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Original Article

# Retentive force and dislodgment time variations between three implant overdenture stud attachments in an acidic environment: An in-vitro pilot study

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A R T I C L E I N F O

*Keywords:*
Implant overdentures
In-vitro study
Attachment systems
Cyclic dislodging
Retention
Dislodgment time

A B S T R A C T

*Introduction:* This in-vitro study aimed to evaluate the retentive force and dislodgment time of three stud attachment systems used for mandibular two-implant overdentures by simulating insertion/removal cycles.
*Materials and methods:* From a simulation of a completely edentulous mandible with two parallel implants (Ø4.5 mm internal hex connection) (Zimmer Biomet, Warsaw, IN), 15 resin bases were fabricated and divided into three groups (n = 5 each): OT Equator (Rhein83, Bologna, IT), Locator (Zest Dental Solutions, Escondido, CA) and Locator R-Tx (Zest Dental Solutions, Escondido, CA). Pink inserts underwent 2000 cycles of thermocycling (SD MECHATRONIK GmbH, Feldkirchen-Westerham, Germany) and were soaked in citric acid for 24 days in an incubator. Each base underwent 2000 insertion/removal cycles on the Versa Test testing machine (Mecmesin Ltd., W. Sussex, UK) which was used to measure the retentive force and dislodgment time. The results were analyzed using ANOVA followed by the post-hoc Tukey test, Kruskal–Wallis test, and Pearson correlation coefficient test. A p-value of $< 0.05$ was considered statistically significant.
*Results:* The retentive force and dislodgment time of the three systems significantly decreased over the cycles ($p < 0.05$). The Locator R-Tx showed significantly greater retentive force than did the other systems ($p < 0.05$), except for the last cycles wherein no significant difference was found with the OT Equator ($p > 0.05$). The OT Equator had the most stable retention over the cycles ($p > 0.05$; cycle 1500).
*Conclusion:* The three systems showed satisfactory retentive force during the 2000 cycles. The Locator R-Tx demonstrated the best retention, while the OT Equator exhibited the most stable retention over time.

## 1. Introduction

Mandibular prostheses retained by two implants are considered the standard treatment for edentulous patients according to the McGill Consensus Statement in 2002 (Feine et al., 2002). These prostheses improve patient satisfaction by providing better comfort, stability, and masticatory efficacy compared with conventional prostheses (Kutkut et al., 2018). Implant overdentures are retained with attachments, and several types are available on the market, including bars, balls, studs, and magnets (Abdelkoui et al., 2016; Kim et al., 2012). One of the stud attachment systems that have become popular is the Locator (Zest Dental Solutions, Escondido, CA), introduced in 2001. It features a pivoting technology, self-aligning design, and dual retention ability and allows for restoration of up to 40° of divergent implants (Zest Dental Solutions, n.d.). The Locator is indicated in cases of limited prosthetic spaces (Miler et al., 2017; Yilmaz et al., 2019), owing to its low profile (3.17 and 2.5 mm for externally hexed and non-hexed implants, respectively) (Vasant and Vasant, 2013; Zest Dental Solutions, n.d.) and excellent retention (Ahuja and Cagna, 2011). Being prone to wear and retention loss, the Locator's design was modified, and a new attachment called the Locator R-Tx (Zest Dental Solutions, Escondido, CA) was introduced in 2016 (Yilmaz et al., 2019). Its abutment has a narrower coronal geometry, stronger DuraTec coating to prevent surface wear, and greater flexibility that allows it to compensate for up to 60° between

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implants (Srinivasan et al., 2020; Zest Dental Solutions, n.d.). The OT Equator (Rhein83, Bologna, IT), an implant overdenture attachment launched in 2007, is the smallest attachment system available on the market with a low vertical profile of 2.1 mm and a diameter of 4.4 mm, making it an optimal solution when the prosthetic space is compromised. Its abutment has a nitride coating providing wear resistance over time (Cervino et al., 2019; Mínguez-Tomás et al., 2018; Rhein83, n.d.; Satti, 2013). This in-vitro study aimed to evaluate the behavior of these three stud attachment systems used for implant overdentures. The null hypotheses were as follows:

- There would be no significant difference in the retentive force between the three stud attachment systems.
- There would be no significant difference in the dislodgment time between the three stud attachment systems.

## 2. Materials and methods

### 2.1. Thermocycling and immersion

In this in-vitro pilot study, pink retention inserts were used for the three attachment systems. The inserts were immersed in distilled water in a thermocycler (SD MECHATRONIK GmbH, Feldkirchen-Westerham, Germany) and subjected to 1000 cycles consisting of alternating 30-s exposures to temperatures of 5 ± 1 °C and 55 ± 1 °C (Goiato et al., 2014). They were subsequently soaked in a citric acid aqueous solution (3.84 g/L; pH = 3.8) in an incubator for 12 days at 37 °C (Fatemi et al., 2019). This procedure was repeated twice. In total, the specimens underwent 2000 cycles in the thermocycler simulating thermal changes inside an oral environment for 2 years of clinical denture use (Goiato et al., 2014) and 24 days of immersion in the citric acid solution equivalent to 2 years of consumption (Fatemi et al., 2019).

### 2.2. Specimen fabrication

A simulation of a completely edentulous mandible with two parallel implants (Ø4.5 mm internal hex connection) (Zimmer Biomet, Warsaw, IN) in the symphyseal region, spaced by 22 mm, was used (Fig. 1). Three secondary models were obtained through a polyether impression (Impregum Soft; 3 M ESPE, St. Paul, MN) with an individual open tray fabricated from the master cast. Each secondary model contained two implant analogs fitted with abutments of the three attachment systems. Fifteen corresponding prostheses were fabricated: five prostheses for each attachment system, each with two metal housings. Three metallic chains were attached to each prosthesis: one on the midline and two posteriorly on the first molar. The three chains were hooked together equidistantly in one point (geometric center) to be mounted on the machine.

### 2.3. Machine testing

The models and prostheses were mounted on the Versa Test testing machine (Mecmesin Ltd., W. Sussex, UK) (Fig. 1), which was used to measure the retentive force and dislodgment time during insertion/removal cycles. The removal speed was set at 50 mm/min. Each prosthesis underwent 2000 insertion/removal cycles, with a 10-s interval between each insertion/removal cycle in the presence of artificial saliva (Biotène Mouthwash; Laclede Inc., Rancho Dominguez, CA) (Boulos et al., 2018; Jalllian et al., 2015; Yilmaz et al., 2019).

### 2.4. Data collection

The first three cycles were not considered to ensure complete wettability of the attachment systems (Tohme et al., 2018). The retentive force was recorded in Newton values as follows: all values for the first 30 cycles, one value every 10 insertion/removal cycles up to cycle 100, and then one value every 100 insertion/removal cycles up to cycle 2000. A total of 56 values were recorded for each prosthesis. The dislodgment time was recorded in seconds for the first cycle, and one value was documented every 200 cycles. A total of 11 values were recorded for each prosthesis.

### 2.5. Statistical analysis

ANOVA was conducted to compare multiple means using SPSS version 26, followed by the post-hoc Tukey test to compare each mean with every other mean for the retentive force. The Kruskal–Wallis test was used to assess the differences in the retentive force and dislodgment

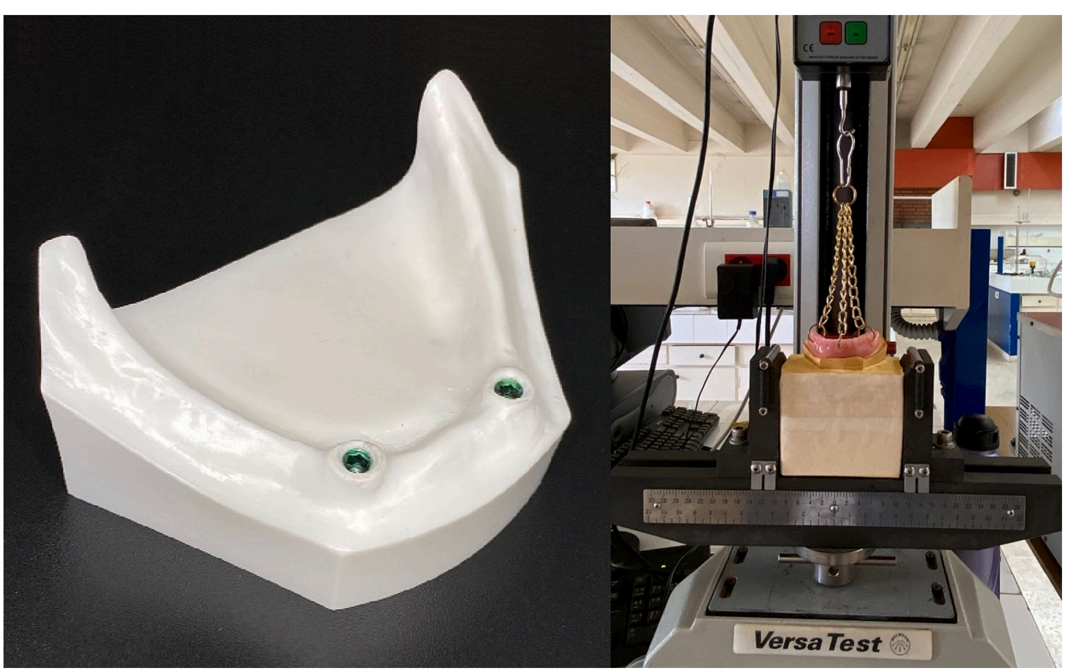


**Fig. 1.** Simulation of the completely edentulous mandible with two parallel implants (left); mounting on the Versa Test testing machine (right).

time between the three groups at specific cycles. The same test was applied to evaluate the changes in the retentive force over the cycles compared with the initial cycle. Pearson correlation coefficients were calculated to determine the correlation of the number of cycles with the retentive force and dislodgment time. A p-value of $< 0.05$ was considered statistically significant.

## 3. Results

### 3.1. Retentive force

The variations in the retentive force during the cycles are shown in Fig. 2. The Locator demonstrated significantly greater mean retentive force than did the OT Equator for cycles 1–40 ($p < 0.05$). For cycles 50–1500, there was no significant difference between the two systems ($p > 0.05$). The OT Equator had significantly greater mean retentive force than the Locator for cycles 1600–2000 ($p < 0.05$). The Locator R-Tx showed significantly greater mean retentive force than did the OT Equator during all cycles ($p < 0.05$), except for cycles 1600–2000 wherein the difference was not significant ($p = 0.123$). The Locator R-Tx exhibited significantly greater mean retentive force than did the Locator throughout most cycles ($p < 0.05$) (Table 1). At baseline (Table 2), no significant difference was found between the OT Equator and Locator. However, there was a significant difference between the Locator R-Tx and OT Equator and between the Locator and Locator R-Tx. The difference in the initial retentive force was found at cycle 1000 for the Locator ($p = 0.047$), at cycle 1500 for the Locator R-Tx ($p = 0.009$), and at cycle 2000 for the OT Equator ($p = 0.047$) (Table 3). The three attachments showed a significant negative correlation between their retentive forces and the number of cycles, with the OT Equator showing the most stable retention over time (Pearson correlation coefficient: OT Equator: −0.26 [$p = 0.04$]; Locator: −0.93 [$p < 0.001$]; Locator R-Tx: −0.72 [$p < 0.001$]).

### 3.2. Dislodgment time

The variations in the dislodgment time during the cycles are shown in Fig. 2. The Locator showed significantly longer dislodgment time than did the OT Equator for cycles 1–1000 ($p = 0.010$). For cycles 1200–2000, no significant difference was found ($p = 0.095$). The Locator R-Tx demonstrated significantly longer mean dislodgment time than did the OT Equator throughout all cycles ($p < 0.05$). There was no significant difference between the Locator and Locator R-Tx throughout all cycles ($p > 0.05$) (Table 4). The three attachments showed a significantly negative correlation between their dislodgment time and the number of cycles (Pearson correlation coefficient: OT Equator: −0.77 [$p = 0.006$]; Locator: −0.78 [$p = 0.005$]; Locator R-Tx: −0.73 [$p = 0.010$]).

## 4. Discussion

The retention of stud attachments is critical to the success of the

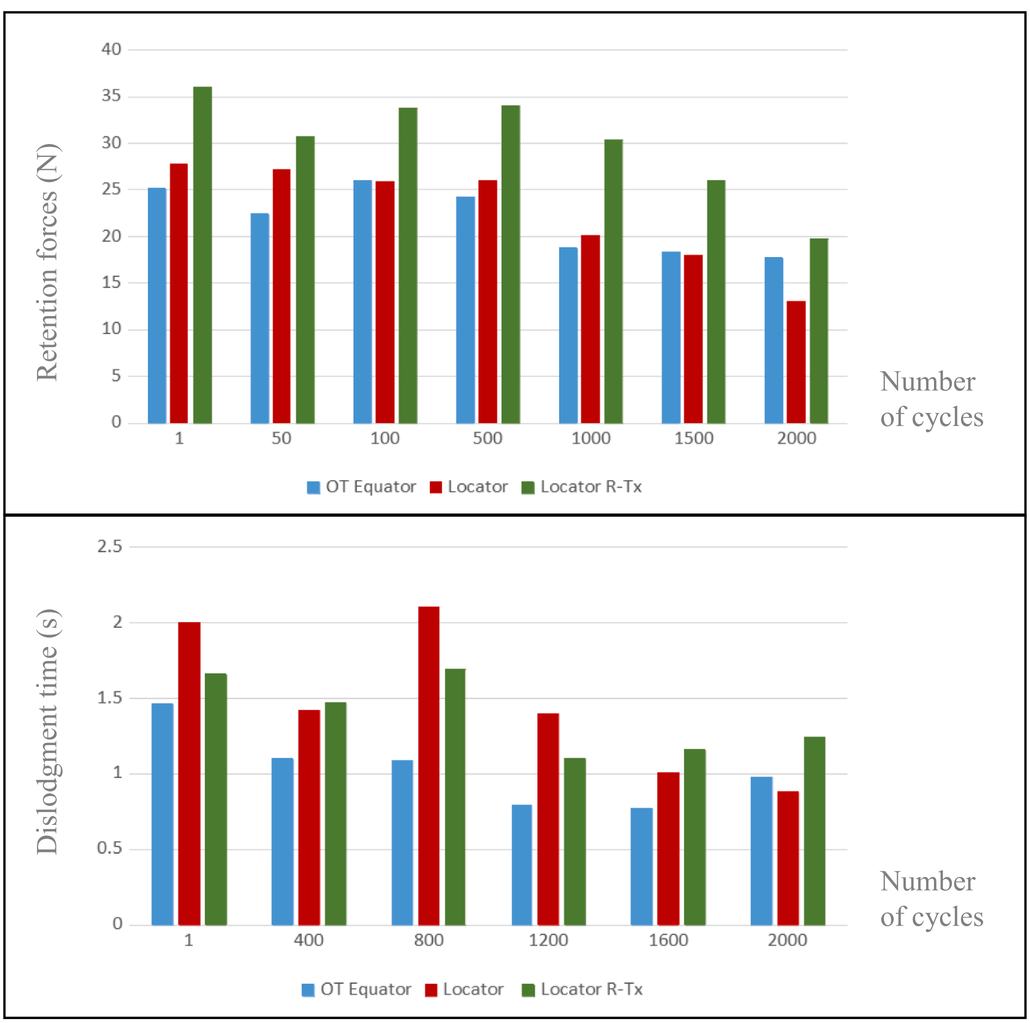


**Fig. 2.** Results of the retention forces in Newton (N), and the dislodgment time in seconds (s) of the three attachment systems.

**Table 1**
Comparison of means between the groups: retention forces.

| ANOVA/Post-hoc Tukey test | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Number of cycles | OT Equator | | Locator | | R-Tx | | p-value OT Equator/ Locator | p-value OT Equator/ R-Tx | p-value Locator/ R-Tx |
| | Mean (N) | Standard Deviation (N) | Mean (N) | Standard Deviation (N) | Mean (N) | Standard Deviation (N) | | | |
| 1–40 | 20.50 | 1.92 | 28.47 | 1.50 | 31.80 | 3.62 | <0.001 | <0.001 | <0.001 |
| 50–90 | 21.02 | 1.85 | 24.71 | 1.78 | 30.03 | 4.71 | 0.185 | 0.002 | 0.046 |
| 100–500 | 24.86 | 1.77 | 27.38 | 2.50 | 32.60 | 1.71 | 0.163 | <0.001 | 0.004 |
| 600–1000 | 21.17 | 1.61 | 22.72 | 1.72 | 26.07 | 2.95 | 0.516 | 0.010 | 0.076 |
| 1100–1500 | 19.60 | 0.95 | 19.80 | 1.48 | 24.24 | 1.58 | 0.973 | <0.001 | <0.001 |
| 1600–2000 | 18.83 | 1.44 | 15.02 | 1.78 | 21.03 | 1.63 | 0.007 | 0.123 | <0.001 |

**Table 2**
Comparison of initial retention values between the groups.

| Kruskal–Wallis test | | | | | | |
|---|---|---|---|---|---|---|
| | OT Equator | Locator | R-Tx | p-value OT Equator/ Locator | p-value OT Equator/ R-Tx | p-value Locator/ R-Tx |
| Initial retention values (N) | 25.16 | 27.8 | 36.04 | 0.602 | 0.009 | 0.047 |

**Table 3**
Comparison with the mean initial retention value for each group.

| Kruskal–Wallis test | | | |
|---|---|---|---|
| Cycles | p-value OT Equator | p-value Locator | p-value R-Tx |
| 1 and 100 | 0.917 | 0.465 | 0.531 |
| 1 and 500 | 0.754 | 0.835 | 0.602 |
| 1 and 1000 | 0.060 | 0.047 | 0.076 |
| 1 and 1500 | 0.060 | 0.028 | 0.009 |
| 1 and 2000 | 0.047 | 0.009 | 0.009 |

implant overdenture treatment. This experimental study tested the variations in the retentive force and dislodgment time between three stud attachment types after a simulation equivalent to 2 years of use. The results reject the null hypotheses because significant differences were observed.

The initial values obtained arose from the synergy of forces of two inserts, providing a total force greater than that of an individual insert given by manufacturers (Locator: 13.33 N; Locator R-Tx: medium retention; OT Equator: 11.77 N).

The Locator had greater mean initial retentive force than the OT Equator, but no significant difference was found between them. The Locator R-Tx had greater mean initial retentive force than the Locator. These findings are consistent with other reports (Mínguez-Tomás et al., 2018; Satti, 2013; Yilmaz et al., 2019). The Locator R-Tx showed greater mean initial retentive force than did the OT Equator; no previous study has compared these two attachments. The differences in the initial retentive force noted herein are also found in previous studies owing to differences occurring during attachment manufacturing (Al-Ghafli et al., 2009).

In this study, both the Locator and OT Equator exhibited retention loss, with the OT Equator maintaining greater mean retentive force at the end of the cycles. The Locator R-Tx had the greatest mean retentive force, except for the last cycles with the OT Equator, wherein no difference was found between the two attachments. A significant decrease in the initial retentive force was found at cycle 2000 for the OT Equator and cycle 1500 for the Locator R-Tx. The OT Equator showed the weakest correlation between the number of cycles and retentive force. These findings demonstrated that the OT Equator maintained better retention over time. In all three groups, the retentive force decreased as the number of cycles increased, which is consistent with most in-vitro findings (Al-Ghafli et al., 2009; Srinivasan et al., 2016; Tohme et al., 2018), considering that the behavior of this loss varies according to the attachments used and the experimental conditions. These differences are also seen clinically, explaining the variability in maintenance needs among implant overdenture wearers (Srinivasan et al., 2016). A previous study showed that after cyclic dislodgment (1440 cycles), there was no significant difference between the Locator and Locator R-Tx (Yilmaz et al., 2019). This finding differs from the present data, perhaps because the authors did not use any lubricant, which may have accelerated the retention loss for the Locator R-Tx. Another study showed that the Locator maintained more stable and greater retention than did the OT Equator at the end of cycles (Mínguez-Tomás et al., 2018). The use of one implant, the lack of lubrication, and the higher number of cycles (14600) may explain these differences from our results. Other studies showed a more stable retention loss for the OT Equator than for the Locator (Satti, 2013) and a retention loss for the Locator starting at cycle 1000 (Kobayashi et al., 2014), similar to our findings. Another study found no difference in the Locator's retention at cycle 1000 (Srinivasan et al., 2016). This differs from our results possibly owing to thermocycling and soaking in citric acid, which may accelerate the aging of inserts. Other authors concluded that the retention of the Locator R-Tx decreased significantly starting at cycle 30000. They used a different experimental protocol and conducted 30,000 cycles in a chewing simulator using one implant (Wichmann et al., 2020).

Herein, the initial retentive force increased at the early stages of

**Table 4**
Comparison of means between the groups: dislodgment time.

| Kruskal–Wallis test | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Number of cycles | OT Equator | | Locator | | R-Tx | | p-value OT Equator/ Locator | p-value OT Equator/ R-Tx | p-value Locator/ R-Tx |
| | Mean (s) | Standard Deviation (s) | Mean (s) | Standard Deviation (s) | Mean (s) | Standard Deviation (s) | | | |
| 1–1000 | 1.15 | 0.16 | 1.65 | 0.30 | 1.58 | 0.14 | 0.010 | 0.010 | 0.936 |
| 1200–2000 | 0.90 | 0.12 | 1.07 | 0.18 | 1.15 | 0.05 | 0.095 | 0.009 | 0.117 |

cycling and then decreased at the later stages owing to the attachments' wear. This initial increase has been noted and explained by several authors as the result of the roughness caused by the early wear of nylon inserts and thermal expansion in polymers during the first cycles, thus increasing nylon and abutment friction (Boulos et al., 2018; Kobayashi et al., 2014; Mínguez-Tomás et al., 2018; Pigozzo et al., 2009; Satti et al.,2013; Setz et al., 1998). Other authors have explained it as a run-in period for the attachment wherein the retentive force increases and then decreases until it stabilizes over time (Besimo and Guarneri, 2003).

An average retention loss of 27.84 %, 15.82 %, and 25.36 % was recorded at cycle 1000 and 52.95 %, 45.17 %, and 29.65 % at cycle 2000 for the Locator, Locator R-Tx, and OT Equator, respectively. At cycle 1500, the loss was 35.25 %, 27.97 %, and 26.95 %, respectively. These findings are close to those of the study by Yilmaz et al. (2019). Other authors reported a loss of 33 % for the Locator (cycle 1440), which is close to our findings, and 45 % for the OT Equator, which differs from our findings probably because of the transparent inserts (Satti, 2013).

The minimum retentive force required for the satisfaction of implant overdenture wearers has been reported to range from 5 to 20 N (Abi Nader et al., 2011; Al-Ghafli et al., 2009; Kobayashi et al., 2014; Pigozzo et al., 2009; Sia et al., 2017; Uludag et al., 2014; Yilmaz et al., 2019).

To date, there is limited evidence on the dislodgment time. Understanding the dislodgment time is valuable for several reasons: A too short dislodgment time can cause a sudden dislodgment of prostheses during function, which can be discomforting for patients and necessitate frequent insert replacements; conversely, a too long dislodgment time can cause difficulties in prosthesis removal, especially for older adults or medically compromised patients. In our study, the Locator R-Tx showed the most favorable dislodgment time: It showed significantly higher mean values than did the OT Equator and more stable values than did the Locator throughout the cycles. Nevertheless, satisfaction with denture retention and stability varies depending on patients' expectations and preferences (De Albuquerque et al., 2019).

Several solutions have been previously applied to simulate clinical conditions (Boulos et al., 2018; Cervino et al., 2019; Kobayashi et al., 2014; Pigozzo et al., 2009; Rutkunas et al., 2011; Satti, 2013; Srinivasan et al., 2016; Wichmann et al., 2020) and saliva which forms a protective layer between attachments' components (Fatemi et al., 2019; Goiato et al., 2014; You et al., 2011). In our study, we used Biotène Mouthwash as the salivary substitute (Boulos et al., 2018).

In previous studies, the number of insertion/removal cycles has varied from 540 to 14,600 (Kobayashi et al., 2014; Mínguez-Tomás et al., 2018; Satti, 2013; Tohme et al., 2018; Yilmaz et al., 2019; You et al., 2011). In our study 2000 cycles were performed, equivalent to 2 years of use, assuming that patients remove their prosthesis three times/day, once for each meal (Cervino et al., 2019; Wichmann et al., 2020; You et al., 2011).

Between each insertion/removal cycle, an interval of 10 s was allowed to help in elastic recovery (Boulos et al., 2018; Jalllian et al., 2015). Many researchers have adopted the speed of 50 mm/min since it is close to the speed at which patients remove their implant overdenture, and it avoids damaging the nylon or polymer components used in inserts (Mínguez-Tomás et al., 2018; Uludag et al., 2014; Yilmaz et al., 2019; You et al., 2011).

Non-anatomical or anatomical models in small or real sizes have been used previously with one or more parallel or angulated implants (Abi Nader et al., 2011; Al-Ghafli et al., 2009; Boulos et al., 2018; Kobayashi et al., 2014; Mínguez-Tomás et al., 2018; Sia et al., 2017; Srinivasan et al., 2016; Tehini et al., 2020; Wichmann et al., 2020; Yilmaz et al., 2019). In this study, real-sized models and corresponding hybrid prostheses were fabricated.

The thermocycling, citric acid (incubator), artificial saliva, and models/prostheses used, improved the simulation in our study. In previous studies, the absence of these factors has been cited as a limitation that might influence the credibility of their results (Cervino et al., 2019; Jalllian et al., 2015; Sia et al., 2017).

With the retention loss, the remaining retentive force appeared to be sufficient to hold an implant overdenture in our study (OT Equator: 17.7 ± 3.38 N; Locator: 13.08 ± 3.31 N; Locator R-Tx: 19.76 ± 3.10 N).

This study is limited by the absence of simulation of mastication, which generates lateral forces, and the lack of ridge resilience, which causes rotational forces during mastication on posterior teeth. The movements of nylon inserts in the metal housing typically absorb these forces (depending on the resorption and prosthesis adaptation), which can cause further wear of the attachment in addition to the insertion/removal cycles or the type of consumed food (temperature/acidity). Therefore, the results may vary depending on the clinical conditions. Herein, the initial values were not identical between the groups, although pink inserts were used for all three systems, as they had the closest retentive forces according to the manufacturers. Further studies should be conducted to obtain more accurate results by increasing the sample size, using different colors of inserts and numbers/positions/angulations of implants, comparing the dislodgment forces before and after acid immersion, or increasing the number of cycles and/or simulation forces in different directions. It would be interesting to compare attachments with the new Smart box housing manufactured by Rhein83, which is compatible with the OT Equator abutment and can correct up to 50° of divergence between implants (Rhein83, n.d.).

## 5. Conclusion

This in-vitro pilot study revealed that the OT Equator, Locator, and Locator R-Tx demonstrated satisfactory retentive forces during the 2000 cycles. The Locator R-Tx showed the greatest retentive force, while the OT Equator showed the most stable retention over the cycles, followed by the Locator R-Tx.

## CRediT authorship contribution statement

**Maya Farhat:** Conceptualization, Methodology, Data curation, Software, Visualization, Writing – original draft, Writing – review & editing. **Tony Daher:** Writing – review & editing. **Jean-Jacques Hajjar:** Writing – review & editing. **Paul Boulos:** Conceptualization, Methodology, Supervision, Writing – review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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