameter implants. A mini-implant is a rigid, non-hollow implant with less than a 3 mm diameter. The mini-implant surgical technique is simple and quick with a high success rate compared to standard-size implants.[14,15] A meta-analysis of randomized controlled trials had shown that mini-implants provided good patient satisfaction compared to standard diameter implants when used for implant-retained overdentures.[16,17] Another systematic review also concluded that mandibular mini-implant retained overdentures are predictable regarding implant survival, marginal bone resorption, and patient satisfaction.[18,19] Mini-implants used with overdenture can lower the total cost of the treatment and is applicable in patients with narrower ridges. However, the most common complication is the loss of attachment retentive ability over time. This is due to the wear and deformation of the ball abutment and O-ring through the patient's insertion-removal routine.[20] Maintenance of the attachment system such as changing the O-ring or replacing the worn abutment will contribute to the long-term cost of the prosthesis. More importantly, abutment wear in mini-implants will result in the need for total fixture replacement.

Other than dental implants, titanium alloy is also used for joint prostheses in the medical field. Titanium alloy wear produces metal debris and ions, which causes adjacent tissue inflammation. A class of amorphous carbon that shares some properties of diamonds called DLC (Diamond-Like Carbon) was introduced to modify the surface of these prostheses. DLC coating was studied to greatly increase titanium alloy wear resistance by up to three folds. Furthermore, studies on DLC coating on titanium and titanium alloy implant surfaces have shown to be biocompatible for hard and soft tissue and did not alter bacterial adhesion.[21,22] This introduces the possibility of DLC coating on the ball titanium alloy abutment of the RetenDent mini-implant overdenture system to provide exceptional wear resistance.

The Osstem MS denture® type implant (OSSTEM, Germany GmbH) was selected to compare to the product (RetenDent) developed by Chulalongkorn University in this study. Osstem mini-implant system is a Korean product widely used in Thailand with U.S. FDA approval and the EU CE quality certification. They are relatively affordable and have great clinical validations and yearly clinical publications. A study has found that the MS mini-implants have good clinical prosthetic effects even in immediate loading cases.[23] The Osstem MS mini-implant ball abutment has a bare machined titanium surface in contrast to the DLC-coated RetenDent abutment.

The RetenDent mini-implant overdenture system developed by Chulalongkorn University aims to provide an attachment complex with good wear resistance, to be more accessible, with a lower cost to Thais in need of complete dentures. This experimental study's objective was to evaluate wear characteristics and retention force of the RetenDent mini-implant overdenture system after the insertion-removal fatigue test.

Material and method

One-piece mini-implants fixtures for overdenture, MS denture® type implant (OSSTEM, Germany GmbH), and RetenDent mini-implant for overdenture (a product of Chulalongkorn University) were tested. The samples were designated as the OS group (MS denture®) and the RD group (RetenDent). Sample size calculation performed with G*Power program version 3.1.9.7. Input data was obtained from a similar experimental study with power $(1-\beta) = 0.95$ and $\alpha = 0.05$.24 The sample size determined was 10 per group.

Fatigue test

All samples were subjected to repeated insertion and removal fatigue cycles by the universal testing machine (E1000, INSTRON Instrument, England). Matrix and O-ring complexes were fixed to the upper member of the machine while implant fixtures were fixed to the lower member of the machine (Fig.1). The lower member stayed stationary while the upper member of the machine moved vertically. The fatigue frequency is 1.00Hz, for a total of 5500 cycles to mimic five years insertion with removal three times per day.

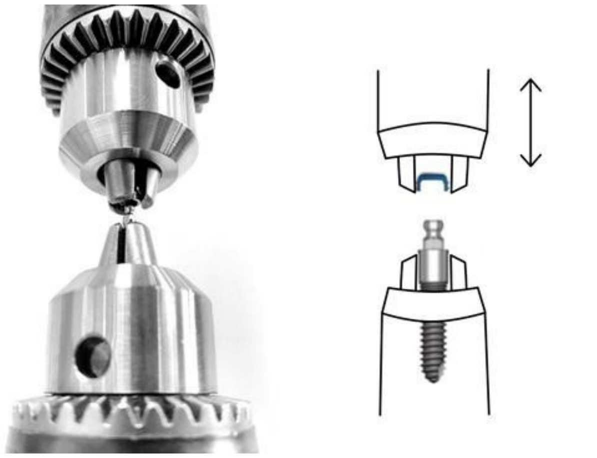

Figure 1 The testing apparatus (left: The sample was mounted in the universal testing machine, right: Diagram of the apparatus with an arrow showing the movement of the machine)

Retention force measurement

The retention force was determined by separating the O-ring from the abutment. The force was performed and monitored by the universal tester (EZ-SX, SHIMADZU, Japan), and the test speed was 50mm/min. The retention force was measured six times, at baseline and the end of 1100, 2200, 3300, 4400, and 5500 fatigue cycles. These were intended to represent 1, 2, 3, 4 and 5 years of denture use, respectively.

Stereo Microscope imaging

Stereomicroscope images of the mini-implant ball abutments and O-rings were taken before cyclic fatigue (SZ 61 OLYMPUS, Japan). After 5500 cyclic fatigue, the samples were examined by a stereomicroscope again.

Data analysis

The normal distribution of data collected was checked and confirmed with the Kolmogorov-Smirnov test. Mixed-Model Factorial ANOVA was performed to evaluate the effect of the attachment system and cyclic fatigue on retention force. Retention forces measured from the two attachment groups were compared by independent samples *T*-test. The comparison of retention force within the group was done with repeated ANOVA and followed with Bonferroni post hoc analysis. All analyses were performed at α=0.05. Data were calculated with the SPSS Statistics 22. The qualitative comparison was used for the evaluation of stereomicroscope images.

Results

Mixed-Model Factorial ANOVA result in Table 1, showed cyclic fatigue alone and the interaction between factors have significant effects impacting the retention force. In contrast, the effect of the attachment systems was insignificant. The mean retention forces of RD and OS groups recorded are shown in Table 2.

Table 1 Mixed-Model Factorial ANOVA

Effects	Sum of Squares	df	Mean Squares	F	Sig.
Cyclic fatigue	162.480	2.256	72.026	27.828	0.000
Cyclic fatigue x Attachment system	218.127	2.256	96.694	37.359	0.000
Attachment system	1.118	1	1.118	0.329	0.573

Retention forces between the two groups at each fatigue cycle were compared by independent samples *T*-test. The RD group showed significantly higher retention forces when compared to the OS group at baseline (*P*=0.000) and 1100 cycles (*P*=0.002). At 2200 cycles, there was no statistical difference between both attachment groups (*P*=0.750). At 3300, 4400, and 5500 cycles, the OS group retention force was higher than the RD group statistically (*P*=0.002, 0.000, 0.000).

Table 2 Retention force for each fatigue cycle (N)

Attachment system	Retention force in newton after cycles count (N)						
	Baseline	1100	2200	3300	4400	5500	Mean
RD	10.96±1.78[a]	8.73±1.23[b]	6.78±1.34[c]	5.04±1.19[cd]	4.49±1.26[de]	3.88±1.44[e]	6.65±0.24
OS	6.50±0.88[a]	6.66±1.27[a]	6.96±1.16[a]	6.86±1.07[a]	7.06±0.997[a]	6.997±1.02[a]	6.84±0.24
Comparison between groups (*P*-value)	0.000	0.002	0.750	0.002	0.000	0.000	0.573

The significant difference within the same attachment system was shown as different lowercase letters. (α=0.05)

The pairwise comparison within the same attachment system is also shown in Table 2. The retention force of the RD group when comparing the baseline to 1100 and 1100 to 2200 decreased significantly. However, statistical significance was not found when comparing 2200 to 3300, 3300 to 4400, and 4400 to 5500 cycles. In the OS group, the retention force was not statistically different between all fatigue cycles.

The stereomicroscope images of O-rings in Fig. 2 express material loss and changes for both groups after 5,500 cycles. The RD group exhibited surface roughness and material loss around the internal surface of the O-rings. In contrast, the OS group showed surface roughness and material loss on the upper surface of the O-rings. The ball abutment images of both groups indicated no wear in the stereomicroscope images.

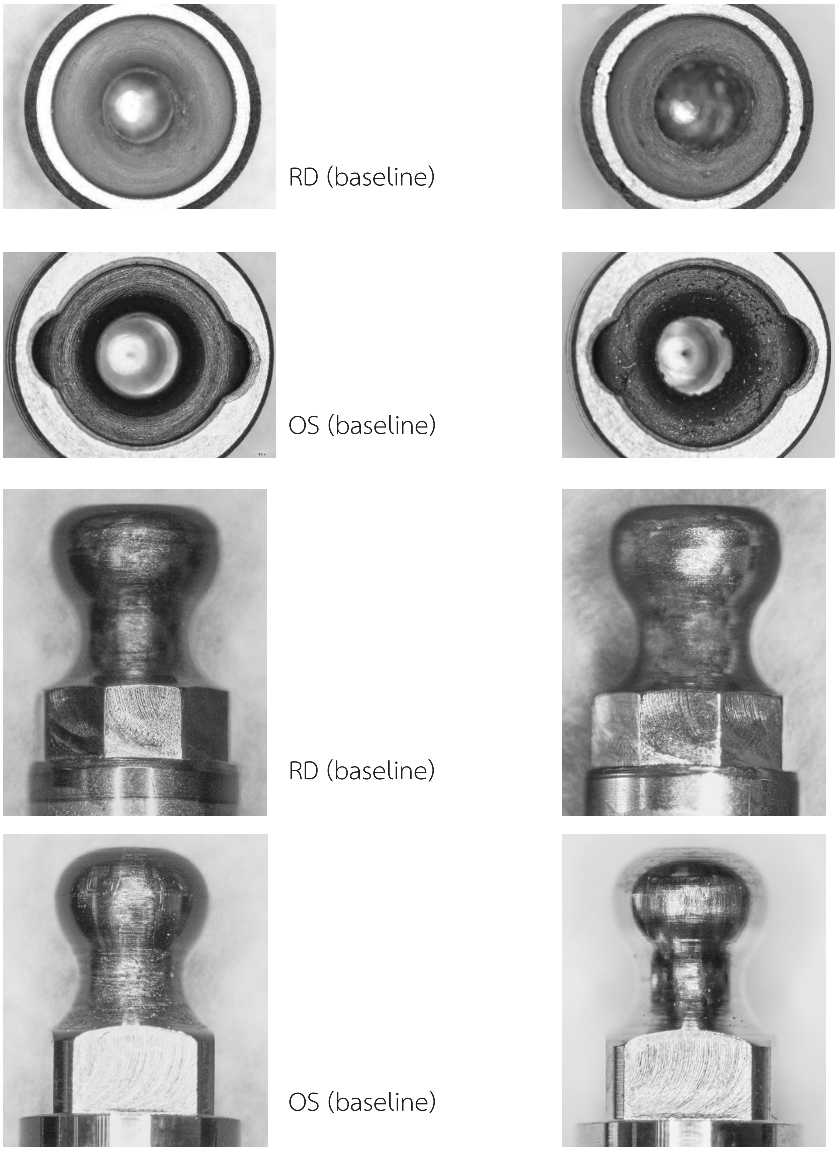

Figure 2 *Stereomicroscope images of O-ring and abutment at baseline and after 5500 fatigue cycles*

Discussion

The mini-implant overdenture has proven to be a long-term successful treatment option for edentulous patients.[25] The RetenDent product developed with Chulalongkorn University aims to be a great alternative with global standard, performance, and quality while being more affordable to Thai people.

The result from mixed ANOVA shows that the attachment systems had no statistical effect on retention force. The mean retention force of five years of fatigue cycles is 6.65±0.24N for the RD group and 6.84±0.24N for the OS group. The required retention for implant-overdenture has been studied with a variety of attachment types and methods. Pigozzo *et al.* had considered the minimum recommended retention force for 2-implant overdenture is 5N-7N.[26] Lehmann had considered a minimum of 5N for overdenture stability from their study.[27] However, the retention from this study was recorded from only a single mini-implant. A study has found that two-implant overdenture gives more than double the retention force of a single implant overdenture.[28] The recorded retention force in this study is comparable to previous studies. Leung and Preiskel measured the retention of 12 commercially available stud-type attachments. Retentive forces varied between 3N to 15N. Most of the attachments (8 of 12) exhibited forces between 6N to 9N. Fatigue test was not performed.[29] Besimo and Guarneri reported initial retention force of six brands of stud attachments were between 4.4N to 9.1N. Fatigue test was concluded to be sufficient for implant-retained overdentures in the long term.[30] Another study from Abou–Ayash *et al.* found a newly delivered attachment retention force ranged from 3.7±1.1N to 4.0±1.7N is sufficient for overdenture retention (MDI, condent GmbH, Germany). This value fell over time and can be re-established by an O-ring replacement.[31]

Patient satisfaction in overdenture cases greatly depends on the retentive ability of the attachment system, to stabilize the underlying denture.[32] The RD group in this test showed significantly higher retention forces compared to the OS groups at the first two years simulated. The RD group also had significant retention force change during the 0-2200 cycles. A previous study showed that the ball and O-ring attachment could lose its retention significantly in the first 1,500 cycles, with up to 75 % retention lost after 5,500 cycles.[33] In contrast, the OS group had significantly lower initial retention after 1100 cycles and held up better after 3300 cycles. A study expresses the same retention force stability for the ball and O-ring after 5,500 cycles in some systems.[34] This result coincides with the significant interaction of cyclic fatigue and attachment system effect calculated from the Mixed-Model Factorial ANOVA. However, despite the RD group changes in retention force, the significantly higher retention force at the simulated first two-years of use would be beneficial. Recall visits to reevaluate denture retention and O-ring replacement should be considered since overdenture cases required routine maintenance to achieve long-term success.[35]

The difference in wear characteristics of the attachment systems studied could be a result of variation in abutment design, O-ring material, or dimension. The microscope finding after 5500 fatigue cycles showed no wear on the RD and OS abutments. There have been reports of significant ball abutment wear in both an *in-vitro* study and a clinical situation.[36,37] This would be a consequential complication for one-piece mini-implants, as the treatment would require invasive removal surgery and a re-implantation procedure. In the OS group the O-ring implement has high elasticity and low hardness. This allows the O-ring to slide in and out of the titanium ball abutment smoothly, giving stable retention over time without damaging the abutment. However, this resulted in the compromise of a significantly lower initial retention. In the case of the RD group, a diamond-like coating (DLC) was implemented on the abutment with the aim to improve the wear resistance properties of the abutment.[38] The O-ring of the RD group has higher hardness (80±5 Shore A) with a smaller internal diameter, which contributed to the significantly higher initial retention force. Nonetheless, there was no visible wear presented in the RD abutment after fatigue cycles. In future developments, the coated ball abutment of the RD group would allow a more rigid attachment such as PEEK material to be coupled, thus providing better retention with a longer lifetime.

An additional finding in this study is regarding the abutment O-ring and housing design. Due to the dimensional differences of the ball abutment and O-ring between the OS and the RD groups, the OS samples experience O-ring dislodgement several times during fatigue cycling (Fig. 3). The O-ring was re-inserted, and the test continued. The housing of the RD group is larger than the OS group (Fig. 4). This was a design decision to improve housing retention in overdentures. A study showed that complications leading to housing replacements were common (26.9 %) and were very costly for their patients.[35]

Figure 3 *The O-ring dislodgement (arrow) was presented during the test only in the OS group*

Figure 4 *The O-ring housings (left: RD group, right: OS group) have design differences*

In the present study, only controlled vertical movements were performed to simulate the insertion and removal of overdentures. This action is the major factor causing retentive force reduction in overdentures. This experiment allows a controlled *in-vitro* comparison between the two systems. This also gave a possibility of relative comparisons to other studies because of the similarities in the testing methods. Other clinical factors and oral environment would further impact the wear characteristic of the attachment. For example, masticatory functions were not taken into account. However, several studies indicated simulated mastication had no effect, rather insertion-removal cycles caused a reduction in retention forces.[39,40] Saliva was proven to provide lubrication, and lessen attachment wear.[41] Clinically, the attachments may have better retention stability for this reason. Therefore, further study and clinical trials should be considered. Regardless of the overall similarity in the mean retention force of the two systems, the operator and patients should also take the long-term maintenance cost, availability, and technical difficulty into account when choosing an overdenture system.

Conclusion

The mean retention force from five years of fatigue cycles is 6.65±0.24N for the RetenDent system and 6.84±0.24N for the MS denture® system. They were not statistically different, and both were higher than the minimum recommended retention force for overdenture. The RetenDent system showed a significantly higher retention force at baseline and 1100 cycles than the MS denture®. However, the MS denture® system showed a significantly higher retention force at 3300, 4400, and 5500 cycles. There was no wear on the ball abutment of both groups under the stereomicroscope after 5,500 fatigue cycles.

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