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# Evaluation of the Retention Force of Double Conical Crowns Used in Combination with a Galvanoforming and Casting Fabrication Technique

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**Keywords**
Double conus crown; galvanoforming; reciprocating wear test; retentive force; telescopic denture.

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*Financial support from the Erciyes University Department of Scientific Research Projects (DHA 05–02).*

*The authors deny any conflicts of interest.*

Accepted March 24, 2012

doi: 10.1111/j.1532-849X.2012.00897.x

## Abstract

**Purpose:** The aim of this study was to measure the in vitro retention force of double conical crowns fabricated using primary galvanoforming and secondary casting techniques and those fabricated using primary casting and secondary galvanoforming techniques under simulated clinical conditions before and after a wear test.
**Materials and Methods:** Primary galvanoformed crowns ($n = 10$) with non-noble secondary crowns ($n = 10$; group A) and primary non-noble crowns ($n = 10$) with secondary galvanoformed crowns ($n = 10$; group B) were fabricated. Each primary and secondary crown was embedded in acrylic resin and weighed with a digital balance. Retention forces were then measured using a universal testing device. To simulate wear, specimens were inserted and separated horizonatally 3285 times in wear equipment with artificial saliva. Retention forces and weights of the double crowns were then remeasured. Data were analyzed using paired *t*-tests and Wilcoxon tests, and the groups were compared using Mann–Whitney *U*-tests.
**Results:** In group A, the wear test had a significant influence on the retentive force ($p < 0.05$), but wear produced no significant difference in weight ($p > 0.05$). In group B, the wear test had a significant influence on the retentive force ($p < 0.05$), and wear produced a significant difference in weight ($p < 0.05$).
**Conclusions:** The results of this study indicated that the use of different combinations of galvanoforming and casting techniques in the fabrication of conical crowns significantly affected retention force.

A telescopic system with a conical crown as a retainer for removable partial dentures (RPDs) can be used for the retention of combined fixed partial dentures[1-4] and implant prostheses.[5] Such systems are most commonly used in elderly patients.[6] The patrix (male) component of the attachment, or primary crown, is cemented to the abutment tooth, and the matrix (female) component of the attachment, or secondary crown, is the removable part of the restoration.[1,6] Whereas all walls are parallel in cylindrical telescopic crowns, parallelism in a conus crown occurs only between the contact surfaces of the primary and secondary crowns, forming a double crown.[2,7] This effect is of paramount importance when conus-crowned prostheses are removed. Because such systems lack friction or contact, the prosthesis can be removed with the initial application of force. The retentive force and stress on the teeth and alveolar bone can be controlled by the angle of the primary crown.[1,2,8,9]

Special technical skill and experience are required to fabricate a double crown using a casting technique that provides adequate and precise frictional retention ("conus friction force") between the copings and the primary crown.[10,11] In double-crown retention, frictional wear is a frequently encountered problem during the functional period.[12,13] The more sophisticated "double-crown" retainer system has higher technical failure rates.[3] As reported by Becker[14] for telescopic systems and Körber[15] for conical double crowns, retention forces of 3.5 to 7 N per attachment should achieve adequate denture retention.[16] Restoration casting and fit problems due to casting shrinkage have been discussed in evaluations of the double-crown manufacturing process.[1,3] The retention mechanism has also been described comprehensively.[1]

In contrast, galvanoforming crowns facilitate the precise fit of dental restorations because they are deposited directly onto duplicated dies. Such crowns are not affected by casting shrinkage, and the technique increases the marginal fitness of the crown restoration. Furthermore, the galvanoforming process requires no special technical skill.[1,17]

The use of a galvanoforming telescopic retainer has been reported.[7,11,12] However, no published study has evaluated the retentive force of telescopic denture-retained double conical crowns fabricated with a combination of galvanoforming and casting techniques.

The aim of this study was to measure the in vitro retention force of double conical crowns fabricated with a galvanoforming primary crown and casting secondary crown and those fabricated with a casting primary crown and galvanoforming secondary crown under simulated clinical conditions. We also evaluated the retentive force after insertion–separation cycles and determined the wearing weight values of the double conical crowns. The null hypotheses of this study were that 1) retentive force would have no influence on the double crowns, 2) there would be no change in retention force after the wear test, and 3) there would be no change in weight value in each group after insertion–separation cycles.

## Materials and methods

### Specimen preparation

The maxillary right second premolar was prepared using commercially available models (Frasaco GmbH, Tettnang, Germany). A tapered conus angle of 3° and a chamfer width of 1 mm were created using a parallelometer for the master metal die. The die was cast using a nickel-chromium (Ni-Cr) alloy (Perlablast; Bego Goldschlägerei Wilh. Herbst GmbH & Co. KG, Bremen, Germany) and connected to the parallelometer to check the taper.

### Primary and secondary crown fabrication

For group A, gold galvanoformed primary crowns and conventionally cast non-noble secondary crowns were created. Before beginning the galvanoforming process, an impression of each galvanoformed primary crown was obtained on the metal die using impression material (Bresil; Bredent, Senden, Germany). Ten 0.25-mm galvanoformed primary crowns were then fabricated using a galvanoforming machine (GES Gold Galvanoforming System; Gramm Technik GmbH, Ditzingen, Germany) according to the manufacturer's instructions.

Each galvanoformed specimen was placed on the master die, and its integrity was examined at 25× magnification under a stereomicroscope (Carl Zeiss f 170; Carl Zeiss Surgical GmbH, Oberkochen, Germany). Each galvanoformed primary crown was placed on the metal die, and secondary crowns were prepared on the primary crowns using pattern resin and a brushing method. The secondary crowns were then cast with a Ni-Cr alloy (Perlablast) using the conventional casting technique. Casting and grinding procedures for the secondary crowns were completed, and they were fully adapted on the primary crowns.

For group B, conventionally cast non-noble primary crowns and galvanoformed secondary crowns were created. The primary crowns were prepared on the master die using pattern resin and a brushing method. A 3° tapered conus angle was formed with a parallelometer (Paraskop; Bego). The primary crowns were then fabricated using non-noble Ni-Cr alloy and a conventional casting technique.

Before fabricating the galvanoformed secondary crowns, casting and grinding procedures for the primary crowns were completed, and they were fully adapted on the master die using the method described previously. Secondary crowns for the ten primary crowns were then fabricated with a 250-$\mu$m layer using the galvanoforming technique according to the manufacturer's recommendations. The galvanoformed secondary crowns were then adapted onto the primary crowns. Group A thus consisted of ten galvanoformed primary crowns with ten non-noble secondary crowns, and group B consisted of ten non-noble primary crowns with ten galvanoformed secondary crowns.

### Evaluation of initial retention force and weight

To prevent movement of the specimens and to fix them in the same position during the measurement of retention force, carrier components were prepared from a lathe, and each specimen was fixed with an autopolymerizing acrylic resin. At this stage, inner surfaces of the primary crowns and outer surfaces of the secondary crowns were sandblasted with 110 $\mu$m aluminum oxide particles (Rocatector Delta, 3M ESPE, Seefeld, Germany). The autopolymerizing acrylic resin was filled into the carrier components and primary crowns. Subsequently, each primary crown was embedded into the carrier components. After polymerization, each acrylic resin was polished to a smooth surface and covered with a thin layer of wax. Secondary crowns were then placed onto the primary crowns, and carrier components filled with acrylic resin were placed onto the double crowns. After polymerization, the double crowns were separated from the carrier components and then separated from each other. Each resin-embedded primary and secondary crown was then weighed with a digital balance (GH-500; A & D Company Ltd., Tokyo, Japan) capable of measuring to an accuracy of 0.1 mg. Each specimen was weighed three times, and a mean weight was calculated. Retention forces were then applied at a speed of 1 mm/min using a universal testing device (Zwick 1445; Zwick, Ulm, Germany). The measurements were repeated ten times for each specimen, and a distribution of the results was recorded.

### Wear test

To simulate wear, specimens were inserted in specially designed wear equipment that used a reciprocating movement and consisted of a crank and an electrical motor (Fig. 1). The speed of the testing equipment was 120 times/min, providing the fit of the pieces at 5 kgf.[2] The tests were performed in artificial saliva (Biotene; GlaxoSmithKline UK Ltd., Middlesex, UK) with NaCl solution (ratio 1 : 2) to lubricate the double crowns during the wear process. The crowns were inserted and separated 3285 times in a horizontal direction, to simulate a patient's removal and replacement of the denture three times daily for 3 years. After this process, the retention forces of the double crowns were measured with an Instron machine (Model 6022; Instron Corp., Norwood, MA), and the primary and secondary crowns were weighed again using the digital balance as described above.

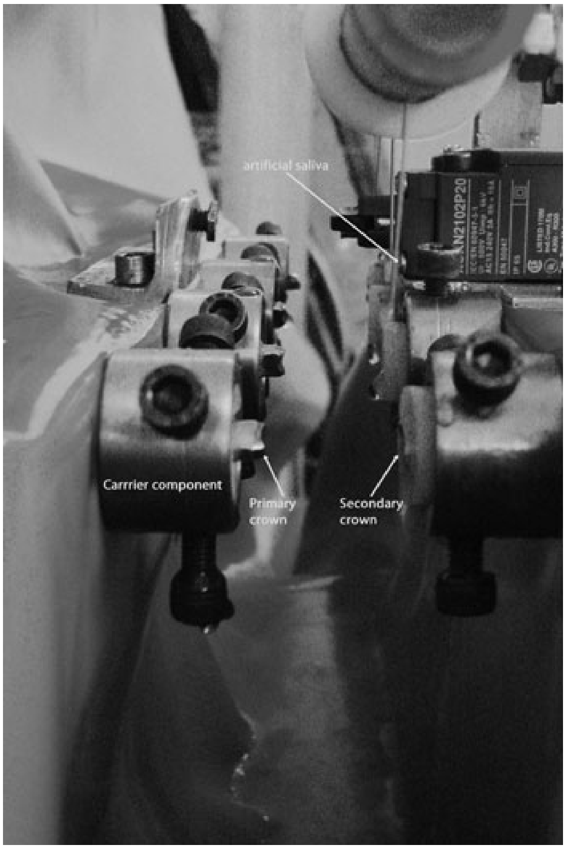


**Figure 1** Wear test equipment.

### Statistical analyses

Statistical analyses were performed using the SPSS program (v.11.0; SPSS Inc., Chicago, IL). Intragroup comparisons before and after the wear test and weight changes were compared with paired *t*-tests and Wilcoxon tests. Comparisons between groups were made using Mann–Whitney *U*-tests. The level of significance was set at $a = 0.05$.

## Results

Mean retention force (N) and weight (g) values for each group are shown in Figures 2 and 3. In group A, the mean retention force was 5.51 N before the wear test and decreased to 1.86 N after 3285 insertions and separations. Paired *t*-tests demonstrated that the wear experiment had a significant influence on retentive force ($p < 0.05$), but wear produced no significant difference in weight ($p > 0.05$) in group A (Table 1).

In group B, mean retention force and weight values before and after the wear test were 18.7 and 25.23 N and 7.85 and 7.71 g, respectively. Paired t-tests demonstrated that the wear test had a significant influence on retentive force ($p < 0.05$), and that abrasion produced a significant difference in weight before and after the wear experiment ($p < 0.05$) in group B (Table 1).

The median retention force and weight values for groups A and B before the wear test are shown in Table 2. Mann–Whitney *U*-tests indicated that the median retention force of group A (5.50 N) was significantly lower than that of group B (18.24 N; $p < 0.05$), but no significant difference in weight was observed between groups ($p > 0.05$; Table 2).

The median retention force and weight values for groups A and B after the wear test are shown in Table 2. Mann–Whitney *U*-tests indicated that the median retention force of group B (23.06 N) was significantly higher than that of group A (0.98 N; $p < 0.05$), but no significant difference in weight was observed between groups ($p > 0.05$; Table 2).

## Discussion

In the present study, the effect on retention force of conus-crowned telescopic dentures fabricated using two combinations of galvanoforming and casting techniques was examined. Retention force was determined by in vitro measurement. To estimate changes in retention force during a 3 year period, measurements were taken at baseline and after 3285 insertion–separation cycles. To simulate clinical conditions, the wear test was performed using artificial saliva.

The type and retention mechanism of a double crown affect the retention of an RPD and can influence the patient's quality of life.[2] The retention force of a telescopic crown is influenced by factors of abutment tooth preparation, such as taper angle, height, and marginal design, and also by factors associated with the fabrication process, such as milling speed, degree of cutter wear, polishing, casting technique, and setting method. Retention forces vary greatly, and a very wide distribution of values has been reported.[1,2,18,19]

In our study, the abutment tooth was prepared using a chamfer design to accommodate the wear process. The final apical position of the secondary crown was limited by the chamfer, which also prevented conus friction effects.[1]

To increase the comparability of our results with recently published data,[20] the wear test was performed with a lubricating solution to simulate clinical conditions, and initial and final measurements of retention force and weight were taken to evaluate wear-related changes. Bayer et al[20] stated that saliva was a necessary component of wear tests because it was part of the tribological system comprising the primary crown, intermediary agent (saliva), and secondary crown. The absence of an intermediary agent causes significant changes in frictional wear. Bayer et al[16] also reported that the effects of saliva can be determined by analyzing the surface structures and the changes in retention force. We used saliva for the wear test in the present study to simulate clinical conditions.

Denture retention is of primary importance for patients. The results of the present study indicate that galvanoformed primary and non-noble secondary conical crowns were less effective than non-noble primary and galvanoformed secondary conical crowns. Crowns fabricated using the latter technique showed a retention force before the wear test that was approximately three times that of the galvanoformed primary and non-noble secondary conical crowns. The results of this study thus indicate that different combinations of galvanoforming and casting techniques in the manufacture of conical crowns significantly affected retentive force; therefore, the first null hypothesis was rejected. Although the double-crown fabrication process cannot explain this result, the use of different combinations of

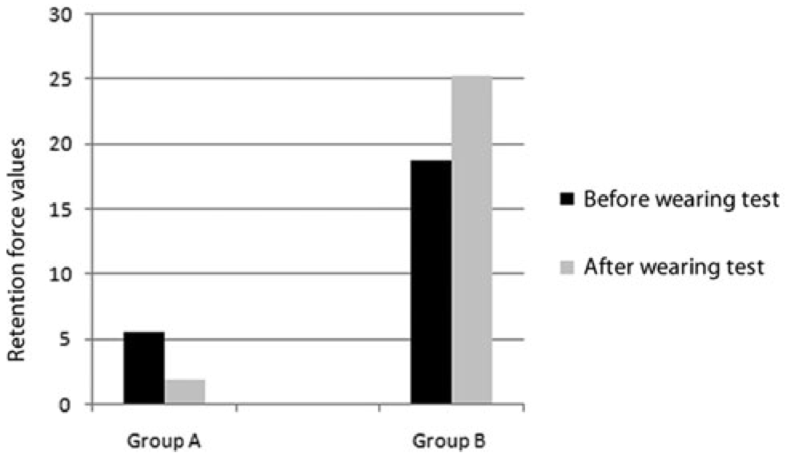


**Figure 2** Mean retention force values (N) for all study groups.

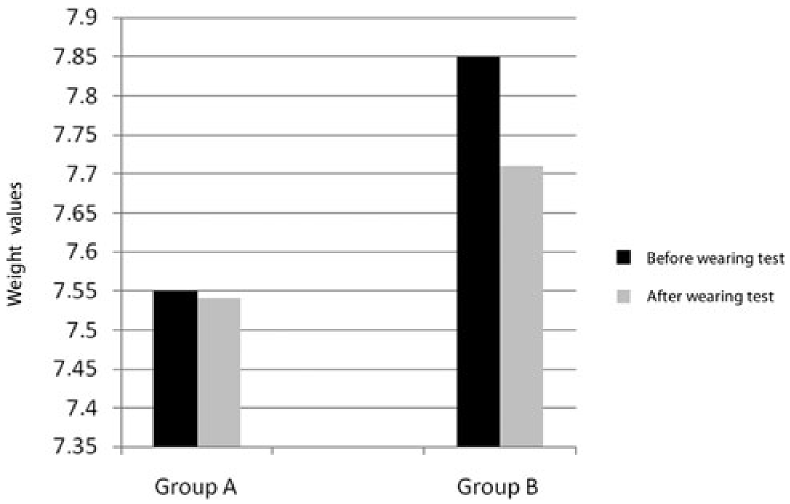


**Figure 3** Mean weight (g) in all study groups.

**Table 1** Retention forces and weight values of Group A and Group B before and after wear test

| | Group A | | | Group B | | |
|---|---|---|---|---|---|---|
| Variables | Before wear Mean (SD) Med (25% to 75%) | After wear Mean (SD) Med (25% to 75%) | $p^*$ | Before wear Mean (SD) Med (25% to 75%) | After wear Mean (SD) Med (25% to 75%) | $p^*$ |
| Retention force | 5.51 (1.92)<br>5.50 (4.61 to 6.47) | 1.86 (1.51)<br>0.98 (0.78 to 2.84) | $<0.05$ | 18.70 (5.83)<br>18.24 (15.01 to 18.93) | 25.23 (13.35)<br>23.06 (13.58 to 37.57) | $p < 0.05$ |
| Weight | 7.55 (0.97)<br>7.69 (7.38 to 8.28) | 7.54 (0.96)<br>7.69 (7.38 to 8.21) | $>0.05$ | 7.85 (0.98)<br>7.724 (7.38 to 8.84) | 7.71 (0.96)<br>7.722 (7.37 to 7.96) | $p < 0.05$ |

SD: standard deviation; Med (25% to 75%): median (25$^{th}$ to 75$^{th}$ percentile)
$p^*$: Paired *t*-test/Wilcoxon test

double conical crowns can explain it. Galvanoformed crowns fit precisely to dental restorations and also improve marginal fitting.[1,17,21] The marginal fit of the galvanoformed primary crowns likely contributed to effective cementation.[21,22] Behr et al[4] described the loss of cementation as a frequent complication of the use of telescopic crowns. Galvanoformed secondary crowns also provide a perfect fit to primary crown surfaces, which could have increased the retentive force of the double conical crowns consisting of cast primary crowns and electroformed secondary crowns in our study.[23]

After the wear test, retention force had decreased by approximately 66% in group A but had increased approximately

**Table 2** Comparison of retention force and weight values between groups before and after wear test

| | Before wear | | | After wear | | |
|---|---|---|---|---|---|---|
| Variables | Group A<br>Mean (SD)<br>Med (25% to 75%) | Group B<br>Mean (SD)<br>Med (25% to 75%) | $p^{\#}$ | Group A<br>Mean (SD)<br>Med (25% to 75%) | Group B<br>Mean (SD)<br>Med (25% to 75%) | $p^{\#}$ |
| Retention force | 5.51 (1.92)<br>5.50 (4.61 to 6.47) | 18.70 (5.83)<br>18.24 (15.01 to 18.93) | $<0.05$ | 1.86 (1.51)<br>0.98 (0.78 to 2.84) | 25.23 (13.35)<br>23.06 (13.58 to 37.57) | $p < 0.05$ |
| Weight | 7.55 (0.97)<br>7.69 (7.38 to 8.28) | 7.85 (0.98)<br>7.72 (7.38 to 8.84) | $>0.05$ | 7.54 (0.96)<br>7.69 (7.38 to 8.21) | 7.71 (0.96)<br>7.72 (7.37 to 7.96) | $p > 0.05$ |

SD: standard deviation; Med (25% to 75%): median ($25^{th}$ to $75^{th}$ percentile)
$p^{\#}$: (Unpaired *t*-test \ Mann–Whitney *U* test)

134% in group B (electroformed secondary crowns). These changes in the retention forces of the conical crown combinations differed significantly, and the second null hypothesis was therefore rejected. The wear test dramatically decreased the retention force in Group A, which may have been due to the fit of the secondary crown to the surface of the primary crown. In contrast, the retention force in Group B increased significantly after the wear test, which could be explained by two factors. First, the galvanoformed secondary crown fit better on the primary crown than did the non-noble cast secondary crown. Second, the retentive force of a telescopic conical crown system is influenced by contact surface pressure, cone angle, and the static frictional coefficient (SFC). In the present study, contact surface pressure and cone angle did not vary, but the difference in crown materials caused a variation in SFC. Retentive forces in conical double crowns are generated by the residual elastic strain in the secondary crown, which correlates with the SFC. Thus, retentive force may be expressed using the SFC. Ohida et al[22] investigated the SFC of non-noble and gold alloys used to make conus crowns. They reported that the SFC of the cobalt–chromium (Co-Cr) alloy was lower than that of the gold alloy. In the present study, retentive force after the wear test exceeded the clinical results of Körber[15] and Becker.[14] This increase could be due to the effects of the SFC in the incomplete secondary crown and could be controlled by changing the taper angle of the double crown and the thickness of the secondary crown.

In the present study, the effect of frictional wear was investigated by calculating changes in weight. Group A showed no significant change in weight before and after the wear test, but a significant change was observed in group B. Thus, the third null hypothesis was partly rejected.

The retention mechanism of conical double crowns is based on the adhesive friction created near the end of the joining process. Elastic deformation of the secondary crown promotes this effect. The principle of the conical crowns works well and is reproducible if the joining surfaces are smooth and provide a good fit.[11,24]

In the casting method, casting beads can form on the internal and external surfaces of the crown.[25] Unfortunately, it is technically impossible to remove these casting beads from the internal surface of cast secondary crowns, as in group A. Changes in retentive force could be explained by the quality of the contact provided by the position of the secondary crown. The internal surfaces of the secondary crowns in group B were adapted automatically to the polished primary crowns by the galvanoforming process. This process creates smooth internal surfaces in the galvanoformed secondary crowns. The good fit and adaptation of the secondary crown could be also promoted by increasing its contact with the primary crown. The SFC and elastic deformation of gold galvanoformed crowns are larger than those of non-noble crowns. As mentioned above, the use of electroformed secondary crowns may have significantly increased retentive force after the wear test in group B. The lack of a significant change in retention force in group A may be due to the casting fabrication technique and the non-noble alloy used for the secondary crown.

Amonton's law states that the SFC depends not on the apparent contact area, but on the actual contact area. Thus, the SFC increases with an increase in the actual contact area. This effect suggests that surface roughness influences the SFC. When plastic deformation occurs at the actual contact, a new surface forms, and strong adhesion occurs between the materials, contributing to the increase in the SFC. In telescopic conical crown systems, retentive force is generated by residual elastic strain in the secondary crown.[22] The retention mechanism of conical double crowns is also based on the adhesive friction created toward the end of the insertion process. Elastic deformation of the secondary crown promotes this effect.[11,26-28] In the present study, the increased retentive force and weight observed in group B after the wear test were consistent with Amonton's law.

This in vitro study found differences in retentive force that were likely due to the use of an electroformed secondary crown. The following limitations affected this study: 1) incomplete retainers were tested; 2) in clinical practice, a minimum of two splinted retainers are necessary; and 3) clinical conditions were not replicated absolutely in the in vitro tests. The following parameters were not investigated in the present study: 1) nonlubricated conditions in the wear test; 2) two combinations of two fabricating techniques were tested; however, an electroforming and/or a conventional casting technique were not tested; (3) examination of the joining surface under scanning electron microscope after the wear process and the gap between the joining surface of secondary and primary crown using cross section before and after the wear process were not investigated;

and (4) the wear process did not compare secondary crowns with cast primary crowns with a tapered conus angle of 0°.

## Conclusions

The results of this study allow the following conclusions to be drawn regarding the retentive force of telescopic conical crowns.

1. The retention force of the conical double crown with a cast secondary crown was clinically sufficient before the wear test but not after the test, according to published criteria.
2. The wear process increased both the wear value and retentive force in the double crown with a galvanoformed secondary crown.
3. In the present study, the secondary crown determined the retentive force.
4. The advantages of the galvanoforming technique were manifested in the secondary crown but not in the primary crown.

This study and other recently published research have sought to determine the amount of retention force necessary to produce a telescopic denture that is sufficiently stable, functional, and satisfactory for the patient in terms of the protection of residual teeth and alveolar bone. This question should be futher examined in in vitro and in vivo studies, as well as in clinical studies that include intraoral follow-up and the monitoring of patient satisfaction.

## Acknowledgment

The authors thank Set-Dent Dental Labour for preparing the conical crowns.

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