# Survival of Dicor Glass-Ceramic Dental Restorations Over 20 Years: Part IV. The Effects of Combinations of Variables

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***Purpose:*** Previous studies have shown the relationship of individual clinical variables to the survival of Dicor (Corning Glass Works) restorations. The purpose of the present investigation was to examine the effect of combinations of these variables on the intraoral survival of Dicor restorations. ***Materials and Methods:*** Dicor glass-ceramic restorations (n = 1,444) were placed in 417 adult patients. Failure was defined as a restoration that required remake because of material fracture. The survival of restorations with different combinations of variables that were each individually associated with survival was described using Kaplan-Meier survivor functions. The statistical significance of differences in survival between different combinations of specific predictor variables was examined using the proportional hazards model. ***Results:*** Kaplan-Meier survival analysis indicated that significantly worse survival rates were found for restorations that included combinations of molar teeth, a dentin core, and a glass-ionomer luting agent; molar teeth, a dentin core, and a resin luting agent; and single-rooted teeth, a dentin core, and a glass-ionomer luting agent than for any other combinations tested. The Cox proportional hazards model described a hazard ratio of 3.37 (95% confidence interval [CI]: 2.23 to 5.08) for molar teeth (versus single-rooted teeth), 2.65 (95% CI: 1.44 to 4.87) for dentin core (versus gold core), 2.35 (95% CI: 1.58 to 3.51) for men (versus women), and 1.72 (95% CI: 1.13 to 2.60) for glass-ionomer luting agent (versus resin) after adjusting for the other variables in the model. ***Conclusion:*** Factors beyond individual restoration design impact the survival of Dicor glass-ceramic. These include sex, tooth position, and restorations luted to gold core foundation bases. *Int J Prosthodont 2010;23:134–140.*

The fracturing of ceramic restorations can limit their usefulness in clinical practice. Thus, it is essential to understand the factors, or combinations of factors, that can lead to ceramic restoration failure. Although not currently employed in clinical practice, Dicor (Corning Glass Works), a Pyroceram glass-ceramic, is arguably the most extensively studied ceramic material in both laboratory and clinical settings. For this reason, the study of clinical and restoration design factors that influence the survival of this material provides a foundation for comparison between it and the different modes of failure for other dental ceramic materials. In earlier publications[1–6] a number of factors that affected the survival of Dicor restorations in the human oral cavity were described based on data for 1,444 Dicor restorations placed in 417 subjects who were monitored for up to 16 years. It was found that acid etching of the internal Dicor surface significantly increased the survival of restorations, and that complete coverage restorations on molar teeth were at a far greater risk for failure than similar restorations placed on anterior teeth and premolars. Survival of Dicor complete coverage restorations was significantly greater in women than men. The vast majority of Dicor glass-ceramic partial coverage inlay and onlay restorations and cores survived over time.[2] The cited studies demonstrated the relationship of Dicor restoration failure to expected variables, such as tooth position, and unexpected variables, such as sex, core structure, acid etching, and luting agent. In addition, some variables that might have led to restoration failure were found to be somewhat less important, such as margin design and material thickness.

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One limitation of these studies was that the relationship of the variables to restoration failure was examined individually. Thus, the purpose of the present investigation was to examine the effect of combinations of these variables on the intraoral survival of Dicor restorations.

## Materials and Methods

### *Subject Population*

The subject population and inclusion and exclusion criteria were described previously.[1] In brief, 417 subjects who required single-unit fixed prosthodontics in any area of the mouth were recruited in a clinical private practice. Subjects were informed of possible fracture potential when using Dicor compared to feldspathic ceramic materials and were offered the option of a gold or conventional metal-ceramic restoration. The analyses presented previously employed data for up to 16 years; however, the same restorations have continued to be monitored and thus, data are presented for up to 20 years.

### *Study Protocol, Definition of a Failed Restoration, and Variables Recorded*

The study protocol and definition of a failed restoration were previously described.[1] In short, at baseline, restorations were completed in a typical manner.[7] Patients were routinely recalled every 6 months and the status of the restorations was evaluated and recorded. A restoration was considered to be a failure if it exhibited a fractured Dicor-ceramic piece that necessitated remake of the restoration. In some instances, the restoration was replaced for other reasons but not as a result of failure. For example, an adjacent tooth was lost and the restored tooth in the study was needed as an abutment tooth for a fixed partial denture. Such instances were recorded as being replaced without failure.

The data recorded for each subject and restoration were also listed previously.[1] The data were updated at each visit. The analyses used the data from the last recall visit if the restoration was still intact, or the visit at which failure was noted. The present investigation examined the combined effects of variables found in earlier publications to be related significantly to Dicor restoration failure.

### *Statistical Analysis*

Methods of data presentation and statistical analysis are described elsewhere.[1–3] The survival of the restorations or subsets of restorations grouped on the basis of combinations of variables were displayed using Kaplan-Meier survivor functions. The significance of the differences between survival curves was determined using the log-rank test. The total time at risk was computed as the sum of the censored and survival times for each group. Estimated risk was computed as the number of failures in that group divided by the corresponding total time at risk.

The Cox proportional hazards model was used to examine the effect of combinations of variables on the hazard rate. All statistically significant variables described in previous publications[1–3] were tested in this model. The significance of variables in the model and their interaction with one another was tested, as well as the assumptions of the proportional hazards model.[8]

**Table 1** Grouping of Restorations According to Tooth Position, Core Structure, and Luting Agent

| Tooth position | Core | Luting agent | Abbreviation |
|---|---|---|---|
| Single-rooted | Dentin | Resin | SDR |
| Single-rooted | Dentin | Glass ionomer | SDGI |
| Single-rooted | Gold | Resin | SGR |
| Single-rooted | Gold | Glass ionomer | SGGI |
| Molar | Dentin | Resin | MDR |
| Molar | Dentin | Glass ionomer | MDGI |
| Molar | Gold | Resin | MGR |
| Molar | Gold | Glass ionomer | MGGI |

## Results

### *Survival of Acid-Etched Dicor Restorations*

Acid-etched complete coverage restorations were subset into eight categories according to tooth position (single-rooted, including incisors, canines, and premolars, or molars), core structure (dentin or gold), and luting agent (resin or glass ionomer), as described in Table 1. The survivor functions for the eight categories are presented in Fig 1. The probability for survival of restorations on single-rooted teeth with gold cores luted with glass-ionomer luting agents (SGGI) was 96% at 20 years. The probability for survival of restorations was 81% at 20 years for single-rooted teeth with gold cores and resin luting (SGR), 82% at 16 years for molar teeth with gold cores and resin luting (MGR), 77% at 20 years for single-rooted teeth with dentin cores luted with resin luting agents (SDR), 64% at 16 years for molars with dentin cores luted with resin (MDR), 47% at 20 years for single-rooted teeth with dentin cores luted with glass-ionomer (SDGI), and 46% at 20 years for molar teeth with dentin cores luted with glass ionomer

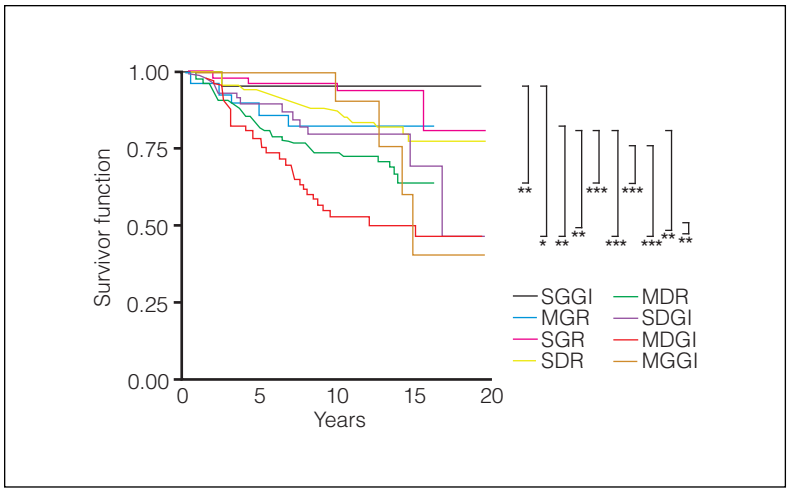


**Fig 1** Kaplan-Meier survivor functions. Significance of differences between survival functions for the restoration groups was tested using the log-rank test. **P* < .01, ***P* < .05, ****P* < .001.

(MDGI). The poorest survival was found for restorations on molar teeth luted to gold core structures with the glass-ionomer luting agent (MGGI). The probability of survival of this group was 40% at 20 years. The significance of differences in the survival of restorations among groups, as determined by the log-rank test, is presented in Fig 1. Figure 2 presents the survivor functions and 95% confidence intervals for the survivor functions presented in Fig 1. When there was a large number of subjects in a clinical group, as indicated by the tighter confidence intervals, there appeared to be a more-or-less continuous failure rate for restorations at about 10 years. This was particularly noticeable for the SDR, MDR, and MDGI restoration groups, and to a lesser extent for the SDGI and MGR restorations. The MGGI restorations exhibited no failures for about 10 years and then a sudden increase in the number of observed failures in subjects who were still available for monitoring. The large confidence intervals for this group indicated the relatively small numbers of subjects in that study group after 10 years. The SGGI and SGR restoration groups showed fewer failures and smaller confidence intervals, at least for the first 15 years of the study.

Vertical lines have been placed on the panels of Fig 2 to highlight the survivor functions and 95% confidence intervals at 3, 5, and 10 years. These times were chosen to represent time points commonly used in longitudinal clinical trials. The survival at these time points for each clinical group is presented in Table 2. Figure 2 and Table 2 indicate that survival in the eight clinical groups was reasonably similar at 3 years, and that the percentage of surviving restorations differed more markedly among groups at 5 and 10 years.

### *Risk of Failure for Acid-Etched Dicor Restorations*

The number of units and failures, cumulative monitoring years, estimated risk of failure, and relative risks for acid-etched complete coverage restorations subset into the eight categories are presented in Table 3. Compared to the lowest risk reference group (SGGI), there was approximately a 12.2 times greater risk of failure for the MDGI group, 7.2 times greater risk for the MDR group, 6.4 times greater risk for the MGGI group, 5.4 times greater risk for the SGGI group, 4.4 times greater risk for the MGR group, 3.5 times greater risk for the SDR group, and 1.4 times greater risk for the SGR group.

### *Examination of Combinations of Variables*

Table 4 presents variables that were statistically significantly associated with Dicor restoration failure in the proportional hazards model after adjusting for the other variables in the model. None of the other variables tested were statistically significant when added to this model, including chamfer (versus shoulder), age of the patient, and thickness of the restoration. In addition, the interaction terms between statistically significant variables were not statistically significant when added to the model. The test for significance of the proportional hazards assumption indicated that the assumptions of the model were valid. The data indicated that molar teeth (versus all other teeth), dentin core (versus gold core), placement in men (versus women), and employing a glass-ionomer luting agent (versus resin) all increased the risk of failure after adjusting for the other variables in the model. The hazard ratio

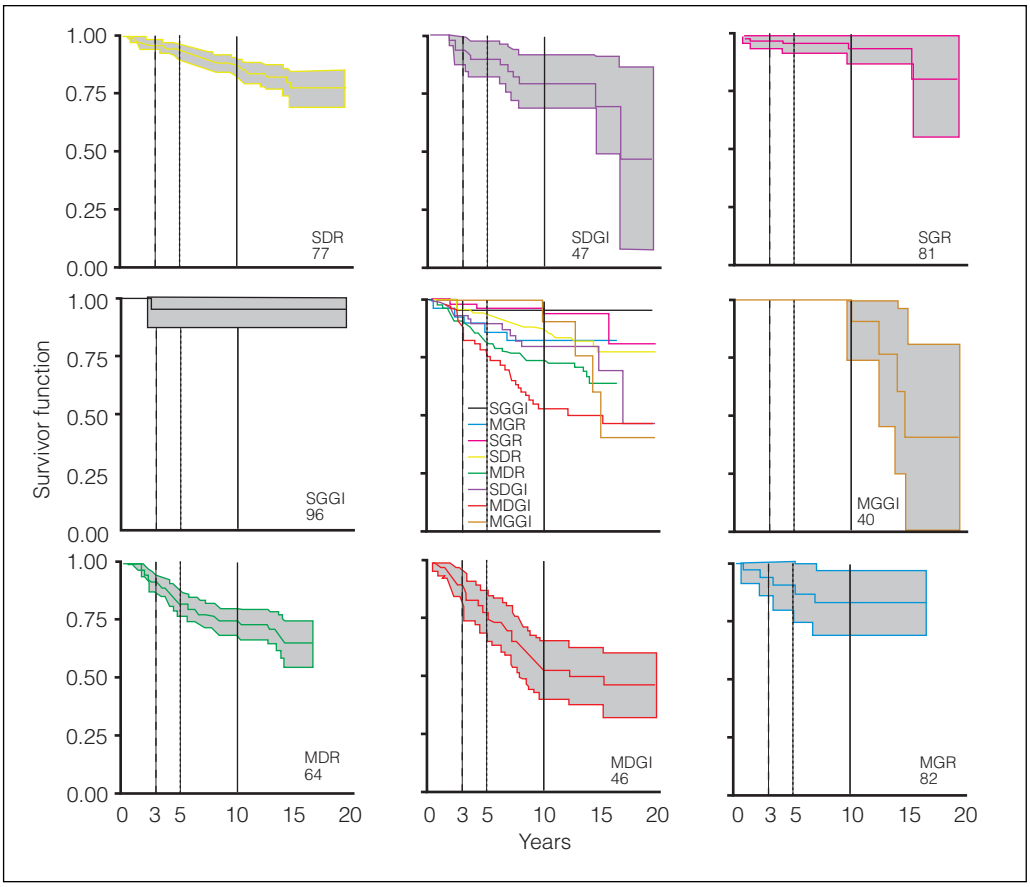


**Fig 2** Kaplan-Meier survivor functions and 95% confidence intervals for restorations. The center panel presents all eight survival functions and is identical to Fig 1.

of 3.37 for molar teeth was particularly troubling, suggesting that molar restorations were at a specific risk for failure. Restorations luted to teeth with dentin cores and in men more than doubled the hazard for complete acid-etched Dicor restorations, after adjusting for the other variables in the model.

## Discussion

The effect of individual factors on the survival of acid-etched complete coverage Dicor restorations was previously reported.[1–6] The emphasis of the present study was to therefore examine the effect of combinations of factors that were shown to significantly affect survival when examined individually. Survivor functions and estimates of risk were used to examine all possible combinations of three independent variables: tooth position, core structure, and luting agent. The data reinforced expected findings, such as the poor survival of restorations on molar teeth with dentin cores and glass-ionomer luting agent (MDGI). When dentin cores were employed with resin luting agents on molar teeth, there was a nonsignificant reduction in the risk of failure when compared with that of the MDGI group. However, placing acid-etched Dicor restorations on gold cores with resin luting agents significantly decreased the hazard on molar teeth. Unfortunately, there were not enough restorations in the MGGI group to draw conclusions

**Table 2** Number of Restorations That "Survived" at Selected Time Points

| Restoration | 3 y (%) | 5 y (%) | 10 y (%) | 20 y (%) |
|---|---|---|---|---|
| SDR | 95.8 | 93.2 | 86.1 | 77.1 |
| SDGI | 93.5 | 89.9 | 79.2 | 46.5 |
| SGR | 98.0 | 96.7 | 94.5 | 81.0 |
| SGGI | 95.7 | 95.7 | 95.7 | 95.7 |
| MDR | 90.4 | 81.5 | 74.2 | 64.1 |
| MDGI | 82.9 | 75.3 | 53.1 | 46.4 |
| MGR | 93.6 | 86.3 | 82.2 | 82.2 |
| MGGI | 100.0 | 100.0 | 90.9 | 40.4 |

**Table 3** Estimated Risk of Failure of Acid-Etched Complete Coverage Dicor Restorations

| Restoration | n | Failures | Cumulative follow-up (y) | Estimated risk of failure (%) | Relative risk |
|---|---|---|---|---|---|
| SDR | 400 | 47 | 3,101 | 1.52 | 3.54 |
| SDGI | 69 | 12 | 518 | 2.32 | 5.41 |
| SGR | 125 | 5 | 832 | 0.60 | 1.40 |
| SGGI | 26 | 1 | 234 | 0.43 | 1.00 |
| MDR | 291 | 61 | 1,974 | 3.09 | 7.22 |
| MDGI | 84 | 33 | 632 | 5.22 | 12.20 |
| MGR | 39 | 5 | 263 | 1.90 | 4.43 |
| MGGI | 13 | 4 | 146 | 2.73 | 6.38 |

**Table 4** Evaluation of Failures Using Proportional Hazards Analysis

| | Hazard ratio | SE | 95% CI | *P** |
|---|---|---|---|---|
| Molar (vs single-rooted) | 3.37 | 0.71 | 2.23–5.08 | < .001 |
| Dentin core (vs gold core) | 2.65 | 0.82 | 1.44–4.87 | .002 |
| Men (vs women) | 2.35 | 0.48 | 1.58–3.51 | < .001 |
| Glass ionomer (vs resin) | 1.72 | 0.36 | 1.13–2.60 | .011 |

SE = standard error.
*Overall *P* value < .00001.

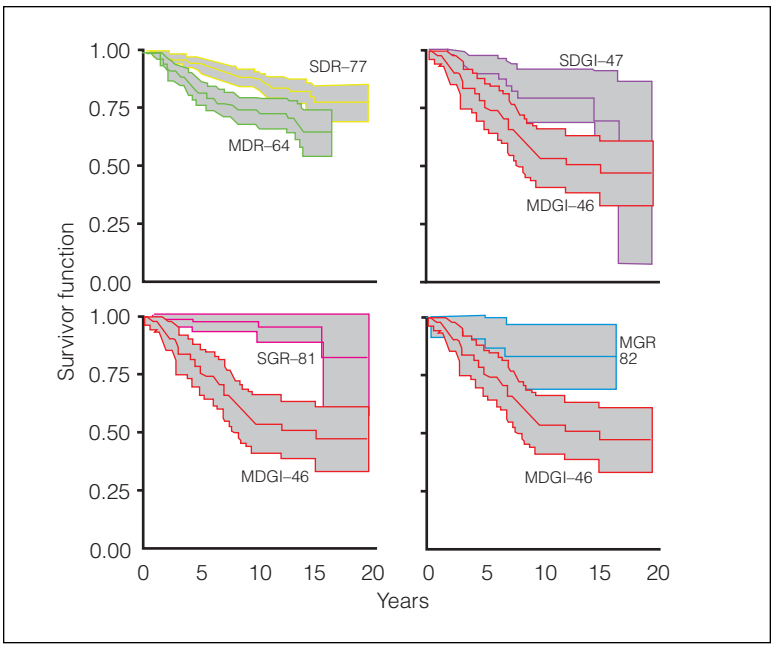


**Fig 3** Comparison of Kaplan-Meier survivor functions and 95% confidence intervals for the SDR and MDR restorations, SDGI and MDGI restorations, SGR and MDGI restorations, as well as MGR and MDGI restorations. The spaces between confidence intervals indicate the time period when the survivor functions were likely to have differed significantly.

as to the effect on the survivor function of this combination of factors. The data from restorations on single-rooted teeth were enlightening. The restorations that employed a gold core and glass-ionomer luting agent exhibited a better survivor function than restorations that employed a resin luting agent with either a dentin or gold core (Fig 1). Although not statistically different from the other single-rooted tooth categories, the 26 restorations in the SGGI group exhibited excellent survival.

In accord with previous findings, restorations on molars exhibited worse survivor functions than those on single-rooted teeth, with the exception of molar restorations with gold cores and resin luting agents.

Most notably, restorations placed on dentin cores with glass-ionomer luting agents survived poorly whether on single-rooted or molar teeth. Restorations with dentin cores and glass-ionomer luting agents, when placed on molar teeth, exhibited significantly poorer survival than when placed on single-rooted teeth.The data presented in Fig 2 and Table 2 examined the effect of the length of follow-up on estimates of long-term survival. Examination of survivor functions suggested that seven of eight combinations of the three factors (tooth position, core structure, and luting agent) demonstrated greater than 90% survival at 3 years. The exception was the MDGI group. At 5 years, the MDR and MDGI groups showed lower survivor functions than the other six groups. By 10 years, SDGI also showed diminished survival. At 20 years, the survivor functions differed markedly from group to group, as previously described. The data in Fig 2 and Table 2 suggest that short-term survival (3 to 5 years) is not necessarily a good predictor of long-term survival, at least in this database. The shape of the survivor functions and 95% confidence intervals were of considerable interest. The data for SDR, MDR, and MDGI suggest that failures may be observed within months of insertion, and that failures continue at more-or-less regular intervals for 5 to 15 years.

Although the failures appear to be occurring at a regular rate in these three groups, the rate of failure in the MDGI group appeared to be about twice as rapid as in the SDR group (Fig 2). There is also a suggestion in Figs 1 and 2 that after 10 to 15 years there may be little further failure for restorations in certain groups, such as MDGI, MGR, SGGI, and perhaps SDR. The survivor functions for the other groups suggest either few failures (SGGI) or possibly a step function (MGGI, SGR). The appearance of these survivor functions may be due to the smaller number of restorations in these groups. Superimposition of the 95% confidence intervals for different restoration groups suggested the time at which statistically significant differences occurred between survivor functions. For example, Fig 3 presents the survivor functions and 95% confidence intervals for the SDR and MDR groups and suggests that the survivor functions differed significantly from 4 to 11 years after restoration insertion. The widened confidence intervals, due to the smaller number of restorations in each group, led to lack of a significant difference from 11 years onward.

When discussing the survival of dental restorations one cannot account for all factors that might affect survival, including different clinical conditions, alterations in technique, and potential unintentionally induced laboratory or clinical damage. This might include adjustments to remove undercuts and fitting restorations, sandblasting,[9] or occlusal adjustment.

The proportional hazards model supported the key roles of tooth position, core structure, and luting agent in the survival of Dicor restorations. These factors and the sex of the patient were the only variables that were statistically significant after adjusting for the presence of the other variables in the model. The model suggests that the risk of failure was increased most by placing restorations on molar rather than single-rooted teeth (hazard ratio: 3.37). Placing restorations on dentin cores and in men also increased the risk of failure markedly after adjusting for the other variables in the model (hazard ratios: 2.65 and 2.35, respectively). Of interest was the finding that all other variables examined were not significant after adjusting for the four variables in this model. These included margin design, restoration thickness, and patient age.

The data in the present investigation described four key factors (tooth position, core structure, luting agent, and sex of the patient) that impact the long-term survival of Dicor restorations. These findings, using long-term clinical survival data of Dicor restorations, serve as a point of departure for studies involving new ceramic materials. Some of the additional lessons learned in this study remind us that *(1)* both clinical (tooth position, sex) and technical (foundation core structure, luting agent) variables should be monitored when evaluating the survival of ceramic restorations, *(2)* the time of follow-up in studies of dental materials is critical in that differences among groups often required 5 or more years to become evident after restoration insertion, and *(3)* physical properties by themselves are not a sufficient predictor of long-term survival.

It is often thought that a new dental material will behave similarly to other materials in the same family (eg, dental ceramics) under all conditions. The present study demonstrates that this is clearly not the case. Unfortunately, the literature has few reports describing how a given material will behave intraorally in different clinical situations. The present study examined clinical and technical variables not typically studied in other investigations, and demonstrated that long-term survival of dental materials is often not predictable through in vitro testing. Some physical properties (eg, material thickness) that were previously believed to be critical were not important for Dicor survival.

Examination of the Dicor glass-ceramic material has influenced the understanding of how all-ceramic dental materials fail physically and how a monolayered material such as Dicor, Empress, or e.max Lithium Disilicate might behave. Some ceramic families of

bilayered materials, such a metal-feldspathic ceramics, alumina-feldspathic ceramics (In Ceram, Procera), or zirconia-feldspathic ceramics (Procera, Lava), behave differently and others exhibit a similar survival pattern to monolayered ceramics. Monolayered materials fail from within and take on a characteristic semiluna or crescent fracture form, observed consistently in this study. Bilayered materials are thought to be plagued by chipping of the feldspathic ceramic veneer, leading to failure in many situations since the restorations need to be remade.

Understanding how different dental prosthetic materials survive over a long period of time and how clinical and design factors influence this survival provides information that can be used to guide the design and physical properties of new ceramic materials.

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*Literature Abstract*

**Analysis of retention and wear of ball attachments**


Different attachment systems are available for use with implant-retained dentures. Ball attachments are often recommended since they are cost effective and simple to use. However, clinical studies have shown frequent changes in the retention of overdentures that use ball attachments. The aim of this study was to evaluate the retention and wear characteristics of commercially available ball attachments. Five ball attachments and one ball-like attachment were included in the study: Dalbo-Plus elliptic with precious alloy ball (Cendres & Metaux) and Dalbo-Plus elliptic (Cendres & Metaux) with titanium ball (Straumann, no. 48.439), Ecco (Unor), Locator (Zest Anchors), Tima (Unor), and Pro-Snap (Metalor). The matrix housings were fixed in a stylized unilateral removable partial denture and spring-loaded to simulate a vertical sliding movement of the matrix to the patrix. After the matrix was placed on its patrix, an eccentric load of 100 N was applied on the denture at a distance of 12 mm from the patrix to simulate chewing forces. The joining and separating forces were recorded for 50,000 cycles. Initially, median retentive forces ranged from 8.2 to 14 N. The retention force differed markedly between the groups over the tested range of cycles. After 50,000 cycles, the Dalbo-Plus elliptic with titanium ball had a significantly higher retentive value (10.4 N) compared to the other groups (1.2 to 3.7 N). The greatest variability of retention occurred in the Locator attachment. The median retention increased to a maximum of 18.5 N after 200 cycles but decreased to 2.0 N at the end of testing, with the matrices showing considerable wear. The mid-test increase in retention was due to wear increasing the roughness of the retentive parts. This roughness resulted in increased joining and separating forces but also resulted in increased long-term wear and decrease in retention. After 50,000 cycles, only the Dalbo-Plus elliptic ball attachments with a titanium ball showed clinically acceptable retention values. Within the limits of this in vitro study, a titanium ball in combination with a precious gold alloy matrix seems to be a favorable option for long-term retention.


**Wolf K, Ludwig K, Hartfil H, Kern M.** *Quintessence Int* 2009;40:405–412. **References:** 35. **Reprints:** Dr Katja Wolf, Department of Prosthodontics, Propaedeutics, and Dental Materials, School of Dentistry, Christian-Albrechts University, Arnold-Heller-Strasse 16, 24105 Kiel, Germany. Email: kwolf@proth.uni-kiel.de—*Clarisse Ng, Singapore*