Evaluation of Retention and Attachment Wear of CAD/CAM Versus Conventional Implant-Assisted Overdenture Frameworks

Previous studies have demonstrated problems with implant-supported overdenture attachments, such as denture base fracture and retention loss of the attachment’s nylon insert. In this study, three implants were surgically inserted at the anterior mandibular region of 16 completely edentulous men (mean age: 50 years), divided into two groups depending on the received mandibular complete overdenture: a conventional metal-reinforced framework with prefabricated metal housing (Group I) or a CAD/CAM metal-reinforced framework with custom metal housing (Group II). At 3 months (prostheses loading), 6 months, and 12 months after implant placement, the retention of the mandibular dentures and wear of O-ring attachments were evaluated. Data were collected, tabulated, and statistically analyzed using Student t test. Statistically significant differences were found between the two groups and within the same groups during the evaluation period (P < .05). Attachment housing incorporated within a CAD/CAM implant overdenture can be a better alternative to the manufacturer's metal housing, as it diminishes retention loss and attachment wear over time, thus increasing patient satisfaction and chewing efficiency. Int J Periodontics Restorative Dent 2023;43:e43–e51. doi: 10.11607/prd.5785

Retention is considered one of the most important factors affecting satisfaction of edentulous patients. Residual ridge resorption and muscle tone reduction can affect retention quality of conventional complete dentures. Implant-supported overdentures (ISOs) improve patient satisfaction and quality of life compared to conventional dentures. ISO retention and support depend on an attachment system.

Different types of attachment systems have been used as retentive elements to stabilize an overdenture to implants, including balls, magnets, bars, and locators. There is not enough evidence to determine the effectiveness of different attachment systems for mandibular overdentures. However, ball attachments are commonly used, as they are simple and well-proven attachment systems that offer acceptable retention and reduce the loading forces directed onto the implants.

The survival and life expectancy of ball attachments regarding wear rates and retention may vary according to multiple factors, such as the position, number, and angulation of the implants, as well as the number of insertions and removals, attachment materials, and denture design.

However, ISOs present some complications, including wear of...
components; periodic maintenance, especially during the first year after loading; an occasional need for replacement of the retention elements; and incorrect pick-up of the metal housing during denture fabrication steps. Further, denture fracture was reported where stresses tend to concentrate around the housing portion of the implant.

Accordingly, it was suggested to include a metal framework within the acrylic resin in the mandibular denture base. Since digital dentistry through CAD/CAM was introduced, it has gained popularity. CAD/CAM–based removable denture fabrication methods have been proven to be a suitable alternative to conventional fabricated dentures.

With CAD/CAM technology, the framework is designed on a 3D model obtained from a 3D digital scan of the working cast. However, the digital workflow has not completely replaced the analog workflow due to the shortage of evidence-based dentistry and costs. Additionally, very limited data are available on retention loss and attachment wear arising from cyclic insertion and removal of digital dentures when compared with conventional dentures.

The aim of the current study was to evaluate CAD/CAM–fabricated and conventional mandibular ISOs to test the null hypothesis that CAD/CAM ISOs are comparable to conventional ones regarding the retentive ability of the ball attachment and wear resistance after 1 year of service.

Materials and Methods

This crossover study was carried out on 16 completely edentulous men (mean age: 50 years). Patients had an Angle Class I maxillomandibular relation with an acceptable interarch distance. Medical histories were taken to evaluate each patient's general health to ensure they were free from any other systemic diseases that may affect implant osseointegration. Laboratory investigations, including the Glycosylated Hemoglobin Test (HbA1c test), were requested. Patients were excluded from the study if their HbA1c level was above 7.5%, if they abused alcohol and drugs, and/or if they had poor oral hygiene.

CBCT scans were taken for all patients to show the height and width of bone in the edentulous areas, the position of the mental foramen and inferior alveolar canal, and to check for any undetectable pathology or bone abnormality. An informed consent approved by the ethics committee was signed by each patient after discussing the treatment plan with them and prior to initiation of treatment.

Three implants (10-mm length × 3.5-mm diameter; T6 root form, NucleOss) were placed—two in the canine region and one parasymphyseal—using a limited surgical guide to ensure implant parallelism and a two-stage surgical technique. Implants were placed with an insertion torque of at least 35 Ncm according to the bone density. Cover screws were then attached to the implants, and wound closure was performed corresponding to the implant.

Three months later, patients were divided into two groups, and each participant was provided, in a random manner, with one mandibular overdenture: either a conventional metal-reinforced framework with a prefabricated metal housing (Group I) or a CAD/CAM metal-reinforced framework with a custom metal housing (Group II).

Healing abutments were connected to implants for 2 weeks to allow for mucosal healing, followed by ball abutments threaded into the implants. Open-tray impressions were taken using polyvinylsiloxane material, and the master casts were made and duplicated (one cast for each prosthesis).

For CAD/CAM metal frameworks, the definitive mandibular master cast of each case was scanned by an extraoral scanner (Freedom HD, DOF) to get the standard triangulation (STL) file. The STL file was then transferred to the CAD/CAM software (Exocad) to begin designing the reinforcement metal framework and housing. The virtual framework design was transmitted to the production center, where a one-piece titanium denture base was manufactured from a homogenous solid block of medical titanium alloy (Ti6Al4V) (Fig 1).

For conventional metal frameworks (Fig 2), the design was made in wax and then fabricated by conventional casting techniques from cobalt-chromium. Frameworks were tested in the patient’s mouth to check the adaptation (Fig 3).

Construction of the complete maxillary and mandibular dentures...
continued according to conventional steps for both metallic framework types for arch relation, try-in, and insertion. After denture insertion, attachments were picked up by the direct technique for both conventional and CAD/CAM dentures. O-rings (NucleOSS) were then added to custom-made metal housing.

At prosthesis loading (3 months after implant placement), 6 months, and 12 months, all patients underwent testing of the retention of the mandibular denture and/or wear of the O-ring attachments.

Evaluation of O-Ring Attachment Retention

The geometric center of the mandibular denture was relatively identified as following:

All undercuts in the fitting surface of the denture were blocked by base plate wax, and a stone mix (Elite Rock, Zhermack) was then poured into the fitting surface of the denture, while another mix (Elite Rock) was used to construct a base. The centers of the retromolar pads and the midline were marked on the polished surface of the denture, and a piece of cardboard was cut to form a triangle that was placed on the plaster base to occupy the space between the three markings (center of retromolar pads and midline). Three lines bisecting each of the three triangle angles were then drawn on the cardboard. The point of intersection of these three lines was considered the geometric center of the denture. A pin was passed through the cardboard at the identified geometric center to mark a point on the plaster base. Wire was then fixed to the base and suspended upward from the marked point to maintain the location of the geometric center.

Three V-shaped grooves were created on the polished surface of the mandibular denture: One was made on the lingual surface of the central incisors at the midline region, just below the central incisal edge, and the other two grooves were created at the retromolar pad area just distal to the second molar on both sides. A wrought wire (1-mm diameter) was then bent at its center and adjusted (without encroaching on the tongue space) to run from the retromolar pad groove of one side to the same groove on the other side, 2 cm
above the occlusal plane. A second wrought wire (same diameter) was adjusted to extend from the groove at the lingual flange upward, positioned 2 cm above the occlusal plane. The two wrought wires were then bent toward each other until they met at the identified geometric center. One end of the second wire was adapted in the groove created just below the central incisors, and the other end was bent to form a C-shaped loop around the first wire. The free ends of the two wires were then fixed to the polished surface of the mandibular denture by self-cured acrylic resin (Cold Cure, Acros tone). Excess acrylic resin was removed, and the denture surface was refinished and polished.

Mandibular denture retention was assessed as follows at 3, 6, and 12 months after implant placement: Each patient was asked to sit comfortably in a dental chair with his head on the headrest and the occlusal plane parallel to the floor. Retention force was measured using digital force gauge (HP-5 Digital Force Gauge, Beijing Lanetech Instruments). Before each retention measurement (measured in Newtons), the force meter display was adjusted to 0. The metallic hook of the digital force gauge device was connected to the loop positioned at mandibular dentures for each group. Vertical pull was applied until denture dislodgment occurred, and the peak load value was recorded (Fig 4).

**Evaluation of O-Ring Attachment Wear**

Wear of the O-ring attachments was evaluated using a scanning electron microscope (SEM; Quanta 250, FEI) with an EDX (energy dispersive x-ray; FEI) unit attached, with an accelerating voltage of 30 kV and ×400 magnification.

**Statistical Analysis**

Data were collected, tabulated, and statistically analyzed by an independent statistician using paired and unpaired Student t tests. Statistical analysis was performed using SPSS (version 20, IBM). The level of significance was set at .05.

**Results**

Table 1 lists the paired and unpaired Student t test results for retention values at different follow-up periods between study groups. Three months after prosthesis insertion, the mean ± SD retention value was 2.45 ± 0.59 N for Group I patients and 3.26 ± 0.55 N for Group II patients.

Retention values for Group II were better than that for Group I, and a statistically significant decrease of the retention values between the two groups was found during the follow-up periods (P < .05). Within each group, time affected the retention values of the attachments. During the observation period, no implants were lost, and no fractures occurred.

**SEM Analysis**

The SEM images (×400 magnification) revealed surface characteristics of the O-ring attachments throughout the follow-up periods. Initial photos revealed a smooth inner surface of both study groups (Fig 5), while the images at 6 months showed surface irregularities and few cracks (Fig 6). At the 1-year follow-up, numerous oblique, horizontal, and vertical scratches were seen on the O-ring attachment in Group I, more so than in Group II (Fig 7).
It is well known that placing two or more implants to retain an overdenture increases the satisfaction of edentulous patients. Although reducing the number of implants supporting overdentures is recommended to reduce cost and invasiveness of surgical and prosthetic procedures, three implants were used in the present study, following the conclusions that this design allows better stress distribution, minimizes crestal bone loss, and decreases the overdenture rotation around the implants (which occurs with two-implant overdenture designs), thus increasing overdenture stability.\textsuperscript{21,22}

In the present study, implants were placed with a surgical guide to ensure parallelism; however, achieving 100\% parallel implants may be impossible, especially when implants are placed in the curved edentulous arch.\textsuperscript{23} Parallelism is considered a crucial factor in removable ISOs for ease in fabrication and to prevent issues related to the wear of the retainers.\textsuperscript{24}

While intraoral scanners are more comfortable and accurate than ordinary impressions, they eliminate the cumulative errors resulting from handling the impression materials, it was reported that color temperature and illuminance affected the trueness and precision of intraoral scanners, and it is still considered an evolving device that is expected to be improved in the future.\textsuperscript{25–27} In general, intraoral scanning still faces some limitations during the fabrication of removable prostheses, especially complete dentures, concerning accuracy\textsuperscript{28}; likewise, there are difficulties in the functional recording of the mucosa and underlying supporting structures.\textsuperscript{29} Although earlier studies

| Table 1 Results of Student $t$ Test for Retention Values at Different Follow-up Periods |
|---------------------------------|-------------------------------|-----|-----|-----|-----|
| Group I | Group II | $t$ | $P$ |
| 3 mo | 2.45 ± 0.59 | 3.26 ± 0.55 | 2.54 | < .001* |
| 6 mo | 2.11 ± 0.67 | 2.70 ± 0.58 | 1.44 | < .001* |
| 12 mo | 1.10 ± 0.38 | 2.11 ± 0.50 | 1.25 | .003* |
| 3 mo–6 mo | | | | |
| Difference | 0.34 ± 0.32 | 0.56 ± 0.11 | | |
| Paired test | $t$ | 0.792 | 0.786 |
| $P$ | .442 | .352 |
| 3 mo–12 mo | | | | |
| Difference | 1.35 ± 0.42 | 1.15 ± 0.29 | | |
| Paired test | $t$ | 0.416 | 0.943 |
| $P$ | < .001* | < .001* |
| 6 mo–12 mo | | | | |
| Difference | 1.01 ± 0.35 | 0.59 ± 0.41 | | |
| Paired test | $t$ | 0.083 | 1.303 |
| $P$ | < .001* | < .001* |

Group I = conventional metal-reinforced framework with a ready-made metal housing; Group II = CAD/CAM metal reinforced framework with a custom-made metal housing. Nonstatistical data are presented as mean ± SD. *Statistically significant ($P < .05$).
recommend conventional impression techniques for edentulous arches,\(^{30,31}\) the present study used extraoral scanning, following the recommendations of previous literature that it produces high precision for cross-arch scanning.\(^{32}\) Additionally, when compared with intraoral scanning in complete-arch digital scans, extraoral scanning provides better results concerning accuracy, trueness, and precision.\(^{33,34}\)

Hack et al\(^{35}\) evaluated the applicability of intraoral scanning in fully edentulous arches compared to conventional impressions and scanned stone casts. The results showed significant deviation in the intraoral scanning method, mainly at the peripheral seal zone, soft palate, and the maxillary and mandibular vestibules. The superiority of conventional impressions over intraoral scanning was explained as (1) the difficulty in capturing optical impressions of viscoelastic bodies, such as mucosa, required for removable prostheses, and (2) difficulty in obtaining data regarding the amount of mucosal tissue displacement.\(^{36}\)

The direct technique (pick-up) was used in the present study for incorporating the implant attachments to the conventional mandibular dentures, as it was concluded that the pick-up technique is superior to the indirect technique (laboratory) in terms of pressure sores (immediate results) and the loss of retention and replacement of retainers (long-term results), regardless of the number of implants used.\(^{37}\) This is because the pick-up technique reduces the attachment incorporation discrepancies and aids in complete adaptation of the fitting surface of the prostheses on the tissue.\(^{38,39}\)

The drawbacks of the pick-up technique concerning the use of an autopolymerizing resin expose ISOs to several problems, including voids, high water sorption, repeated denture fracture, polishing difficulty, flow of resin into undercuts, and contact with excess acrylic monomer.\(^{38,39}\) These disadvantages are overcome in the current study by CAD/CAM dentures incorporating the attachment housing within the implant overdenture framework as one unit. This solves most of the problems experienced with the use of both direct and indirect techniques.
ISOs require periodic maintenance, as retention loss is mainly caused by wear and deformation of the attachment system over time, which is related to the repeated insertion and removal of the attachment components.\textsuperscript{40,41}

The null hypothesis of this study was rejected because the retention values of the CAD/CAM overdentures were higher than conventional ones after 1 year of use. Additionally, more surface roughness, cracks, and scratches were observed at the O-ring attachment of the conventional overdentures.

Although ISOs need retentive forces ranging from 5 to 20 N to maintain their position,\textsuperscript{8} findings of the present study revealed significant retention loss of both study groups over time, starting from the third month of use. This finding matches earlier reports that attachments lose their retention ability over time\textsuperscript{42,43} but contradicts other studies that reported no difference in the retentive properties of attachments and that it is not affected over time.\textsuperscript{44,45}

The present study found that attachment housings incorporated within CAD/CAM overdentures help preserve the retention ability of attachments more than the conventional dentures over the follow-up period. One factor that can explain this is that conventional overdentures (with the housing picked up within the denture base), may rock or move slightly when food is chewed and during mastication. This movement may lead to plastic deformation of the housing portion within the denture base, resulting in diminished retention. This deformation is seen less in CAD/CAM frames, as the housing is incorporated within the design and fabricated from the same material as the framework, thus improving the framework’s integrity and durability.\textsuperscript{46}

A previous study reported detachment of the steel housing in overdentures.\textsuperscript{47} Eliminating the presence of two different materials for the denture base and the metal housing, as done in the present study, and instead using an entirely titanium framework will influence the stress distribution around the attachment, especially as it is one material with the same modulus of elasticity. This decreases the loads applied to the nylon inserts, allowing the ISO to maintain its retention and wear resistance for longer periods.

There is still a shortage in the literature, regarding some aspects of the advantages of CAD/CAM ISOs over conventional ISOs, especially in clinical trials.\textsuperscript{3} Additionally, it is noteworthy that the time and cost of attachment housing maintenance are important for the prosthodontist. More studies with longer follow-up periods are needed to evaluate the CAD/CAM ISOs in comparison to conventional ISOs.

**Conclusions**

Within the limitations of this study, despite the lack of previous clinical trials, and despite the short-term follow-up period, the available evidence supports the claim that incorporating the attachment housing during the design and fabrication of CAD/CAM implant overdentures can be a better alternative to the manufacturer’s housing, as it decreases retention loss and attachment wear over time, thus increasing patient satisfaction and chewing efficiency.

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**References**


