Evaluation of the Effects of Repeated Insertion-Removal Cycles on the Retention of an Indexed Conometric Connection

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Purpose: The objectives of this in vitro study were to evaluate changes in the retention force of the indexed conometric system subjected to repeated insertion-removal cycles and to examine the elements (matrix and patrix) that cause retention changes in the system as a result of repeated cycles. Materials and Methods: Monolithic zirconia crowns were cemented on 24 matrixes and 24 patrixes fixed on the implant analog. The pull-out test was performed with 12 matrixes and 12 patrixes attached, and the initial retention forces were recorded. Six of them were subjected to five insertion-removal cycles (5-cycle group), and the other six samples to 15 cycles (15-cycle group), and the final retention forces were calculated. Then, in both groups, an element of each pair exposed to the cycle was matched by an exchanging with new pieces: 5 cycles of matrix–new patrix (5M/0P), 5 cycles of patrix–new matrix (5P/0M), 15 cycles of matrix–new patrix (15M/0P), and 15 cycles of patrix–new matrix (15P/0M); thus, subgroups were created. A pull-out test was applied to these subgroups, and retention forces were recorded. Data were subjected to a paired-samples t-test (α = .05). Two specimens from the 15-cycle group were randomly selected and analyzed by scanning electron microscopy. Results: In the 5-cycle group, the mean initial retention force was 153.13 ± 7.08 N, and the mean final retention force was 111.59 ± 18.30 N. In the 15-cycle group, the mean initial retention force was 143.30 ± 15.46 N, and the mean final retention force was 78.55 ± 17.03 N. There was a statistically significant loss of retention in both groups (P < .05). The change in retention in the 5P/0M and 15P/0M subgroups was not statistically significant (P > .05). However, significant loss of retention was found in the 5M/0P and 15M/0P subgroups (P < .05). Conclusion: There was a significant loss of the retention force after insertion-removal cycles. The increase in these cycles caused a further decrease in retention force. The decrease in the retention force of this system mainly resulted from the changes in the surface characteristic of the frictional surfaces of the matrix. Int J Oral Maxillofac Implants 2022;37:549–555. doi: 10.11607/jomi.9497

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Implant-supported fixed dental prostheses (FPDs) are secured with either screw or cement retention.1 Cone-in-cone connection between the conometric abutment and coping has been used as an alternative to screw-and cement-retained prostheses for the oral rehabilitation of completely and partially edentulous patients.2–5 Degidi et al proposed a cone-in-cone Morse taper connection between the conometric abutment and coping (called the “conometric concept”) to protect implant-supported definitive FPDs.4,5 The conometric concept could only be applied for implant-supported multunit fixed restorations because their abutments were not indexed and have no antirotational property. To make this system compatible with implant-supported single crowns, the Acuris conometric system (Dentsply Sirona Implants) was designed with antirotational property in the matrix and the patrix abutment by using a triangular lock index.6 This conometric system with specially designed instruments allows the single crown to be easily inserted into and removed from the patient’s mouth by the dentist without the use of cement or screws.

Occasionally, the clinician may need to remove implant suprastructures for hygiene, design modification, unsatisfactory esthetics, or occlusion, and additionally because of technical or biologic complications that comprise peri-implantitis and crestal bone loss.7–11 Cement-retained crowns are not easily retrievable, and incomplete removal of luting cement can cause peri-implantitis.11,12 Screw-retained crowns are retrievable, but the screw access hole can compromise esthetics and weaken the porcelain around the access holes.13,14 Restorations supported by an indexed conometric abutment can be easily removed using a dedicated clamp with plastic inserts.6 However, there are no available data in the literature regarding the retentive force of an indexed conometric system and the effect of repeated

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insertion-removal cycles on the retention force. Therefore, the first objective of this in vitro study was to assess the changes in the retentive force of an indexed conometric system after repeated insertion-removal cycles. The secondary objective was to evaluate surface microstructure and retention force changes in the matrix and patrix after repeated insertion-removal cycles. The null hypotheses were that

1. There would be no change in retention force after repeated cycles of insertion removal and
2. The renewal of only one of the elements of the indexed conometric system that has been subjected to the repetitive insertion-removal cycles would not affect the retention.

**MATERIALS AND METHODS**

Twenty-four matrixes 4.5 mm in diameter (Acuris Conometric Final Cap, Dentsply Sirona) and 24 patrixes (Acuris Indexed Conometric Abutment, Dentsply Sirona) with a 4.5-mm diameter, 4-mm height, and 0-degree angulation were used in this study. Twenty-four implant analogs (Ankylos, Dentsply Sirona) were embedded vertically in autopolymerizing acrylic resin (Meliodent, Heraeus Kulzer) by using a dental surveyor to standardize the implant analog position in acrylic resin. Patrixes were placed in each implant analog and tightened to 15 Ncm. CAD/CAM technology was used for the fabrication of the zirconia crowns. One laboratory cap 4.5 mm in diameter (Acuris Laboratory Cap, Dentsply Sirona) was connected to an abutment analog and then scanned with a laboratory scanner (E-scan 7Series, Dental Wings). A monolithic zirconia crown of the mandibular first molar was designed using CAD software (DWOS, Dental Wings) with a luting space of 20 µm. Then, the CAD file was transferred to the milling machine to mill the zirconia disk (GC Initial Zirconia Disk). The crowns were sintered at 1,500°C for 8.5 hours. The inner surface of each crown was sandblasted with 50 µm of aluminum oxide and then cemented to the matrix with resin-modified glass-ionomer luting cement (GC FuciCEM Evolve) according to the manufacturer’s instructions. Figure 1 shows the diagram of the indexed conometric system used in the study. Thus, separately, 24 matrixes with a zirconia crown and 24 patrixes fixed in the implant analog were obtained for use in experiments. Throughout the work, these were mentioned as the matrix and patrix.

A calibrated strike tool (Conometric Fixation Tool, Dentsply Sirona) was used to interconnect the grouped matrixes and patrixes as described below. The double strikes approach was applied for better connectivity. For removing matrixes with crowns from patrixes for pull-out testing, a custom specimen holder was designed according to the mesiodistal dimensions of monolithic zirconia crowns (Fig 2). Pull-out tests were performed by using a universal testing machine (UTM, Instron 3345, USA) at a constant crosshead speed of 2 mm/min until crown displacement forces needed to reduce the connection between surfaces of the matrix and patrix, and force was recorded in Newtons (N).

In this study, the specimens were divided into two groups: 5-cycle and 15-cycle. In the 5-cycle group, 6 patrixes and 6 matrixes were matched and activated; then, the initial retention force was calculated by being subjected to pull-out testing. Then, these couples (patrix + matrix) were subjected to the insertion-removal cycle five times. The final retention force was calculated at the end of the fifth removal. Subsequently, these six matrixes exposed to five insertion-removal cycles were coupled with six new patrixes and subjected to a pull-out test. This subgroup was coded 5M/0P. This time, the
six patrixes that had been exposed to five insertion-removal cycles were matched with six new matrixes and subjected to pull-out testing. This subgroup was coded 5P/0M (Fig 3). Thus, subgroup retention forces were calculated as a result of the pull-out test. In the 15-cycle group, the same method as described above was carried out by following the insertion-removal protocol 15 times instead of 5. Subgroups were coded as 15M/0P and 15P/0M (Fig 3). The retention changes of the subgroups according to the initial group were calculated as a percentage.

After the experiment, two samples from each group were randomly selected and analyzed using scanning electron microscopy (SEM; FEI Quanta Feg 250, Holland). SEM was used to identify any changes that may have occurred on the frictional structure of patrixes during the pull-out tests. Wear and deformation patterns were examined under 60× to 1,000× magnification.

SPSS (Version 22, IBM) software was used for data analysis. A paired-samples t test analysis was used to investigate the impact of insertion-removal cycles on the retention force.

RESULTS

The mean values and SDs of initial and final retention forces for both groups were shown in Table 1 and Fig 4. The mean initial retention force value was 153.13 ± 17.08 N, and the mean final retention force value was 111.59 ± 18.30 N in the 5-cycle group. In the 15-cycle group, the mean initial retention force value was 143.30 ± 15.46 N, and the mean final retention force value was 78.55 ± 17.03 N. A paired-samples t test was performed to investigate the impact of insertion-removal cycles on the retention force by comparing initial retention force and final retention force in each group. There was significantly less retention force in the 5-cycle and 15-cycle groups (P < .05). In the 15-cycle group, retention force loss was greater than that of the 5-cycle group. The mean retention force value of each subgroup was compared with the initial retention force value of the main groups, and the significance of the retention loss was determined by the paired-samples t test (Table 2, Fig 4). The retention loss was not statistically significantly different in the 5P/0M and 15P/0M groups (P > .05), while the 5M/0P and 15M/0P groups showed significant retention loss (P < .05).
The SEM images of the samples in both groups showed the wear surfaces of the matrix and the patrix. However, the 15-cycle group had more deformation and wear surfaces (Fig 5). The wear and deformation on the internal surfaces of the matrix were obvious (Figs 5a, 5b, and 5c), while the patrix did not exhibit any detectable deformation, and there was slight wear in the coronal part of it (Figs 5d, 5e, and 5f).

**DISCUSSION**

Double crown systems consist of a primary crown, functioning as a male part, cemented on the abutment tooth or implant, and a secondary crown, which serves as a female part for the retention.16 The indexed conometric system consists of a precisely fabricated indexed double crown. This study was designed to evaluate the effects of repeated insertion-removal cycles on the matrix and patrix on retention strength in an in vitro model consisting of an indexed conometric system.

According to the results of the pull-out test applied in this study, it was determined that the mean initial retention force of the 5-cycle group was 153.13 N, and the mean initial retention force of the 15-cycle group was 143.30 N. However, it was found that with repeated insertion-removal cycles, retention forces were reduced. The retentive force in the 5-cycle group decreased to 111.59 N after five cycles, and to 78.55 N in the 15-cycle group. The decrease in retention was statistically significant in both groups (P < .05). Accordingly, it was determined that the additional removal cycles caused retention loss, and increasing the number of cycles caused further loss. Therefore, the first null hypothesis, which asserts that there was no change in retention force with repeated insertion-removal cycles, was rejected.

In many studies that used different materials, retention loss was observed in attachment systems with the matrix and patrix when the system was subjected to repeated insertion and removal cycles.17–27 Although matrix-patrix systems are similar to those in this study,
most of these studies were conducted for removable partial dentures (RPDs).

According to some studies, RPDs were removed at least twice a day. Therefore, at least 5,000 cycles of insertion and removal are recommended to determine the long-term effects (6.5 to 7 years) of insertion and removal in RPDs. However, the indexed conometric system tested in this study is a double crown system used in FDPs, and patients cannot insert and remove this system by themselves; it can only be inserted and removed by the dentist with special equipment. The retentive capacity of double crowns used in RPDs is much less than that of the FDPs for allowing the prosthesis to be inserted and removed. However, the retentive property of specifically the single-unit fixed double crown should be sufficient enough that the prosthesis will not dislodge.

There are no clear data in the literature on the minimum retention force required for a restoration to remain in place in the mouth. During the opening of the mouth, the depressor muscles apply dislodging forces to the prostheses, especially when chewing sticky foods. Therefore, the minimum retentive force should be higher than the maximum force generated by the contraction of the depressor muscles. Koolstra and van Eijden reported a maximum contraction force exerted by the inferior lateral pterygoid muscle as 112.8 N and the anterior digastric muscle of 46.4 N at the same time. One study reported that the retention force of 71.25 N (equivalent to 73 kg) provided by the cement under functional masticatory forces may be insufficient to prevent dislocation of the implant-supported crown.

The retention of double crown attachments is achieved through mechanical interlocking and frictional contact between the matrix and patrix. The frictional retention of double crowns depends on initial load, the cone angle, the abutment height, the structure design, friction between the matrix and patrix, the material used, and the insertion-removal cycle. Wear, which plays an important role in retention loss, is a complex process that involves adhesion, abrasion, surface fatigue, and corrosion in attachment systems. Also, retention is reduced if the plastic deformation limit is exceeded, at least in part of the system, due to the forces the system is subjected to. Under the force produced by chewing on the posterior teeth, the counteracting surfaces of the frictional double crowns adapt and lock together over time. When similar materials are used in double crowns, cold fusion between primary and secondary crowns may develop, which means increased retention.

In this study, only one of the indexed conometric system components (matrix and patrix), which had undergone 5 (5-cycle group) and 15 (15-cycle group) insertion and removal cycles (reduced retention), was renewed, and its contribution to retention was examined. In the subgroup (5M/0P) that had been exposed to cycles 5 times and then renewed patrix, there was no increase in retention; on the contrary, retention decreased further, and the loss compared with the initial retention was found to be 43.73% (P < .05). However, only when a new matrix was used (5P/0M), the retention value almost approached the initial retention value. The retention loss relative to the initial retention was only 2.64% (P > .05). This meant that the retention nearly reached its initial value when a new matrix was used. Although there was a slight increase in retention in the subgroup (15M/0P) exposed to cycles 15 times and then used with renewed patrix, the loss compared with initial retention was 36.7% (P < .005). However, a significant amount of retention was restored only when the matrix was renewed (15P/0M). The loss compared with the initial retention was 8.97% (P > .05).

In this study, the second null hypothesis, which states that the renewal of only one part of the indexed conometric system that has been subjected to the cycle would not affect the retention, was partially accepted. When the indexed conometric system is subjected to a cycle of insertion and removal, while the retention of the system decreases, replacing only the matrix restored a significant amount of retention. In this system, the act of replacing the patrix alone did not restore impaired retention. Schimmel et al stated that wear on primary double crowns was a major problem for clinicians and that replacing them would damage the remaining dental tissue. Changing the patrix in the indexed conometric system also requires a renewal of the entire system. However, replacing the matrix with a new one is relatively easy and does not damage the system. For this reason, in double crown systems, the primary crown especially should be chosen from wear-resistant material. The matrix of the indexed conometric system was made of commercially pure grade IV titanium and patrix manufactured from a harder material (titanium alloy Ti6Al4V ELI). According to the results of this study, the advantage of this system is that the patrix’s surface structure is not affected by the insertion-removal cycle.

Hardness, elasticity, and bulk of the material used in double crowns may affect the retention. In this study, the mandibular first molar made of monolithic zirconia was cemented on the matrix to better reflect the real conditions and support the matrix. On the other side, preloading applied to double crowns also affects retention. The seating force on the secondary crown of the double crown in RPDs is, in a clinical sense, the chewing force. The chewing force of individuals wearing RPDs retained by double crowns may vary between 28 and 252 N. However, in fixed prosthetic double crowns,
preload should be applied as a standard under the control of the physician and with more force. The indexed conometric system used in this study has a specially designed conometric fixation tool that activates friction retention between the matrix and patrix by a combination of pressure and strike. In the present study, the double strike approach was adopted because it increases the frictional retention between the matrix and patrix.

In this study, deformation and wear were observed in both the matrix (Figs 5a, 5b, and 5c) and the patrix frictional interfaces (Figs 5d, 5e, and 5f) by SEM analysis. According to the SEM images, however, the deformations in the matrix were more pronounced. This may be because the matrix is made of softer and thinner material. SEM images support the result that the matrix undergoes more retention loss, and it shows that the matrix undergoes more deformation after repeated insertion-removal cycles.

As a result, for the indexed conometric system used in this study, the authors recommend that the crown should be removed only when necessary and with a specially designed tool to prevent the decrease of the frictional retention between the matrix and patrix. Laboratory procedures and adjustments of the crowns should be conducted on the laboratory cap until the permanent insertion into the mouth. However, if the retentive force of the crown drops below the acceptable value, replacing the matrix with a new one may be enough to restore the retention force. In this study, the effect of insertion-removal cycles on retention of the frictional indexed conometric system was evaluated in vitro conditions. When removing the crown with the specially designed tool, vertical force should be applied. However, this force is difficult to control exactly as in a universal testing machine. Therefore, slight differences may occur between experimental and clinical results. In future studies, the effects of dynamic loading simulating the long-term thermomechanical aging effect on the retention of the system should be examined. Moreover, in vivo studies consisting of a large number of samples are needed.

CONCLUSIONS

In this in vitro study, according to the evaluation of the retention of the retentive elements of the indexed conometric system used, the following conclusions could be drawn:

1. There was a significant loss of the retention force in both groups with insertion-removal cycles.
2. Increasing the insertion-removal cycle numbers of the crown leads to less retention force.
3. The decrease in the retention force of this system mainly results from the changes in the surface characteristic of the frictional surfaces of the matrix. Therefore, only renewing the matrix may be enough to restore retention.

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