Original article

Comparison of Retention between Two Implant Attachment Systems after Fatigue Test

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Abstract

The aim of this study was to compare retention after mechanical fatigue test 5,400 cycles between two implant attachment systems, the Locator® and the Locator R-Tx®. Ten samples of each system were investigated for the retentive forces. The retentive forces before fatigue test and subsequently after 900, 1,800, 3,600, and 5,400 cycles simulated 3-year functional life were recorded. Instron universal testing machine was a measurement with a crosshead speed of 5 cm per minute and 3 mm vertical range (0.14 Hz frequency). Descriptive statistics was represented as means and standard deviations. The retentive forces of both systems across each cycle of the whole fatigue test were compared by independent *t*-test (α = 0.05). Both systems resulted in decreased retentive forces in the overall fatigue test. The retentive force of the Locator R-Tx® exhibited from baseline to 5,400 cycles with 19.24 ± 1.12 N to 10.70 ± 1.75 N accordingly, and the Locator® exhibited from 19.95 ± 0.78 N to 11.65 ± 0.94 N. Although, the retentive forces of the Locator® in each cycle were higher than the Locator R-Tx® through the whole fatigue test, both systems were not statistically significant different (P<0.05) in each cycle. In conclusion, retention of the Locator R-Tx® and the Locator® was not significantly different both initial retention and final retention within 5,400 cycles fatigue test representing 3-year functional life. The Locator R-Tx® was an innovation to replace the Locator®, and it had improved geometry and design. This study supported that the Locator R-Tx® could provide retention similar to the Locator® which was a standard and popular implant attachment in the world's market.

Keyword: Fatigue test, Implant attachment, Implant overdenture retention, Retentive force

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Introduction

In the 20th century, dental implants became an aided dental device in enhancement of denture retention and stability. Implant-supported overdenture allowed more effective chewing, less physical pain and less psychological discomfort compared with conventional complete dentures. An overwhelming number of studies assessing patients' quality of life showed that the implant overdenture was more desirable than the complete denture.[1,2] These studies supported McGill Consensus 2002 which stated that conventional complete denture should no longer be the first-line treatment of choice for edentulous mandible, instead a two-implant mandibular overdenture should be recommended.[3]

Retentive components played an important role in implant-supported overdentures, and they were referred to as an implant attachment. The attachment was ordinarily classified into splinted and unsplinted groups. The splinted group (high-profile attachment) used a rigid connecting bar and a retentive clip when interocclusal space for overdenture was enough, whereas the unsplinted group used a solitary stud (patrix and matrix) such as balls, caps, magnets. The splinted group was indicated to correct implant divergences. The splinted group has more retention and stability, while the unsplinted group (low-profile attachment) was commonly advocated for cases with limited restorative space. The unsplinted group was more popular because of ease of cleaning, technical simplicity and cost effectiveness. A cap attachment was the most common clinical use, especially the Locator® Legacy was a popular brand of implant attachment system.[4-6] There were many laboratory tests and clinical studies[7,8] on the performance of The Locator®.

However, the Locator R-Tx® (Zest Anchors, USA) was launched in 2018 as a novel attachment system. It would be replaced by the Locator® Legacy. It was claimed by the manufacturer to exhibit dual engagement on the external surface of the attachment, potentially improving overdenture retention. Furthermore, it was promoted as a new DuraTec Titanium Carbon Nitride Coating that is 32 % harder and had a 26 % greater wear resistance and a 64 % reduction in roughness. The Locator R-Tx® was designed with a dual retentive surface and a narrower coronal geometry that allowed for an increase in pivoting capabilities of metal housing and allowed up to 60 degrees diversion between two implants. This was a great improvement over the Locator® Legacy that allowed up to 40 degrees diversion between the implants when extended range inserts were used. The pivoting capability also helped reduce damages to the nylon inserts when the implants were misaligned. With the original Locator®, clinicians were often faced with food debris being lodged in the tripod on top of the attachment, causing patients to complain about lack of retention and lack of ability to seat their dentures in place. Replacement of the tripod or drive mechanism with a small cavity of hex drive permitted simplified placement of the attachment and minimized an accumulation of food in the recess of the top. The industry standard hex drive mechanism allowed treating dentists to use most brands of 0.050 inches screwdriver that they had in offices. The housing was redesigned and subjected to pink anodization to reduce the chance of grey color of the housing showing through the acrylic denture base. Flat grooves were added on the cameo surface of the housing to resist vertical and rotational movements of the housing in the dentures after they picked up.[9]

Retention is one of the most important requirements of implant attachments. Maximum tensile load (peak load dislodgement) had been created in laboratories to search for retentive forces. Besides, many types of fatigue tests had been simulated to demonstrate the functional life of the attachments over a long-term period. Mechanical cyclic fatigue test was the most common fatigue test to simulate the wear of the attachments. The number of 1,080 - 15,000 cycles were determined approximately 3 - 10 years of use based on an average of 3 - 5 insertions and

removals per day. Retention of high-profile attachments (bar and clip), magnetic attachment, old-style stud attachment, and the Locator® showed various values depending on the attachment characteristic and the laboratory design.10-20 However, there was no report of the performance of the Locator R-Tx® both *in vivo* and *in vitro.* To our knowledge there was no study of single implants which compared the differences between the Locator® and the Locator R-Tx® before and after long-term fatigue tests. Therefore, the authors would like to compare retentive forces of these attachments *in vitro* after 5,400 cycles representing a three-year functional life. The purpose of this study was to evaluate the retention of the Locator R-Tx® after mechanical fatigue test 5,400 cycles compared to the retention of the Locator®. The null hypothesis was that the retentive forces after the mechanical fatigue test 5,400 cycles of two implant attachment systems are equal.

Materials and methods

In this study, there were two attachment systems in the test; the Locator® and the Locator R-Tx® (Gingival height = 3 mm, Zest anchors, USA) (Fig. 1, 2). Ten samples of each system were measured for the maximum retentive force and compared between the initial values and after the fatigue test. The pink nylon represented the medium retention of both systems (Table 1).

Figure 1 *Illustration of attachments (Left) Locator® (Right) Locator R-Tx®*

Figure 2 *Components of attachments (Left) Locator® (Right) Locator R-Tx®*

Table 1 *Characteristics of implant attachment systems evaluated in this study*

	Locator®	Locator R-Tx®
Number	10	10
Manufacturer	Zest Anchors, USA	Zest Anchors, USA
Nylon insert	Pink medium retention with core and ring (10.15 N)	Pink medium retention with dual step (not available retentive value)
Housing	Stainless steel	Stainless steel
Coating	TiNi	TiCNi (Duratec)

Each sample was composed of two parts: the lower part (Implant replica and metal attachment attached) and the upper part (Metal housing and nylon insert). Forty 22-mm diameter cylindrical plastic pipes with a height of 25 mm were made. Two pipes were used for the lower part fabrication containing two implant replicas (Regular Platform, NobelReplace Conical Connection, Nobel Biocare, Switzerland). Twenty pipes were used for the upper part fabrication (Ten pipes for Locator® and ten pipes for Locator R-Tx®)

For the lower part fabrication, an implant replica was held on the surveyor and axially embedded into self-cured acrylic resin (Unifast TRAD, pink, GC, Japan) in the pipe. Then, the Locator® and the Locator R-Tx® were mounted in each implant replica following the manufacturer's instructions. The metal housing with black nylon and block-out spacer were inserted to the attachments.

For the upper part fabrication, the pipe was filled up with self-cured acrylic resin. The center of the resin was marked and removed by the 8-mm round carbide bur. The pipe's hole was filled with self-cured acrylic resin using a direct technique following the manufacturer's instructions. The nylon insert of each system was changed from black nylon to pink nylon following the manufacturer's instructions. (Fig. 3)

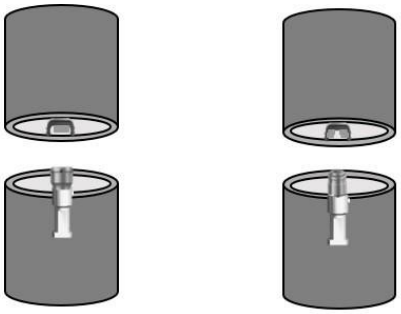

Figure 3 *Diagram of assembly used to test (Left) Locator® (Right) Locator R-Tx®*

Twenty samples, ten from each system, were evaluated. Initial retention and the subsequence after 900 cycles, 1,800 cycles, 3,600 cycles, and up to 5,400 cycles were recorded. It was claimed that 5,400 insertion and removal cycles simulated three years of in wearing dentures based on an average of five insertions and removals per day.[21]

After fabrication, the samples were placed in the Instron universal testing machine (e1000, INSTRON Instruments, England) for maximum retentive load testing using a crosshead speed of 5 cm per minute and 3 mm vertical range (0.14 Hz) in air room condition (Fig. 4). The speed was set approximately an *in vivo* snap removal and the majority of previous studies.[12,17,20,22] Each sample was tested three times and averaged, allowing the calculation of a mean and a standard deviation, to record initial baseline retentive values, which were reported on the graph and table with loads in newton (N) with the software (Instron Bluehill® Universal Software). (Fig. 5)

Figure 4 *Samples and Instron Universal Testing Machine (e1000, England)*

For the fatigue test, the samples were cycled up and down in the same machine and same conditions with the fatigue software (Cyclic Waveform Generator, Instron WaveMatrix™). (Fig. 6) At 900 cycles, 1,800 cycles, 3,600 cycles, and 5,400 cycles, the software was changed to record three times and averaged to correct the position of the samples.

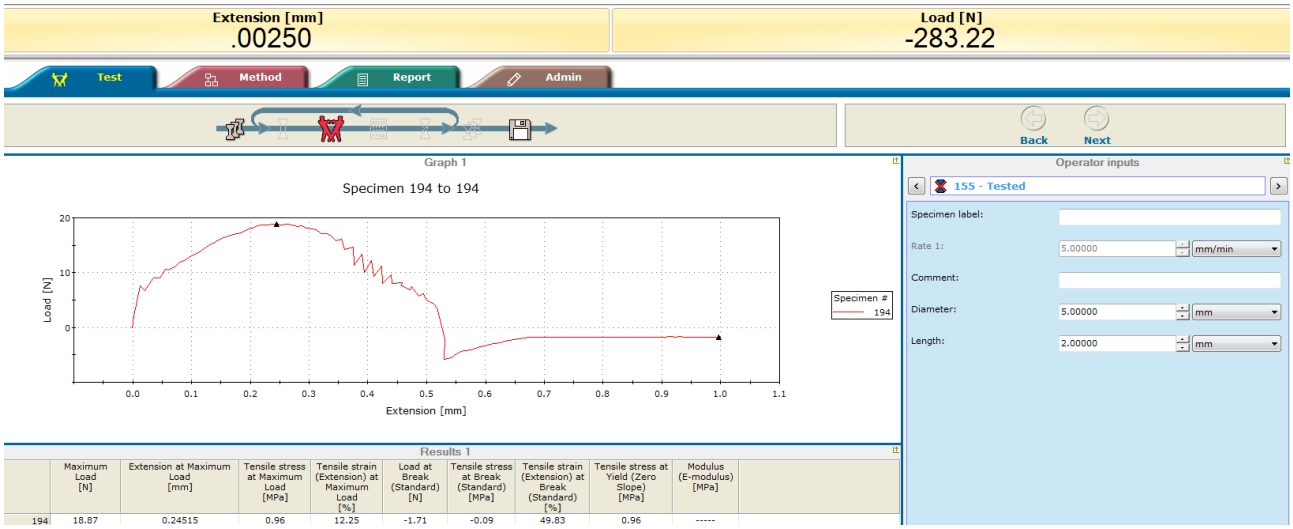

Figure 5 *Setting on computer screen of Instron Bluehill® Universal Software*

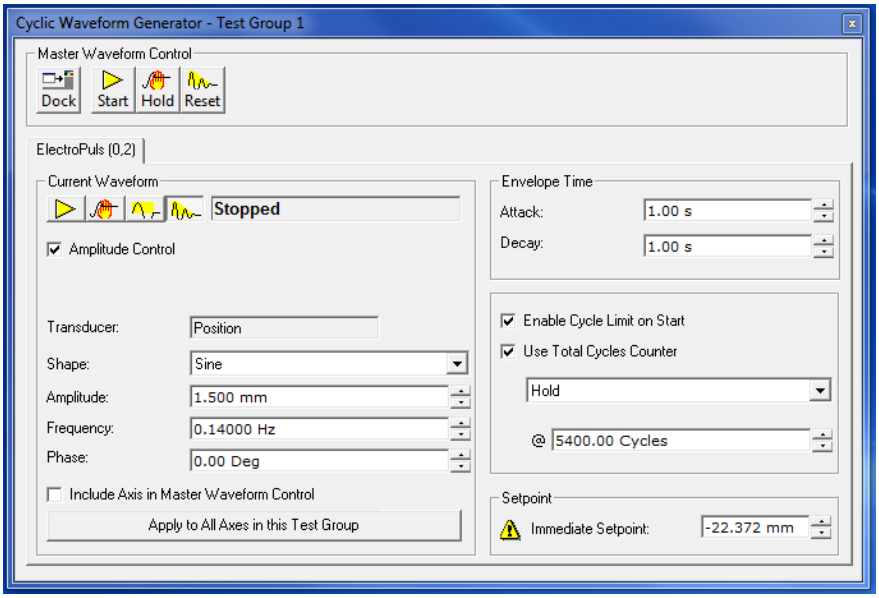

Figure 6 *Setting on computer screen of Cyclic Waveform Generator, WaveMatrix™*

Descriptive statistics was determined as means and standard deviations for maximum retentive forces and percentage reductions. Maximum retentive forces and percentage reductions of each system were compared at baseline, 900 cycles, 1,800 cycles, 3,600 cycles, and 5,400 cycles by independent *t*-test. The level of statistical significance was set at $p<0.05$ with the statistical software (SPSS Statistic 17.0).

Results

The descriptive statistics of changing retentive forces between Locator® and Locator R-Tx® over cycle sequences were described as means and standard deviations in Table 2. Both systems underwent the overall continuous decrease in retentive forces during the fatigue test. With the Locator® system, the mean retention fell from 19.95 ± 0.78 N at the baseline to 11.65 ± 0.94 N at

5,400 cycles (representing three years of functional life). With the Locator R-Tx® system, the retention fell from 19.24 ± 1.12 N to 10.70 ± 1.75 N. Although for each cycle, it was found that the retentive forces of the Locator® were higher than the Locator R-Tx® throughout the whole fatigue test, both systems were not statistically significantly different (P<0.05) in each cycle. The box plot showed the distribution of retention forces obtained by two systems (Fig. 7). Additionally, the data distribution of the Locator R-Tx® was noticed more than the Locator® throughout the whole fatigue test.

Table 2 *The descriptive statistics showed mean, standard deviation and percentage reduction of Locator® and Locator R-Tx® all fatigue cycles*

	Locator®			Locator R-Tx®		
	Retentive force (N)		Percentage reduction (%)	Retentive force (N)		Percentage reduction (%)
Cycle	Mean	SD		Mean	SD	
0	19.95	0.78	0.00	19.24	1.12	0.00
900	18.54	0.68	7.08	17.79	1.35	7.56
1,800	14.34	1.08	28.20	13.48	1.63	30.08
3,600	13.60	1.04	31.90	12.58	1.45	34.68
5,400	11.65	0.94	41.70	10.70	1.75	44.62

Although each system increased in percentage reduction of retentive forces across the whole fatigue test, both systems were compared and found to have no statistically significant differences within the same cycle throughout the whole fatigue test (P<0.05). The percentage reduction of both systems was found markedly at about 30 % of the beginning force between 900 and 1,800 cycles (representing ½ - 1 year functional life). After 5,400 cycles, both systems dropped to about 50 % of the beginning force. The box plot showed the distribution of the percentage reduction obtained by both systems (Fig. 8).

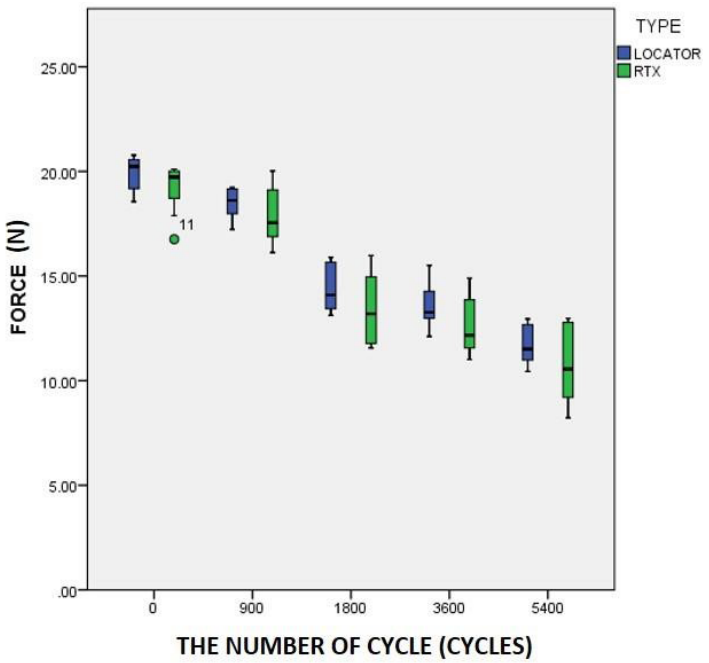

Figure 7 *The box plot showed retentive force of Locator® and Locator R-Tx® all fatigue cycles.*

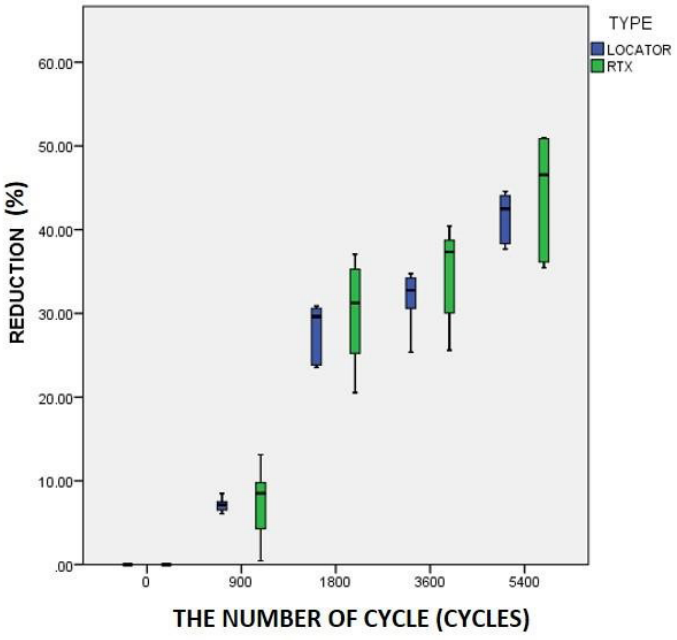

Figure 8 *The box plot showed percentage reduction of Locator® and Locator R-Tx® all fatigue cycles*

Discussion

The null hypothesis of this experiment was acceptable because the retentive forces after simulated wear in three years of two attachment systems were not statistically significantly different. In the same way, prior to the fatigue test, both systems with the pink retentive inserts were not statistically significantly different to the retentive forces.

Retention of the Locator® from the manufacturer evidently revealed the retentive values of all retentive levels: blue (6.66 N), pink (10.15 N) and white (22.20 N). Many studies have sought to explore the retention of different tools and methods. In a previous laboratory study, three retentive levels of a single Locator® were investigated and achieved three significantly different retentive values. All colour-coded Locator® were ten consecutive cycles in vertical pull out to evaluate the initial retention, and they were determined to have a 10-second interval in each cycle due to the elastic recovery of the nylon inserts. However, each retentive level was reported to be lower than the manufacturer: blue (3.83 N), pink (9.40 N) and white (12.39 N). The retention of the blue and the white Locator® was significantly lower than the manufacturer, but the pink Locator® was slightly lower than manufacturer. Nonetheless, different levels of retention matched the manufacturer's recommendation by selecting different retentive levels dependent upon patient needs. Each retentive level was observed with the dimensional misfit between the slightly oversized male part and the smaller diameter inner ring of the female abutment. Therefore, the different retentive levels were observed to be attributed to slight incremental differences in dimensions of the male parts.[23] However, some studies sectioned the retentive component to measure the nylon size of stud attachments affecting the retention. There was controversy that the nylon size was not only the main part of retention, but hardness and elasticity of the nylon inserts also might be another factor of retention.[17,21] Additionally, another study evaluated the retention of all colour-coded Locator®. The authors put up slightly faster crosshead speed than other studies (6.4 cm/min), and they set up the test under controlled

conditions of 37°C, pH 7, and artificial saliva. They found that the initial retentive values of the Locator® were arranged subsequently by the colour-coded levels: blue (9.03 N), pink (9.42 N) and white (11.33 N). Although the retention of the pink Locator® was close to the manufacturer, the retention of the blue and the white Locator® was different. The retention of the blue Locator® was higher than the manufacturer and similar to the pink Locator®. Meanwhile, the white Locator® was greatly lower than the manufacturer.[10] In other studies, the authors picked up the pink Locator® as a reference for the Locator® system. The initial retention of the pink Locator® (10.58 N) in 10 cycles in vertical pull out closely resembled the manufacturer. Besides, further studies by the same authors revealed the initial retention of all colour-coded Locator®. They developed tools and methods to continuously pull out using a spring jig (shock-absorbing spring) under simulated oral conditions. The Locator® was tested in a controlled 37°C demineralised water. The initial retention of the pink Locator® was approximately 8.88 – 15.20 N, and it showed standard deviation variations in three studies (SD = 0.1-9.4 N). Although the initial retention of the blue Locator® (16.50 N) was greatly higher than the manufacturer, the white Locator® (16.61 N) was greatly lower than the manufacturer. In summary, the initial retention of all colour-coded Locator® was not significantly different.[15-17] A further study measured the initial retention of the blue Locator®. The retention of the blue Locator® (15.36 N) in 10 cycles of vertical pulls out was higher than the manufacturer.[24] However, another study used a large sample size (n = 10) to evaluate the retention of the pink Locator®, which was found to be higher than the manufacturer (17.02 N).[12]

From the literature review for the initial retention of a single Locator®, there were different numbers of first period for initial retention, ranging from 3 – 15 consecutive cycles. Furthermore, there were different initial retentive values dependent upon different tools and methods, ranging from approximately 3 – 17 N.[10-20,22,23] Although most of the initial retentions of all colour-coded Locator® were arranged correspondingly to same retentive levels as the manufacturer's level, the initial retentions of each level were not significantly different. The pink Locator® showed retentive value close to the manufacturer, and it was a more reliable retention than the other colours. However, in this study, the initial retention of the pink Locator® (19.95 N) was higher than the manufacturer and all previous studies.

For the Locator R-Tx®, the manufacturer did not clearly state the retentive forces. These are only revealed for the retentive levels, for example, a light level in the blue retentive insert and a medium level in the pink retentive insert. It was therefore difficult to compare with the manufacturer's reference. However, in a previous study of the pink Locator R-Tx®, the authors examined the initial retentive values of two parallel implants with the pink Locator R-Tx® (20.10 N), and the retentive value was close to the two pink Locator® of the manufacturer (20.30 N). Although the retentive value from the previous study was slightly higher than the initial retention in this study (19.24 N), the retentive values of both studies were not significantly different.[20] Therefore, the initial retention could not completely conclude which has better retention between the Locator® and the Locator R-Tx®. Yet we could assume that both single and two implants with the Locator R-Tx® were not different in initial retention. The Locator R-Tx®—a novel implant attachment—could positively replace the Locator® to satisfy the patients' first impression when wearing overdentures.

Initial retention of implant attachments was important for initial impressions when a patient used implant-supported overdentures, but retention after functional use was also significant. The mechanical fatigue test simulated functional use under oral conditions, especially pull in and out tests which represented insertion and removal of overdentures. After the fatigue test, most studies had discussed both remaining retentive values and percentage reduction. Percentage reduction preferred to compare each attachment since it was calculated

individually from initial retention to final retention. In addition, the number of cycles determined the degree of mechanical fatigue test. Many Locator® fatigue studies described both short and long cycles,ranging from 540 – 15,000 cycles. These cycles were determined at approximately 1/2 - 10 years of use based on an average of 3 - 5 insertions and removals per day.[10-20] In a previous study, the authors evaluated fatigue test of a single Locator® at 5,400 cycles, showing the final retention of all colour-coded Locator®: blue (10.11 N), pink (8.82 N) and white (9.30 N). These did not correspond to retentive levels of the manufacturer. Although the pink and the white Locator® changed normally through wear and were found to have a 6 % and 18 % reduction, the blue Locator® increased to 12 % of initial retention. The author claimed abnormal deformation of blue nylon resilience. The pink Locator® was reported to have 8.82 N of remaining retention and a 6.4 % reduction, which was a lower retention and percentage reduction than this study (11.65 N, 42 % of reduction). It was assumed that a faster crosshead speed (6.36 cm/min), electrical fatigue machine, and continuously analysing software affected the results.[10] Another study exhibited retention loss of all colour-coded single Locator® after cyclic fatigue test, and the remaining retention after 15,000 cycles was: blue (6.24 N), pink (11.95) and white (10.28 N). They were not relative to the retentive levels of the manufacturer. Although the number of cycles was 3 times the number used in this study, the remaining retention of the pink Locator® was approximately close to this study (11.65 N). Yet the number of cycles (5,400 cycles) compared to the remaining retention (8.85 N) was lower than this study (11.65 N). This could be due to the shock-absorbing spring used in the study to absorb impaction of the retentive component. The percentage reduction changed ranging from 21 – 62 % at 15,000 cycles. The blue Locator® showed the greatest loss at 62 % of reduction. The pink Locator® was the lowest at 21 % of reduction, and it was lower than 42 % of reduction found in this study. Meanwhile, when comparing the number of cycles at 5,400 cycles, both studies were approximately close to 42 % of reduction.[17] Nevertheless, another study investigated the fatigue of a single pink Locator® at 14,600 cycles. They found that the remaining retention was 8.47 N, which was lower than the previous study (11.95 N). Moreover, the percentage reduction reached out to 50 % of reduction, which was greatly higher than the previous study. This might be affected by wear in dry conditions. Although when comparing the number of cycles at 5,000 cycles, the remaining retention of the study (11.51 N) was very close to this study at 5,400 cycles (11.65 N), percentage reduction (32 % of reduction) was lower than this study at 5,400 cycles (42 % reduction).[12]

To summarise, the tools and methods—especially the number of cycles—affected the remaining retention and percentage reduction after the fatigue test. The remaining retention was not in accordance with the retentive manufacturer's levels due to non-pattern of wear. Although it could not definitively determine the remaining retentive value and percentage reduction after a fatigue cycle, most studies showed that the tendency of retention after fatigue test was a decrease of at least 20 % of reduction. However, at 5,400 cycles representing three-year function life, we found that the remaining retention of a single pink Locator® is about 8 – 12 N, and the percentage reduction was approximately 30 – 40 % of reduction.

Only one study from the literature conducted a fatigue test for the Locator R-Tx®. Two implants with pink Locator R-Tx® were fatigued within 1,440 cycles, representing a one-year functional life. The remaining retention at 1,440 cycles (14.00 N) was slightly higher than this study (13.48 N) which evaluated only a single pink Locator R-Tx® at 1,800 cycles representing a one-year functional life. Conversely, the percentage reduction of both studies was surprisingly similar to 30 % of reduction in a one-year functional life.[20]

However, this study conducted a longer fatigue test at 5,400 cycles, representing a three-year functional life. We found that the remaining retention at only between 900 – 1,800 cycles rapidly declined at an approximate 20 % reduction. Then, the other periods of fatigue showed a

constant retention loss of approximately 10 % reduction in each cycle period. Finally, the Locator R-Tx® gradually decreased to 45 % of reduction and remained at 10.70 N of final retention. Meanwhile, the Locator® in this study had a gradual retentive loss through the fatigue test of approximately 10 % of the reduction in each cycle period. At the end of the test, the Locator® reached to 42 % of reduction and remained within 11.65 N of final retention. Consequently, the retention of both the Locator® and the Locator R-Tx® after a simulated fatigue test in three years were not significantly different. Both systems were also similar to the characteristic of retention loss. In addition, it could be concluded that the Locator® and the Locator R-Tx® were promoted in initial retention, and they were also recommended to have a durable functional life of at least three years (< 50 % of reduction).

Although this study showed higher retentive values of the Locator® than the Locator R-Tx® for all periods of the test, the retention of both systems was not statistically significantly different. The Locator® had the core retention, which was the main part of the retention, but the core was absent in the Locator R-Tx®. It was reformed to a smaller hex drive of 0.050 inches to reduce food debris inside the hole and to be compatible with the hex driver in standard implant prosthetic kits. However, the Locator R-Tx® was improved to be longer and narrower in geometry and dual step attachment to replace the core retention. We could assume that the new design without core retention replaces the core retention of the Locator®. In addition, the Locator R-Tx® was developed not only for the retention, but the Duratec surface coating was also changed to increase wear resistance. The pink colour of the attachment and the metal housing was more esthetic for gingiva and denture base. More flat grooves on the cameo surface of the housing resisted movements of the housing in the denture base. The new geometry and design of the Locator R-Tx® could be useful in real clinical situations.

In addition to the parallel implant attachment, the divergent implant attachment is also found in real clinical situations. A study showed a tendency for implant placement by less experienced surgeons to exhibit more implant divergence.[25] The Locator® was claimed to have a compensate implant angulation to total 20 degrees in a normal range, and 40 degrees in an extended range, while the Locator R-Tx® had a developed geometry and design without core retention to compensate for implant angulation to a total of 60 degrees. Many studies compensated for implant angulation. Initial retention of a single blue Locator® was evaluated in a study with parallel, 10, 30, and 45 degrees. They found that parallel, 10, and 30 degrees were not significantly different (13 – 15 N), but 45 degrees angulation (6.58 N) had a greatly lower initial retention than the previous groups.[24] In addition, two implants with blue Locator® at different angulations were measured for percentage of reduction after 5,500 fatigue cycles. Parallel two implants showed 27 % of reduction, but 10 and 20 degree angulation of two implants were found to have over 50 % of reduction.[26] A study evaluated all colour-coded Locator® with 0 – 20 degrees of angulation. They found over 20 degrees of angulation was higher than the initial retention by about 14 – 28 % due to greater friction in the first period, but they showed more percentage reduction in this group after a fatigue test, with an approximate 35 – 65 % reduction due to greater wear deterioration.[27] Furthermore, a study compared two pink Locator® and two Locator® R-Tx with different implant angulations. For initial retention, 30 degrees angulation did not affect either system. Sixty degrees of angulation showed greatly higher initial retention of both systems, in particular Locator® increased above 50 %. Sixty degrees angulation had a higher initial retention than two parallel implants. For more angulations, greater friction between retentive components was more retention at only the first period of use. The manufacturer claimed the Locator R-Tx® with all colour-coded inserts can be assembled with 60 degrees of angulation because it was compensated to implant divergently by the design of the attachment without core retention. However, the initial forces were considered to be unnecessarily high,

making it difficult for the patient to seat and remove the overdenture. Moreover, after a fatigue test of 1,440 cycles, both 30 and 60 degrees of angulation had a higher percentage reduction (approximately 30 – 57 %), especially the Locator® in 60 degree (57 % of reduction). The parallel group exhibited less percentage reduction (approximately 26 – 30 %). As described, it could be claimed that the Locator R-Tx® better compensated than the Locator®, and it might increase the longevity of the attachment in daily clinical use.[20] In addition, some studies evaluated implant compensation compared to 10, 20, 30, and 60 degrees of angulation. They found that 10, 20, and 30 degrees of angulation were not different in percentage reduction than the parallel group, but 60 degrees of angulation had a distinctly greater percentage reduction of over 50%.[18,20,28] In particular, the green extended range of the Locator® was approved in 20 degrees angulation. It did not have a significantly different retention to the parallel white Locator®.[29]

In summary, it could be concluded that the Locator® was moderately compensated to 30 degrees angulation, especially for extended range. The locator R-Tx® was highly compensated at more than 30 degrees of angulation. However, we did not recommend compensating implant angulation because it had been reported to have more clinical complications and more implant divergence.

A variety of tools and methods had been used in previous studies, and they directly influenced the retentive values of the attachments. A universal testing machine and its software were used to determine the measurements. The Instron universal testing machine (macromaterial testing machine) with Bluehill software—a standard machine—was used for testing in this study. In a previous study, the authors showed that retention of the Locator® was similar to this study.[12] However, a micromaterial testing machine and a fatigue testing machine were used to measure retention of the Locator®. They were shown to have lower retentive forces than the macromaterial testing machine since they might measure forces more delicately in low force tests.[10,17,30] In this study, implant overdentures were tested only according to a vertical removal force direction. Although they generally did not have a specific path of insertion and removal in clinical situations, the vertical direction was a standard test for retention. In addition, we observed during the machine processing when the retentive insert pressed down on the attachment. The range of the position could be zero force as a calibration of force or balanced load. This might be an inaccuracy of force before the attachment had been calibrated to zero force. Therefore, the balance of force and the accuracy of position should be clearly determined for all sample tests.

The crosshead speed used in this study was 5 cm/min which was the same speed used in many previous studies of the Locator®. This speed was easy to compare with other studies. Some studies containing other types of attachments used a faster speed than 5 cm/min, which tended to have a lower attachment retention.[15,16] In addition, we observed in the pilot test with slow speed test (0.2 cm/min) that we found double peak load dislodgement in the load and extension diagram. Although the double peak exhibited only in the first fatigue test, it was absent after the fatigue test. Therefore, this result could support dual step attachments only in the first functional use and in the mastication (slow speed test).

Some studies ensured a sufficient retentive force for overdenture patients. In the literature review, Caldwell *et al.* (1962) simulated chewing tools to evaluate food adhesiveness. They showed that approximately 10 N of retaining forces for normal food, and about 15-20 N of sticky food.[31] Burns *et al.* (1995) claimed that 10 N for ball attachment overdenture resulted in excellent satisfaction among patients and good satisfaction with about 5 N of magnetic attachment overdenture.[32] Naert *et al.* (1999) assessed retention of implant-supported overdentures with different attachments. They measured subjective and objective retentions by interviewing and using a dynamometer from patients wearing the overdentures. They found that the initial retention of the

overdentures with different attachments ranged from 6.42 - 16.43 N. The patients then used the overdentures for five years, and retention of the overdentures were re-evaluated. They found that the remaining retention of the overdentures ranged from 1.08 – 12.52 N, and the percentage reduction of them reached out to 14 – 70 %. Magnetic attachment showed poor retention in all functional periods. Bar and clip attachments maintained the highest retention at all times. Moreover, it was found that subjective and objective retentions were weakly correlated, but the magnetic attachment tended to have low satisfaction from the patients' interviews.[33] Setz *et al.* (1998) and Rutkunas *et al.* (2004) compared their mechanical fatigue experiments to previous clinical studies, concluding that around 20 N was an acceptable retention for overdentures.[16,34]

Although there were rarely studies to show obviously satisfying retention, it could be concluded that 10-20 N showed appropriate retention for overdenture patients. Therefore, in this study, retention of a single attachment could be satisfying for overdentures within a three-year functional life.

Nowadays, there were more clinical studies with acceptable results for single-implant overdentures. A clinical study compared two-implant overdentures and single-implant overdentures by immediate loading with a one-year follow-up. General satisfaction, social life, chewing ability, comfort, and fit were not significantly different between the two groups. In radiographic examination, marginal bone loss of the single-implant overdenture was indicated in the success criteria.[35] Prospective clinical research of midline single-implant overdenture showed low biological complications within a five-year follow-up. Although the patients had high plaque accumulation around the dental implant and attachment, a low gingival response and marginal bone loss was exhibited.[36] A randomised clinical trial comparing single- and two-implant supported overdentures was assessed for implant survival, patient satisfaction, and prosthetic complications within a five-year follow-up. Although both groups were not significantly different for effective results, denture fracture was predominantly noticed around midline single implants.[37] Relining the denture base was also found to be more frequent in midline single implants.[38] Moreover, a meta-analysis study of three trials regarding overall nylon replacements comparing two-implant overdentures and single-implant overdentures revealed no significant differences as there were statistically significantly different more nylon replacements in the two-implant overdentures at the five-year follow-up.[39]

This study attempted to simulate single-implant overdentures in a clinical situation, although it was known that single-implant overdenture could tend to rotate in multiple directions and risk prosthetic complications. We believed that single-implant overdentures could be more acceptable for those who could not afford more implants.

However, a limitation of this study was that the retentive force demonstrated only axially vertical removal of the attachments. The results of the *in vitro* study were information only pink attachment. The study lacked saliva, temperature, and pH control which could affect the results. There was a multifactor for overdenture retention under oral conditions, for example, mastication, multiple direction of overdenture movement, and chemical degradation. Readers should keep in mind that the results were not concluded in all real situations. More clinical studies could be undertaken to better support decisions to use different attachment systems.

Within the limitations of this laboratory study, the following could be concluded:

1. Retention of the Locator® and the Locator R-Tx® were not significantly different for both initial retention and final retention within 5,400 cycle fatigue tests, representing a three-year functional life.

2. Although all the retentive values in each cycle period of the Locator® were higher than the Locator R-Tx®, both systems did not have significantly different retention throughout the whole fatigue test.

3. Overdenture patients were satisfied with 10 –

20 N of retentive force, and the single Locator® or Locator R-Tx® demonstrated sufficient retention after a three-year functional life for overdenture patients.

4. The Locator R-Tx®—a new implant attachment model—would replace the Locator®. The Locator R-Tx® was developed with geometry and materials to solve some problems of the Locator®. This study supported that retention of the Locator R-Tx® was not statistically different to the Locator®, which was a well-designed attachment and a popular attachment in the world market.

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