

Parameters affecting retentive force of electroformed double-crown systems

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Received: 4 February 2008 / Accepted: 19 March 2009 / Published online: 3 April 2009
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Abstract The aim of this study was to determine the values of retentive forces of double crowns. The effect of the abutment height, the material of the inner crown, and the taper were evaluated. Sixty inner crowns each were fabricated from zirconia and a gold alloy having three different abutment heights (5, 7, and 9 mm) and two different tapers (0° and 2°). All outer crowns were made with an electroforming system. The removal test was performed by a standardized setup using a universal testing machine at a crosshead speed of 1,000 mm min⁻¹. Ten separation cycles were performed of each specimen, and the mean was imported into a statistical program. The retention forces were in the range of 0.37 and 2.65 N. The abutment height ($p < 0.001$), the material of the inner crown ($p = 0.035$), and the taper ($p < 0.001$) showed statistical influence on the retention force in the two-way ANOVA. Zirconia primary crowns performed better than gold alloy in the 0° group, especially with short abutments. However, a taper of 0° and short abutments have clinical drawbacks that were not evaluated in this study. In situations with long abutment teeth and a 2° taper zirconia is an alternative to gold alloy primary crowns.

Keywords Dental abutments · Denture precision attachment · Dental casting technique · Dental prosthesis retention · Gold alloys · Dental porcelain · Zirconia

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Introduction

Double-crown systems have been used as retainers for removable partial dentures (RPD) for over 30 years [2, 13, 14, 22, 23]. They can be used for both rigid and resilient support of RPD [3, 35]. They transfer forces along the direction of the long axis of the abutment teeth and provide guidance, support, and protection from movements that might result in a dislocation of the RPD [3, 11, 13, 15, 23]. In cylindrical telescopic crowns, the surface is prepared parallel and a piston-cylinder effect occurs [13, 15, 33]. The continuous contact between the surfaces provides the function of a force arm [15]. However, abrasion on the surfaces occurs resulting from perpetual friction [16]. The difference between the cylindrical telescopic crowns and the conus crowns is the certain taper on the vertical surface [13]. The adaptation of the conus crown is the creation of a pressing effect that is caused by the geometry of the crown [16, 35, 36]. While in cylindrical telescopic crowns, all walls are parallel, in a conus crown, the parallelism only occurs in between the contact surfaces of the primary and secondary crowns [13, 16, 35]. This effect is of paramount importance when conus crowned prostheses are removed [4, 13, 21]. As there is no friction or contact, the prosthesis can be removed with the first forcing movement. In cylindrical telescopic crowns, a frictional movement occurs on all surfaces starting from the first lodging of the prosthesis on the abutments [4, 35, 36]. In technically correct and smooth-surfaced conus crowns, the retentive force can be controlled by the angle [4, 13].

However, special technical skills and experiences are required to fabricate a double crown in the casting technique to provide adequate retention with precise frictional retention (“conus friction force”) between coping and primary crown [19, 33, 34, 36].

A retainer design consisting of a coping made of electroformed gold uses adhesion instead of friction for the retention of the system [33, 34]. The copings fabricated in the electroforming technique showed favorable tribological properties [33]. In addition, those retainers showed clinical advantages compared to conventionally casted double-crown systems [34]. However, low adhesive strength was also reported [34]. No special technical skills are required for this technique as the fabrication of the coping is carried out by electroforming machines [33].

All ceramic materials are used in fixed prosthodontics due to their high biocompatibility and esthetic potential [5, 7, 8, 12, 18, 26, 28–30]. With the introduction of computer-aided design (CAD)/computer-aided manufacturing (CAM) systems into dental laboratories high performance ceramics can be used for crown and fixed partial denture substructures [8–10, 24–27, 31]. The use of all-ceramic materials for primary crowns was reported [33, 34]. However, no literature is available comparing the retentive forces of electroformed copings on zirconia primary crowns. The aim of this study was to determine the retentive forces of double crown systems with zirconia inner crowns and compare them to gold alloy primary crowns. The covariates height of the abutment tooth and conus angle should also be evaluated.

The working hypothesis is that (1) there is no influence of the material of the primary crown, while (2) longer abutment teeth and (3) a smaller taper are increasing the retentive force.

Material and methods

Three different mandibular premolar abutment teeth were designed on the computer (AutoCAD, Autodesk, Munich, Germany) with heights of 5, 7, and 9 mm (Fig. 1). From these data, a total of 120 abutment teeth were fabricated from chrome–cobalt–alloy using the laser sintering technique (Eosint 270, EOS, Krailling, Germany). The teeth were capped into resin (PalaXpress, HeraeusKulzer, Hanau, Germany) and functioned as testing models. The 120 testing models were divided into two groups having ten identical models in each group. First, the 120 primary crowns were manually fabricated on the testing models out of wax (Nawax compact, Yeti Dental Products, Engen, Germany) and shaped in a surveyor (F1, DeguDent, Hanau, Germany) with conical wax burs to assure 0° and 2° angles (H 364 103.015, RAH 356 RA 103.029, Komet, Lemgo, Germany). Particular attention was paid to low pressure and unidirectional milling. The pushing direction on the contact surface of the model was altered in the direction of the bur.

Sixty inner crowns were fabricated from zirconia. All crowns were produced by a CAD/CAM system (InLab, Sirona, Bensheim, Germany). A scan spray was applied onto the outer and the inner surfaces of the wax crown to

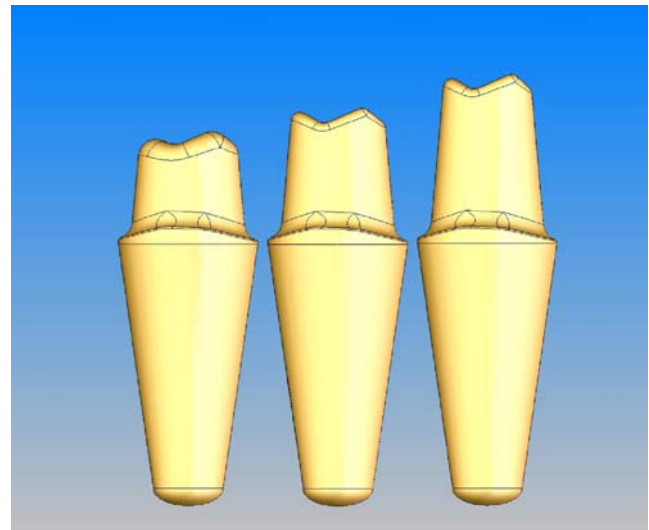


Fig. 1 Three different abutments designed by a computer program (AutoCAD)

make surfaces scannable with a laser scanner. The shape of the wax crown was digitized, and the data were enlarged by 20%. Next, the crowns were milled from semisintered zirconia blanks (InCeram YZ, Vita, Bad Säckingen, Germany). The milled, enlarged crowns were sintered to full density at a temperature of 1,520°C, resulting in shrinkage to the original wax dimensions. The crowns were returned to the corresponding testing model and checked for fit and adapted according to the literature [5, 6, 37]. To identify imperfections that prevented complete seating of the inner crowns, color (Shine Délicieux, L'Oréal, Paris, France) was applied on the testing model, and the crown was placed without force. The traces inside the framework were removed using a red ring diamond ball instrument (Komet) with water-cooling spray. This procedure was repeated until single isolated spots disappeared and a uniform and plane contact of the inner crown on the model was achieved. After each refinement the color was removed from the die using a steam cleaner. The same calibrated dental technician adapted all frameworks.

Then, the surfaces of the primary crowns were ground with diamond burs developed for zirconia surfaces (set 4430 and set 4431, Komet) to form 0° and 2° angles. The grinding and polishing of the zirconia primary crowns was conducted with an air turbine (Turbo-Jet, Acurata, Thurmansbang, Germany), which was mounted in a surveyor (F1) resulting in a 0.3-mm circular chamfer 0.5 mm above the margin. Special attention was paid to sufficient water cooling and low pressure during shaping and polishing.

Sixty primary crowns were fabricated using the traditional casting technique. The wax crowns were invested (Wilavest Quick, Wieland-Dental, Pforzheim, Germany) and casted in a gold alloy (Bioportadur, Wieland-Dental) according to the manufacturer's directions. After removing,

the investment material the crowns were checked for fit and adapted as described above. Finally, the surfaces of the primary crowns were ground (H 356 RGE 103.023, H 364 RGE 103.023, Komet) and polished (9440 C/M/F, Komet) in the surveyor (F1) resulting in a chamfer as described for zirconia primary crowns.

Then secondary crowns for all 120 primary crowns were fabricated by the electroforming technique (AGC Micro, Wieland-Dental) according to the manufacturer's recommendations. The electroforming process was performed on the original primary crowns. A conductive silver lacquer was applied up to the margin of the primary crown with a brush. Special attention was paid on a thin homogeneous layer. A 300- μm layer of gold was applied from a 6-h electroforming process giving the secondary crown enough stability for the separation test. The thickness of the secondary crowns was as high as possible with the electroforming system used; however, plastic deformations could not be completely excluded. The secondary crowns were finished as if they would have been used clinically (Fig. 2).

All inner crowns were cemented to the corresponding testing models by glass ionomer (Ketac Cem, 3 M ESPE). The separation testing was performed at least 24 h after cementation. Wire loops were attached at the top of the secondary crowns by resin (Palavit G, HeraeusKulzer). The resin material covered the complete secondary crowns starting 1 mm above the margin to give the system more stability during the testing procedure.

The experiments for the measurement of the retentive forces were applied by a universal testing device (Zwick 1445, Zwick, Ulm, Germany). Joining and separating the specimens was performed in the presence of artificial saliva (Ptyalin neutral, TMP Tueshaus, Velen, Germany). The specimens were joined with a force of 50 N. A wire connected the loop attached on the secondary crown to the universal testing machine (Fig. 3). To prevent horizontal tension on the coping, a length of 1.0 m was chosen for the



Fig. 2 Zirconia primary crown and electroformed secondary crown



Fig. 3 Experimental setup: primary crown and electroformed coping set together for the separation process in the universal testing machine

wire to use the self-alignment along the long axis. Ten separating cycles of each specimen were performed at a speed of 1,000 mm min^{-1} and the means were calculated. The data were imported into a statistical program (SPSS 15.0, SPSS Inc., Munich, Germany). Descriptive analysis was carried out to evaluate the influence of the primary crown material, the abutment height, and the tapered angle a two-way factorial analysis of variance (ANOVA) was employed. Further comparison of the subgroups was carried out by a one-way ANOVA and a post hoc test (Student–Newman–Keuls) in presence of significant interactions. The level of significance was set at 5%.

In addition, one specimen of each experimental group was embedded into resin (Pala-X-Press, HeraeusKulzer), and cross-sections were made according to previously published experimental design [6]. The complete gap between the primary and the secondary crown was measured under a stereomicroscope at a magnification of 200 (Axioskop 2, Zeiss, Oberkochen, Germany). The mean value of the measured gap was calculated.

Results

The highest mean value was 2.65 N for gold inner crowns with 9 mm and 0° while the lowest mean value was measured for zirconia inner crowns with 7 mm and 2° (Figs. 3 and 4). According to the results of variance analysis, the material ($p=0.035$), the height ($p<0.001$), and the angle ($p<0.001$) had a significant influence on the retentive force. The interaction of the height and the angle ($p<0.001$), the material and the height ($p<0.001$), the material and the angle ($p<0.001$), and the height, the material, and the angle ($p<0.001$) were found to be significant. When the retention values of the gold alloy inner crowns were compared, the angle and the height

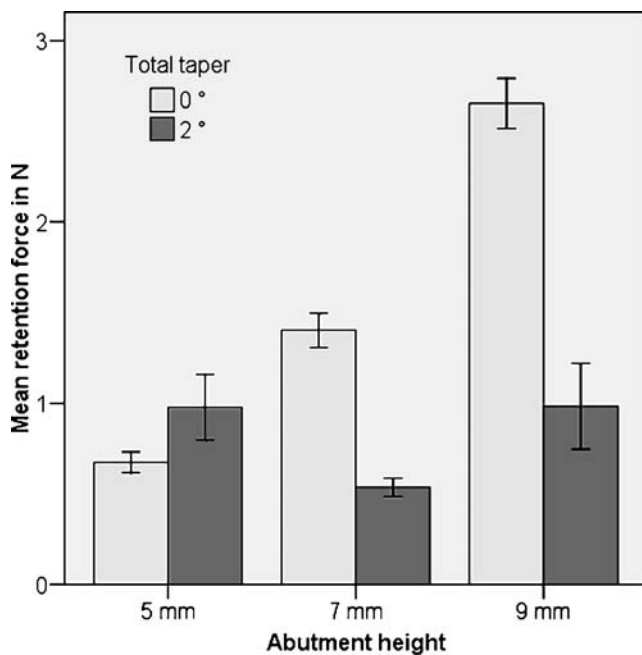


Fig. 4 Means and standard deviations of the retentive forces by three experimental abutment heights and two tapers for gold alloy primary crowns

showed significant influence ($p < 0.001$). The results of analyzing the influence of height are shown in Table 1.

The angle had a significant influence ($p < 0.001$) on the retentive force of specimens with zirconia inner crowns, while the height failed to show significance ($p = 0.762$). The combination of both factors also did not exhibit statistical significance ($p = 0.298$).

The measured gaps between primary and secondary crown are shown in Table 2.

Discussion

The type of double crown and its retention mechanism determine the retention of a RPD and can influence the

Table 1 Student–Newman–Keuls test exhibiting 2 homogeneous subgroups, subgroup 1 (abutment heights 5 mm and 7 mm), and subgroup 2 (abutment height 9 mm)

Height	Number of specimen	Subgroups	
		1	2
5 mm	20	0.83 (± 0.44)	
7 mm	20	0.97 (± 0.50)	
9 mm	20	1.82 (± 1.04)	
<i>p</i> Value		0.324	

The mean values and standard deviations are given. The tests are statistically different at a significance level of 5%; the *p* value describes the difference between the values in subgroups

quality of the patient's life. Considering that the retention is of primary importance for the patients, the results obtained in this study indicated that the material of the inner crown, the abutment height and the angle factors were active on the retentive force (Fig. 5). Selecting an abutment for a RPD several clinical factors have to be taken into account: number, mobility, location, and height of abutment teeth [16, 32, 35, 36].

The most important question to be asked is which retentive force is clinically necessary to support a RPD securely. Becker reported that patients were satisfied with retention of the RPD in the range of 2.5 to 3 N [1]. The maximum retentive force per abutment should not exceed 6.5 N [1]. The retentive forces of the evaluated groups were in the range of 0.37 to 2.65 N.

Most available studies reported higher retentive forces using the traditional casting technique for both fabricating the primary and secondary crown [1, 4, 13, 16]. The difference between conus friction and adhesion is thought to be the major reason for the differences. Different metal alloys and removal apparatus were considered as factors for different results between available studies [4, 13]. However, another study did not find significant differences between titanium and golden secondary crowns [4]. The presence of saliva was reported as a factor influencing the retentive force of casted secondary crowns [13]. Using the electroforming technique a medium between the primary and secondary crown is of paramount importance to build up adhesion [33, 34]. As conus friction works with direct contacts between primary crown and coping, adhesion needs dense medium-like saliva between primary crown and coping. The viscosity and the amount of saliva can influence the retentive forces of those copings. Although only one artificial saliva product was used in this study, it might be supposed that increasing the viscosity of the saliva will increase the retentive forces. A clinical evaluation of the patient's amount and viscosity of saliva is assumed before choosing an abutment for a RPD.

Zirconia primary crowns produced a significant higher retentive force than gold alloy crowns rejecting the first part of the working hypothesis. The fabrication process of the copings cannot explain this, as they were identical for both groups. The zirconia inner crowns showed a smoother surface under the microscope at $\times 200$ magnification (Axioskop 2) after the grinding and polishing procedure. This could cause a smaller gap between primary crown and coping and increase the retentive force. However, no significant difference in the gap between the two materials was found. Different layering techniques of silver lacquer can influence the gap between primary crown and coping. It can be assumed that spray coating by an air jet would have caused different gaps compared to the used paintbrush method. It might be concluded that zirconia primary crowns

Table 2 Mean measured gap between primary and secondary crown for all experimental groups

Inner crown material	Taper	Abutment height in mm	Gap in μm
Zirconia	0°	5	6.3
Zirconia	2°	5	7.2
Zirconia	0°	7	6.1
Zirconia	2°	7	5.9
Zirconia	0°	9	7.1
Zirconia	2°	9	6.5
Gold	0°	5	5.9
Gold	2°	5	6.1
Gold	0°	7	6.4
Gold	2°	7	7.2
Gold	0°	9	5.6
Gold	2°	9	7.0

with a conus angle of 0° should be facilitated if a little number of abutment teeth is available. However, primary crowns with a conus angle of 0° are associated with some fabrication difficulties. As “passive fit” is the primary objective of RPD, it is recommended to lute the splinting framework to the secondary crowns intra-orally. However, in case of primary crowns with 0°, the risk of misalignment of the abutments according to the common insertion path is very high and excludes the intraoral luting. The assembling of the framework has to be performed on the master cast with inaccuracies of fit due to used impression material, technique, and master cast fabrication. Therefore, the

demand “passive fit” cannot be achieved. The chamfer design could have influenced the retention forces of the tapered primary crowns negatively. After loading the copings with 50 N, the final apical position of the coping was limited by the chamfer. No conus-friction effects could occur resulting from the chamfer design. It might be assumed that higher retentive forces would have been measured without chamfer. However, this effect should influence conus-friction double-crown systems more than double crowns using adhesion. The chamfer design is necessary for sealing the space between primary crown and coping and building up adhesion.

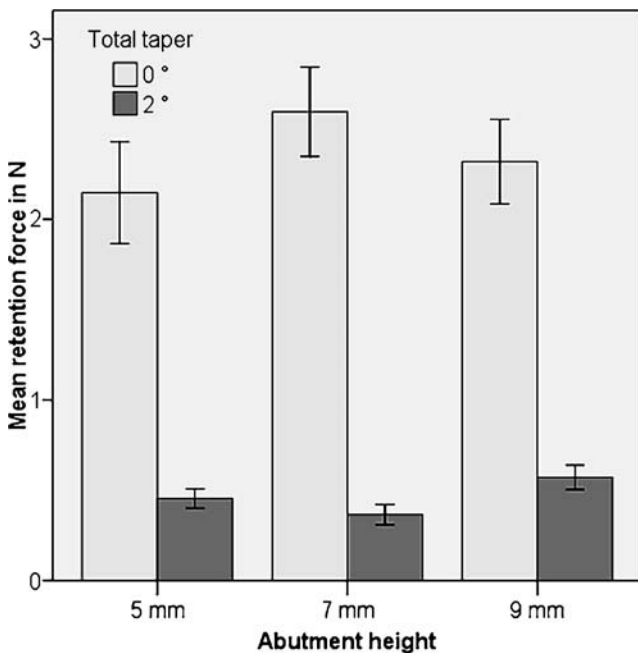


Fig. 5 Means and standard deviations of the retentive forces by three experimental abutment heights and two tapers for zirconia primary crowns

The influence of the abutment height on the retentive force was significant supporting the second part of the working hypothesis. A study investigating the retentive force of conus crowns also reported an increase of retentive force if the abutment height was increased [13]. However, that study used casting instead of electroforming and reported values in the range of 10 to 14 N [13]. A high loss of retention was observed after 10,000 separation cycles in that study [13]. Weigl et al. did not find a significant influence of the number of separation cycles on the retentive force using the electroforming technique for coping fabrication [33]. The reason might be that adhesion produces less wear than conus friction or piston-cylinder effect as no direct contact between both crowns occurs. It is an important issue using wear independent telescopic or conical crowns, otherwise additional elements are necessary to guarantee long-term retention [15, 17, 20].

The majority of authors reported that retention decreases as the conus angle increases concurring with the findings of this study and supporting the third part of the working hypothesis [13, 20].

The following limitations apply to this study: (1) incomplete retainers were tested as the electroformed copings were not embedded completely in a stiff material. Although the highest coping thickness possible was chosen

and the copings were covered by resin starting 1 mm above the margin, it could not be controlled completely that no deformation of the electroformed copings had occurred. (2) In clinical use, a minimum of two splinted retainers are necessary. The second retainer influences the retentive properties not only by adding up the retention forces of the retainers. The second retainer also prevents the sensitivity of the denture to lateral forces. This parameter was not evaluated in this study. (3) Only one electroforming system was tested. (4) Only one artificial saliva product was used. (5) The initial retention force was measured; possible effects of wear were not taken into account. On the one hand, it can be supposed that less wear will occur compared to conventional double-crown systems as no direct contact should exist. On the other hand, there are no data on the wear of 0° primary crowns with electroformed secondary crowns.

Conclusions

According to the results including the limitations of the study, the following conclusions can be drawn:

1. Primary crowns made of zirconia showed higher retentive forces than crowns made from gold alloy.
2. Decreasing the conus angle increased the retentive forces.
3. Longer abutment teeth showed higher retentive forces.
4. In situations with 2° taper and long abutment teeth, zirconia primary crowns are an alternative to gold alloy primary crowns.

Acknowledgements Wieland supported this study with material. The authors wish to sincerely thank Josef Schweiger (head of dental laboratory) for his support in manufacturing the specimen. The authors wish to thank Dr. Kurt Erdelt for designing the abutments and his support with the universal testing machine. The authors would like to thank Dr. Michael Hanna (Medical manuscripts) for proof-reading the manuscript.

Conflict of interest The authors declare that they have no conflict of interest.

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