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EVALUATION OF MARGINAL ADAPTATION IN METAL-CERAMIC VERSUS ALL-CERAMIC FIXED PARTIAL DENTURES USING CLINICAL METHODS

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Abstract

Background: Marginal adaptation is a critical determinant of the biological and mechanical success of fixed partial dentures (FPDs). While metal-ceramic FPDs have long been considered the clinical standard, advances in zirconia-based all-ceramic systems necessitate comparative clinical evaluation of marginal integrity using in vivo methods.

Aim: To clinically compare marginal adaptation of metal-ceramic and zirconia-based all-ceramic three-unit fixed partial dentures using standardized clinical assessment methods over a 12-month period.

Materials and Methods: This prospective comparative study included 60 patients requiring posterior three-unit FPDs, divided equally into metal-ceramic (Group MC) and all-ceramic zirconia-based (Group AC) groups. Standardized tooth preparation, impression, fabrication, and cementation protocols were followed. Marginal adaptation was evaluated at baseline, 6 months, and 12 months using modified United States Public Health Service (USPHS) criteria and the silicone replica technique for marginal gap measurement. Statistical analysis was performed with significance set at $p<0.05$.

Results: Both groups demonstrated clinically acceptable marginal adaptation throughout follow-up. USPHS scores showed no statistically significant intergroup differences at any interval. Mean marginal gap values increased over time in both groups; however, at 12 months, the all-ceramic

group exhibited significantly lower marginal gaps compared to the metal-ceramic group (p=0.02). Clinical events such as sensitivity and gingival bleeding were infrequent and comparable.
Conclusion: Zirconia-based all-ceramic FPDs demonstrated marginal adaptation comparable to metal-ceramic FPDs, with superior quantitative marginal gap values at 12 months, supporting their clinical reliability in posterior applications.

Keywords: Marginal adaptation; Fixed partial denture; Metal-ceramic restoration; All-ceramic restoration; Zirconia FPD

Introduction

Long-term success of fixed partial dentures (FPDs) depends on the biologic and mechanical harmony between restoration, tooth, and periodontal tissues. Among the clinical determinants of longevity, marginal adaptation is consistently emphasized because marginal discrepancies can promote plaque retention, gingival inflammation, secondary caries, hypersensitivity, and ultimately loss of abutment integrity. Even when occlusion and proximal contacts are satisfactory, a poorly adapted margin may compromise outcomes by increasing microleakage and cement dissolution, particularly in high-load posterior segments and in patients with moderate caries risk. Clinical marginal adaptation is therefore not only a laboratory quality parameter, but also a chairside predictor of serviceability over time [1].

Metal-ceramic FPDs have historically been regarded as the benchmark for multi-unit restorations due to favorable strength, proven clinical performance, and tolerance to functional stress. However, esthetic expectations and the evolution of ceramic systems have accelerated the adoption of all-ceramic FPDs, including zirconia-based frameworks with veneering ceramic or monolithic ceramics. All-ceramic restorations offer superior translucency and color stability, with reduced risk of metal show-through at the cervical region and improved patient satisfaction. Nevertheless, concerns remain regarding technique sensitivity, marginal chipping in layered systems, and the influence of milling and sintering shrinkage on marginal accuracy—especially for multi-unit spans [2,3].

Marginal adaptation is typically reported using laboratory methods such as micro-CT, stereomicroscopy, and cross-sectional measurements on dies. While these approaches provide high-resolution numeric gap values, their translation to clinical reality can be limited by the absence of intraoral variables such as moisture control, seating dynamics, cementation pressure, periodontal biotype, and occlusal function. Clinical methods—modified United States Public Health Service (USPHS) criteria, explorer “catch” evaluation, intraoral radiographic assessment, and silicone replica techniques—help bridge this gap because they evaluate the restoration in vivo, incorporating clinical handling and patient-specific factors [4,5].

The choice between metal-ceramic and all-ceramic FPDs in daily practice often relies on a balance of esthetics, cost, material strength, and perceived fit. However, clinicians also need evidence-based guidance on whether contemporary all-ceramic systems can match or exceed the marginal adaptation of conventional metal-ceramic restorations under standardized clinical conditions. Prior studies suggest that manufacturing workflows, finish line design, and cement selection significantly influence marginal outcomes, but results are heterogeneous across ceramic systems and measurement protocols [6–10]. Additionally, many published investigations focus on single crowns rather than multi-unit FPDs, despite the higher technical demands of multi-unit fabrication.

Accordingly, this study prospectively compared the marginal adaptation of metal-ceramic versus zirconia-based all-ceramic three-unit FPDs using standardized clinical evaluation methods and a silicone replica-based marginal gap assessment at defined follow-up intervals. The null hypothesis was that there would be no significant difference in marginal adaptation between the two groups at baseline and during 12 months of clinical service.

Materials and Methods

Study design and setting: A prospective comparative clinical study was conducted in a university prosthodontic clinic over 14 months (including recruitment and follow-up). The study protocol adhered to institutional ethical requirements, and written informed consent was obtained from all participants.

Participants:

Sixty adult patients requiring replacement of a single missing tooth with a three-unit tooth-supported FPD (posterior premolar–molar region) were recruited. Participants were allocated into two equal groups (n=30 each) based on the planned restorative material:

- **Group MC (Metal-Ceramic FPD):** cobalt–chromium framework with veneering porcelain.
- **Group AC (All-Ceramic FPD):** zirconia framework (CAD/CAM milled) with veneering ceramic (layered zirconia system).

Inclusion criteria:

1. Age 20–55 years.
2. Single posterior edentulous space bounded by sound or adequately restored abutments.
3. Periodontally healthy or treated stable periodontal condition (probing depths ≤4 mm, no active inflammation).
4. Adequate inter-arch space and occlusal stability.

Exclusion criteria:

1. Uncontrolled systemic disease affecting healing.
2. Parafunctional habits (severe bruxism) reported or clinically evident.
3. Poor oral hygiene (plaque index >2) at baseline.
4. Need for cantilever FPD, long-span FPD, or compromised abutment prognosis.

Tooth preparation and impression: Standardized full-coverage preparations were performed using a deep chamfer finish line (0.8–1.0 mm) with rounded internal line angles. A uniform total occlusal convergence of approximately 6–10 degrees was targeted. Gingival retraction was performed using a double-cord technique. Final impressions were made with polyvinyl siloxane (two-step putty-wash). Working casts were poured in type IV die stone.

Fabrication protocols:

- **MC group:** Wax pattern, casting (Co–Cr), porcelain application and glazing.
- **AC group:** Digital scanning of dies, CAD design with standardized cement space (set at 50 μm starting 1 mm above margin), CAM milling of zirconia, sintering, veneering ceramic application and glazing.

Cementation:

Try-in was performed to verify contacts and occlusion. All FPDs were cemented with resin-modified glass ionomer cement under standardized seating pressure. Occlusal adjustments were completed, and patients received oral hygiene instructions.

Outcome measures and follow-up: Marginal adaptation was assessed at **baseline (1 week after cementation), 6 months, and 12 months** using two clinical methods:

1. **Modified USPHS marginal adaptation score**: Alpha (ideal), Bravo (clinically acceptable minor discrepancy), Charlie (unacceptable—replacement indicated).
2. **Silicone replica technique** for marginal gap measurement (μm): light-body material was injected at the margin, stabilized with heavy-body putty, sectioned, and measured at four

standardized sites per abutment (mid-buccal, mid-lingual, mesial, distal) using a calibrated optical microscope. The mean marginal gap per FPD was computed.

Statistical analysis: Data were analyzed using appropriate parametric/non-parametric tests after normality checks. Between-group comparisons of marginal gap were performed using independent t-tests (or Mann–Whitney U if required). Changes over time were assessed using repeated measures analysis. USPHS scores were compared using Chi-square/Fisher's exact tests. Significance was set at $p<0.05$.

Results

Participant flow and baseline comparability

All 60 participants completed baseline evaluation. At 12 months, 58 participants remained (one loss to follow-up in each group). Baseline demographics, location of FPDs, and oral hygiene indices were comparable between groups ($p>0.05$).

Table 1. Baseline characteristics of participants and restorations

Variable	Group MC (n=30)	Group AC (n=30)	p-value
Age (years), mean ± SD	37.6 ± 8.4	36.9 ± 7.9	0.74
Sex (M/F)	14 / 16	13 / 17	0.80
Arch (Maxilla/Mandible)	12 / 18	11 / 19	0.79
Site (Premolar–Molar / Molar–Molar)	21 / 9	20 / 10	0.78
Plaque Index, mean ± SD	1.2 ± 0.4	1.1 ± 0.4	0.41
Gingival Index, mean ± SD	1.1 ± 0.3	1.1 ± 0.3	0.92

Narrative findings (Table 1): Table 1 demonstrates that the two groups were clinically comparable at baseline. Mean age was similar (37.6±8.4 vs 36.9±7.9 years), and sex distribution was balanced. Most restorations were placed in the mandibular arch in both groups. The majority of FPDs were premolar–molar replacements, reflecting common posterior tooth loss patterns. Oral hygiene and gingival indices were low and statistically comparable, supporting a fair comparison of marginal outcomes between metal-ceramic and all-ceramic FPDs.

Table 2. Modified USPHS marginal adaptation scores over time

Time point	Group MC (n) Alpha / Bravo / Charlie	Group AC (n) Alpha / Bravo / Charlie	p-value*
Baseline (n=30 each)	24 / 6 / 0	26 / 4 / 0	0.49
6 months (MC n=30; AC n=30)	22 / 8 / 0	24 / 6 / 0	0.56
12 months (MC n=29; AC n=29)	19 / 9 / 1	22 / 7 / 0	0.32

*Chi-square/Fisher's exact test as appropriate.

Narrative findings (Table 2): As shown in Table 2, both groups exhibited high rates of clinically ideal margins (Alpha) at baseline, with a slight shift toward Bravo scores over time. At 12 months, the all-ceramic group maintained a higher proportion of Alpha ratings (22/29) than the metal-ceramic group (19/29), though the difference was not statistically significant. One metal-ceramic FPD reached a Charlie score at 12 months, indicating a clinically unacceptable marginal condition requiring intervention.

Table 3. Marginal gap (µm) measured by silicone replica technique

Time point	Group MC mean ± SD (µm)	Group AC mean ± SD (µm)	Mean difference (MC–AC)	p-value
Baseline (n=30)	92.4 ± 18.6	84.7 ± 16.9	7.7	0.10
6 months (n=30)	98.9 ± 20.3	89.6 ± 18.1	9.3	0.07
12 months (n=29)	107.8 ± 23.9	93.8 ± 19.5	14.0	0.02

Narrative findings (Table 3): Table 3 indicates that mean marginal gap values increased modestly over time in both groups, consistent with clinical aging, cement washout, and functional loading. At baseline and 6 months, the all-ceramic group showed lower mean marginal gaps than the metal-ceramic group, without reaching statistical significance. At 12 months, the difference widened (107.8±23.9 μm vs 93.8±19.5 μm), and the intergroup comparison became statistically significant, favoring the all-ceramic FPDs.

Table 4. Clinical events potentially related to marginal integrity (12-month period)

Event	Group MC (n=29)	Group AC (n=29)	p-value
Post-cementation sensitivity (>2 weeks)	5 (17.2%)	3 (10.3%)	0.45
Gingival bleeding localized to abutment margin	6 (20.7%)	4 (13.8%)	0.49
Recurrent caries at abutment	2 (6.9%)	0 (0.0%)	0.15
Debonding/need for recementation	1 (3.4%)	1 (3.4%)	1.00
Marginal repair/polishing required	3 (10.3%)	2 (6.9%)	0.64

Narrative findings (Table 4): Table 4 summarizes clinically relevant events observed during follow-up. Post-cementation sensitivity and localized gingival bleeding were slightly more frequent in the metal-ceramic group, but differences were not significant. Two cases of recurrent caries occurred in the metal-ceramic group and none in the all-ceramic group; the sample size limited statistical significance, but the pattern aligned with higher mean marginal gaps at 12 months for metal-ceramic FPDs. Debonding was rare and comparable across groups.

Discussion

This prospective clinical study compared marginal adaptation of metal-ceramic and zirconia-based all-ceramic three-unit FPDs using chairside USPHS scoring and silicone replica marginal gap measurement. The main finding was that both systems demonstrated clinically acceptable marginal adaptation at baseline and 6 months, but by 12 months the all-ceramic group exhibited significantly lower mean marginal gap values, while USPHS differences remained statistically non-significant. These findings suggest that clinically detectable marginal integrity may remain acceptable in the short term for both materials, whereas quantitative marginal gap assessment may reveal earlier divergence in marginal performance [11].

The slight increase in marginal gap values over time in both groups is consistent with the dynamic oral environment, where masticatory stress, thermal cycling, and minor cement dissolution can magnify marginal discrepancies. Even when restoration margins are initially well-adapted, the interface is subject to hydrolytic degradation and mechanical wear that may not immediately translate into clinically unacceptable USPHS scores. This may explain why the silicone replica technique detected a significant difference at 12 months, whereas categorical USPHS scores, which are less sensitive to small numeric changes, did not show a statistically significant separation between groups [12,13].A plausible explanation for the superior 12-month marginal gap values in the all-ceramic group relates to contemporary CAD/CAM zirconia workflows. Digital design with controlled cement space parameters and standardized milling can reduce variability introduced by manual waxing, investing, casting distortion, and porcelain firing cycles. In metal-ceramic systems, cumulative inaccuracies may arise from casting shrinkage, finishing steps, and repeated firing, potentially affecting marginal stability over time. Additionally, marginal finishing quality and framework rigidity can influence micro-movements at the margin under load, which may be reflected in replica-based gap measurements after functional service [14,15].

Clinical relevance must be interpreted cautiously. Although the mean difference at 12 months favored all-ceramic FPDs, both groups' mean marginal gaps remained within ranges commonly considered clinically acceptable for fixed restorations in many clinical protocols. Importantly, the clinical event profile (sensitivity, gingival bleeding, debonding) was broadly similar across groups, indicating that short-term patient-centered outcomes may not differ substantially when both restorations are fabricated and cemented under standardized conditions. Nonetheless, the observed

pattern—higher mean gaps and two recurrent caries cases in the metal-ceramic group—supports the concept that marginal adaptation is a risk-modifying factor for biologic complications over time, particularly in caries-susceptible patients [16].

The USPHS trend toward increased Bravo scores over time in both groups likely reflects mild explorer catch or slight marginal discontinuities that remain clinically acceptable. This reinforces the need for periodic recall and margin-focused maintenance, including plaque control reinforcement and localized finishing/polishing when indicated. Given that modified USPHS criteria are widely used in clinical research, the present results align with the notion that both metal-ceramic and zirconia-based all-ceramic FPDs can achieve acceptable chairside marginal outcomes in the first year when standard protocols are followed [17].

The study's methodology intentionally combined a categorical clinical index (USPHS) with a semi-quantitative measurement approach (silicone replica). This dual-method strategy strengthens inference because it captures both clinical detectability and numeric gap behavior. However, the silicone replica method has limitations, including potential deformation during sectioning and measurement variability depending on section location. The study minimized these effects through standardized measurement sites and calibration. Additionally, the follow-up period was limited to 12 months; marginal behavior beyond one year—where cement dissolution and secondary caries risk may become more pronounced—requires longer observation [18].

Other limitations include the single-center setting and restriction to a specific all-ceramic system (layered zirconia framework) and a specific metal framework (Co–Cr). Results may not generalize to monolithic zirconia, lithium disilicate, or different manufacturing workflows. Moreover, cement selection can influence marginal sealing and microleakage; while resin-modified glass ionomer cement was standardized here for both groups, alternative resin cements may alter marginal behavior, particularly for ceramic restorations [19,20].Within these constraints, the study provides clinically applicable evidence that zirconia-based all-ceramic three-unit FPDs can achieve marginal adaptation comparable to, and potentially better than, metal-ceramic FPDs by 12 months when evaluated using sensitive clinical measurement methods. Future studies should incorporate longer follow-up, multi-center sampling, and stratification by caries risk and periodontal biotype to better predict biologic outcomes linked to marginal integrity [21-26].

Conclusion

Both metal-ceramic and zirconia-based all-ceramic three-unit fixed partial dentures demonstrated clinically acceptable marginal adaptation at baseline and throughout the first 6 months of service. Over 12 months, marginal gaps increased modestly in both groups, reflecting expected intraoral aging. Quantitative assessment using the silicone replica technique showed significantly lower mean marginal gap values for all-ceramic FPDs at 12 months, whereas modified USPHS categorical scores did not differ significantly between groups. Clinically relevant events such as sensitivity, localized gingival bleeding, and debonding were infrequent and comparable, although recurrent caries occurred only in the metal-ceramic group. Within the study limits, zirconia-based all-ceramic FPDs achieved marginal adaptation that was at least comparable—and numerically superior at 12 months—to metal-ceramic FPDs when evaluated with standardized clinical methods.

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