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RESEARCH AND EDUCATION

Marginal discrepancy of noble metal–ceramic fixed dental prosthesis frameworks fabricated by conventional and digital technologies

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ABSTRACT

Statement of problem. Studies evaluating the marginal adaptation of available computer-aided design and computer-aided manufacturing (CAD-CAM) noble alloys for metal–ceramic prostheses are lacking.

Purpose. The purpose of this in vitro study was to evaluate the vertical marginal adaptation of cast, milled, and direct metal laser sintered (DMLS) noble metal–ceramic 3-unit fixed partial denture (FDP) frameworks before and after fit adjustments.

Material and methods. Two typodont teeth were prepared for metal–ceramic FDP abutments. An acrylic resin pattern of the prepared teeth was fabricated and cast in nickel-chromium (Ni-Cr) alloy. Each specimen group (cast, milled, DMLS) was composed of 12 casts made from 12 impressions (n=12). A single design for the FDP substructure was created on a laboratory scanner and used for designing the specimens in the 3 groups. Each specimen was fitted to its corresponding cast by using up to 5 adjustment cycles, and marginal discrepancies were measured on the master Ni-Cr model before and after laboratory fit adjustments.

Results. The milled and DMLS groups had smaller marginal discrepancy measurements than those of the cast group ($P<.001$). Significant differences were found in the number of adjustments among the groups, with the milled group requiring the minimum number of adjustments, followed by the DMLS and cast groups ($F=30.643$, $P<.001$).

Conclusions. Metal–ceramic noble alloy frameworks fabricated by using a CAD-CAM workflow had significantly smaller marginal discrepancies compared with those with a traditional cast workflow, with the milled group demonstrating the best marginal fit among the 3 test groups. Manual refining significantly enhanced the marginal fit of all groups. All 3 groups demonstrated marginal discrepancies within the range of clinical acceptability. (J Prosthet Dent 2017;■:■-■)

Minimizing marginal discrepancy to improve marginal adaptation is an essential goal for both the clinical longevity and the success of a dental restoration.[1-3] The term marginal discrepancy does not have a single definition[4] but has been described by a variety of terms that include gap, misfit, vertical discrepancy, and crown elevation. However, the vertical distance from the finish line of the preparation to the cervical margin of the restoration is commonly used to describe marginal discrepancy.[5,6]

Holmes and Bayne[5] reported 2 common techniques for measuring fit relative to marginal adaptation: those using embedded and sectioned specimens[7,8] and those using measurement by direct visualization.[6,7] The number and site of measurements used to determine discrepancies also varies considerably, with studies using 4 to more than 100 measurements per specimen.[9-12] Groten et al[4] concluded that 50 measurements along the margin of a crown provided adequate information about discrepancy size.

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Clinical Implications

Both branches of CAD-CAM technology (subtractive and additive) may provide efficient alternatives to traditional casting procedures for noble metal–ceramic alloys.

The precise definition of a clinically acceptable margin is also undetermined.[13] The absolute value of the vertical marginal discrepancy deemed clinically acceptable continues to be debated, with proposed values ranging between 39 and 120 μm,[5,6,14,15] with the values depending upon the instrumentation used and the location measured.[16-18] The American Dental Association (ADA) specification 8 suggested a marginal discrepancy ranging from 25 to 40 μm as a clinical goal for an acceptable marginal discrepancy for fixed restorations.[19]

Metal–ceramic restorations are still widely used for fabricating fixed dental prostheses (FDPs). However, the steps involved in conventional fabrication can be time consuming, expensive, and technically challenging, leading to inconsistencies in prosthesis fit. These concerns multiply with frameworks involving multiple retainers and pontics. In addition, casting and soldering procedures for conventional FDPs introduce even more variability in marginal adaptation.[20-23]

Computer-aided design and computer-aided manufacturing (CAD-CAM), including both milling and direct metal laser sintering (DMLS) procedures, have recently been introduced to fabricate frameworks for metal–ceramic crowns. These technologies have overcome many of the disadvantages of conventional casting. However, scanning protocols, software design, milling parameters, and material processing have introduced new variables to the fabrication process. It is not surprising, therefore, that studies of the fit of CAD-CAM restorations have produced conflicting results. Some studies have reported larger marginal discrepancies for CAD-CAM restorations than for conventional metal–ceramic crowns,[13,24-26] whereas others have reported that CAD-CAM restorations have better marginal fit than conventional cast restorations.[27-29] A recent study compared milled, DMLS, and cast cobalt-chromium (Co-Cr) copings for metal–ceramic restorations and determined the mean marginal discrepancy values to be 86.64 μm for CAD-CAM milled, 96.23 μm for DMLS, and 75.92 μm for cast copings.[30] Another study used a visual scoring system to compare the marginal and internal adaptation of Co-Cr FDP fabricated by conventional and digital methods and revealed that the best marginal adaptation occurred with the milled group, whereas the poorest fit was from the DMLS group.[31] In addition, some authors have reported larger discrepancies for molar retainers in digitally manufactured FDPs than for premolars within the same tested specimen and related these findings to the size differences between the abutments, with the larger molar surface area associated with more internal discrepancies.[31-33] Because marginal discrepancies with FDP retainers can occur in both digitally and conventionally manufactured FDP restorations, the fit of test specimens should be evaluated based upon the largest discrepancy detectible across the specimen as a single tested unit, regardless of which retainer the discrepancy was detected in.

Most studies of CAD-CAM technology have compared copings and frameworks made from titanium or base metal alloys. Available noble alloys for metal–ceramic copings and FDP substructures are currently manufactured by milling (Strategy Milling) and by DMLS (The Argen Corp). Noble alloys are used widely in the fabrication of metal–ceramic restorations; they avoid some of the drawbacks of other alloys, including technique sensitivity, difficulty in casting or milling, and troublesome formation of oxide layers.[34-36] The authors are unaware of an investigation that has tested the performance and marginal adaptation of CAD-CAM frameworks fabricated from noble alloys marketed for cast metal–ceramic restorations.

The primary purpose of this study was to evaluate and compare the vertical marginal adaptation of cast, milled, and DMLS, metal–ceramic 3-unit noble alloy FDP frameworks before and after internal fit adjustments. A secondary objective was to evaluate the marginal discrepancy across the same specimens, comparing the measurements between the premolar and molar retainers of the FDP.

The primary null hypothesis of the study was that the fabrication method of a metal–ceramic noble alloy FDP substructure does not significantly affect the vertical marginal fit of the framework. The secondary null hypothesis was that for all fabrication techniques tested, internal fit adjustments do not affect the marginal accuracy of the framework specimens.

MATERIAL AND METHODS

A mandibular left second molar and second premolar were prepared on a typodont model (I3D-400D; Kilgore Intl) by following the suggested preparation guidelines for metal–ceramic restorations.[37] Impressions were made at room temperature by using polyvinyl siloxane monophase and extra-light viscosity impression materials (Aquasil; Dentsply Sirona) by using the 2-phase 1-step technique in a visible-light–polymerized resin customized tray (Triad; Dentsply Sirona) with approximately 2 to 3 mm of relief.[38] An acrylic resin pattern was fabricated (GC Pattern Resin; GC America) and then cast in nickel-chromium (Ni-Cr) alloy (Premium 100; Nobilium Co) (Fig. 1).

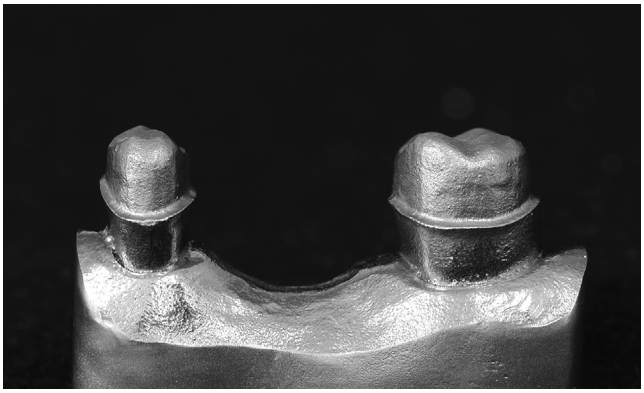

Figure 1. Ni-Cr alloy master model.

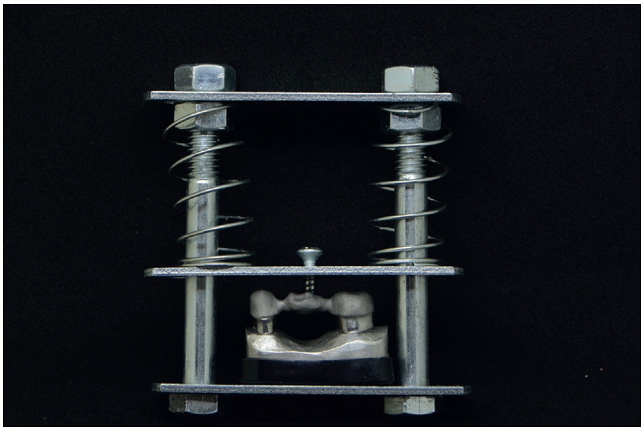

Figure 2. Seating assembly for marginal discrepancy measurement.

Visible-light–polymerized resin sheets (Triad; Dentsply Sirona) were used to fabricate 36 custom-made trays with 3 mm of internal relief. Polyvinyl siloxane tray adhesive (Genie; Sultan Healthcare) was then applied to each tray at least 15 minutes before impression making.[39] Thirty-six impressions were made. Each group (Cast, Milled, DMLS) was composed of 12 stone casts made from 12 impressions.

A single virtual design for the FDP metal–ceramic framework was created by using a laboratory scanner (D900; 3Shape A/S), saved, and used for all specimens in the 3 groups. The milling parameters were set to closely approximate conventional waxing methods: material wall thickness of 0.5 mm; cement space of 0.01 mm; extra cement space of 0.04 mm; distance to margin line of 0.5 mm; smooth distance of 0.5 mm; and margin line offset of 0.05 mm. The drill compensation radius was 0.65 mm for the milled group.

All casts from all groups (12 milled, 12 DMLS, 12 cast) were scanned by using the 3Shape scanner. Twelve digitally designed standard tessellation language (STL) files for the milled group were exported to a milling center (Strategy Milling); the noble metal–ceramic alloy specimens were milled (Atlantic Precious Metal Refining) from Pd 63.7%, Ag 26.0%, Sn 7.0%, In1.5%, and Ga 1.8%. The 12 specimens for the DMLS group were sent to a center to be sintered out of a noble metal–ceramic alloy (Nobel 25; The Argen Corp) from Pd 25%, Co 42.75%, Mo 12%, Cr 20%, and Be <1%. The specimens for the cast group were milled in wax pattern form (ArgenWAX; The Argen Corp) with the same recommended setting for die relief as for the other 2 groups. All margins of the milled wax patterns were sealed with inlay wax and trimmed to appropriate contours, sprued, and invested with phosphate-bonded investment material (Bellavest SH; BEGO USA Inc) following manufacturer's recommendations. The same noble metal–ceramic alloy used for the DMLS group was used for the conventional casting procedure. After bench cooling and chemical devesting,[40] the sprues were sectioned by using a carborundum disk.

A measuring microscope (AmScope FMA050; United Scope LLC) was used to measure marginal discrepancies at ×120 magnification. Each framework was seated on the Ni-Cr master model with a spring-loaded custom-made seating device by applying 20 N of force on the framework at the midpoint of its mesiodistal length, seating both retainers evenly (Fig. 2). This complex was examined by using light microscopy for the measuring phase.

Forty measurements were recorded per tooth in equal increments, with a total of 80 measurements per specimen prior to fit adjustments. Once adjusted, another 80 measurements were recorded (Fig. 3).

The fit of the intaglio was adjusted after spraying a disclosing medium (Occlude spray; Pascal Co) into each retainer. Each specimen was adjusted with a $^{1}/_{4}$-round tungsten carbide bur (Brasseler USA) by 1 investigator (A.A.), removing points of interference showing through the disclosing medium. The intaglio was adjusted at ×5 magnification up to a maximum of 5 adjustment cycles until margins appeared visually acceptable. At least 1 adjustment cycle was accomplished for each test specimen. A single adjustment cycle was considered complete when all interferences disclosed with a single disclosing coat were adjusted for both retainers. Each adjustment cycle was separated by steam cleaning of the residual disclosing medium from the internal aspect of each specimen, followed by reapplication of the disclosing medium to the intaglio surface of the coping. Margins were not refined during the adjustment cycles of any test specimens.

The Kruskal-Wallis with post hoc Bonferroni tests were used to compare marginal discrepancy among the 3 test groups. The Mann-Whitney *U* test was used to compare the differences between premolar and molar marginal discrepancies within each specimen, and the Wilcoxon signed rank test was used to determine the significance of

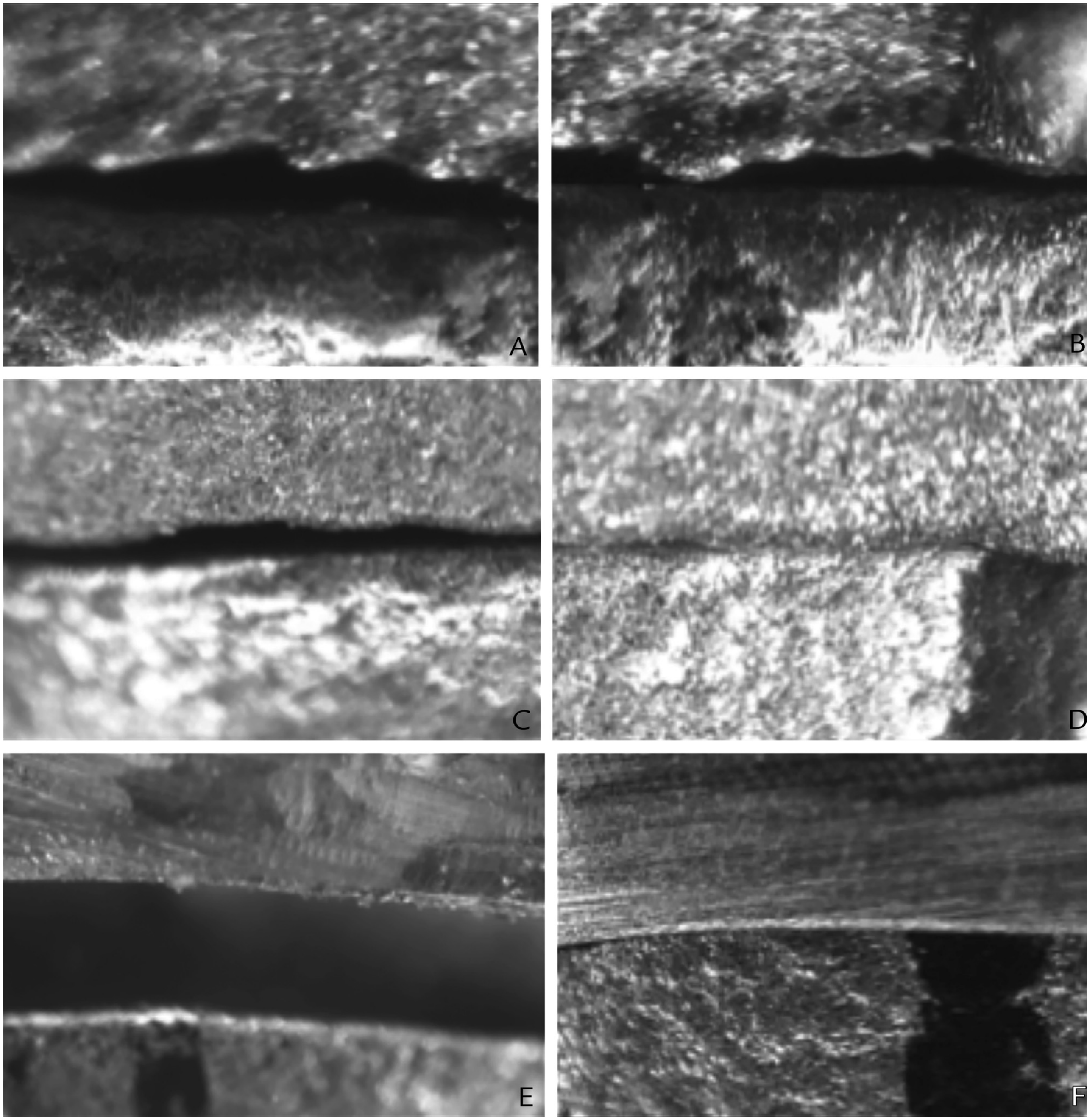

Figure 3. Photomicrographs of castings on master model (original magnification ×120). A, Cast before adjustment. B, Cast after adjustment. C, DMLS before adjustment. D, DMLS after adjustment. E, Milled before adjustment. F, Milled after adjustment. DMLS, direct metal laser sintered.

the internal adjustments of specimens. ANOVA and post hoc Bonferroni were used to compare the significance of the number of adjustment cycles between groups. Statistical software (SPSS SamplePower v3.01 for Windows; IBM Corp) was used (α=.05) for all tests.

RESULTS

The mean vertical marginal discrepancy measurements before and after adjustment for cast, DMLS, and milled groups are listed in Table 1. The range of marginal discrepancy data among specimens per group is illustrated in Figure 4. Significant differences in discrepancies were found before (H=28.810; P<.001) and after adjustment (H=18.663; P<.001) among the different fabrication techniques. The DMLS group had smaller discrepancy measurements than the cast and milled groups before internal fit adjustment (P<.001). After the adjustment cycles, the milled and DMLS FDP specimens had smaller discrepancy measurements than the cast group (P<.001).

Table 1. Comparison of mean ±SD marginal discrepancies of the 3 test groups before and after adjustments and mean number of adjustment cycles per group

Group	Premolar Before (μm)	Premolar After (μm)	Molar Pre (μm)	Molar Post (μm)	Total (Premolar+Molar) Pre (μm)	Total (Premolar+Molar) Post (μm)	No. of Adjustments
Cast	93.8 ±46.1	38.6 ±24.0	87.0 ±38.5	32.4 ±10.7	90.4 ±41.7	35.5 ±18.5	4
DMSL	31.0 ±15.4	21.5 ±11.2	34.3 ±23.9	24.1 ±15.8	32.6 ±19.8	22.8 ±13.5	2.6
Milled	100.9 ±207.3	18.2 ±20.8	101.1 ±205.5	19.2 ±20.9	101.0 ±201.9	18.7 ±20.4	1.3

DMSL, direct metal laser sintered.

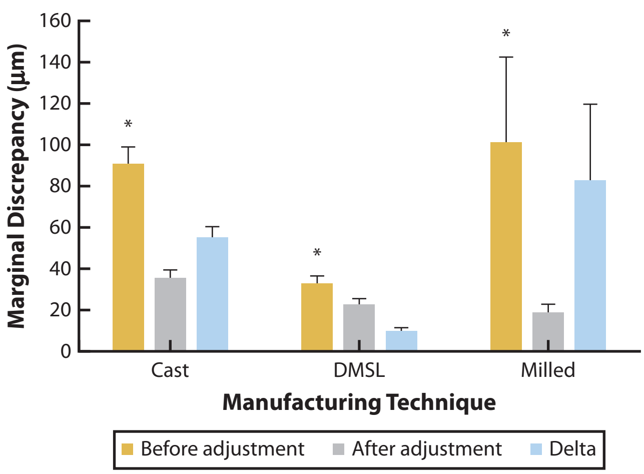

Figure 4. Range of marginal discrepancy data among specimens in each group before and after adjustments with delta measurements (difference in the marginal discrepancy before and after adjustment).

No significant differences were found in the vertical marginal discrepancy between premolars and molars before (Z=.023; *P*=.982) or after adjustment (Z=.208; *P*=.835), suggesting data can be collapsed to the fabrication method only regardless of which retainer the discrepancy was detected in. Significant differences were found in the number of necessary adjustments by methodology. The milled group required the smallest number of adjustments, followed by the DMSL and cast groups (F=30.643; *P*<.001).

DISCUSSION

Based on the results, both null hypotheses were rejected. Frameworks fabricated by the milled and DMLS techniques proved to have better marginal adaptation after adjustment than those fabricated by using the conventional casting method, with the milled group having the best after-adjustment adaptation of all groups tested. A possible explanation for the reduced number of fit adjustments with the milled group is that CAM milling is subtractive in nature and uses milling burs to cut the desired component from a solid block. If the design parameters are altered, or if the design includes fine details and sharp angles smaller than the dimension of the cutting bur, some software will direct additional internal milling to accommodate features sharper than the milling bur diameter permits. This feature is known as drill compensation (Fig. 5). DMLS technology, however, works by using a high-temperature laser to sinter a metal powder, which is then fused together in layers. As a layer is finished, the table holding the metal powder descends so that a new layer of granules can be added over those previously sintered, building up the reconstruction layer by layer until finished. As a result, no drill compensation is required with the DMLS method, and a restoration closely replicating the design parameters is fabricated (Fig. 6).

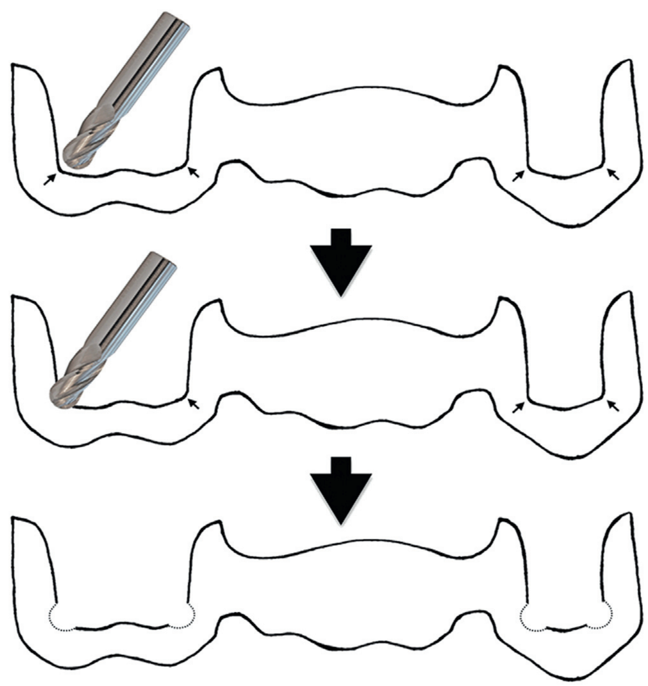

Figure 5. Drill compensation with small angles overmilled to permit complete seating of framework.

The necessity of adjusting the intaglio of frameworks to improve fit is routinely accepted and has been found to improve the marginal accuracy of both cast and CAD-CAM restorations.[28,41] A common concern with CAD-CAM restorations, however, is that marginal discrepancy precision is sometimes achieved at the expense of internal adaptation, leading to a degree of internal instability that exceeds what would be permissible for cast restorations. In this study, the digital milling and sintering parameters were set to match the die relief

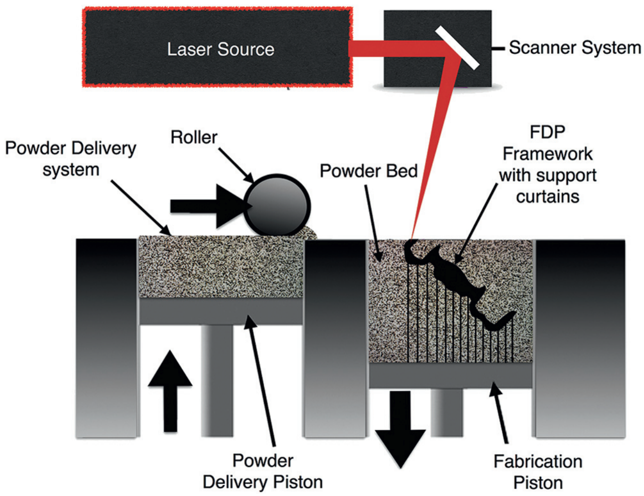

Figure 6. Mechanism of DMLS fabrication. As 1 layer is finished, fabrication piston lowered, and a new layer of granules were added over sintered granules. DMLS, direct metal laser sintered.

of a cast coping. That method reduces the bias toward restorations with excessive internal relief but would be expected to produce digital restorations with a somewhat tighter fit.

Internal fit adjustments of the tested specimens revealed clues to the etiology of the misfit and the number of adjustments needed to optimize the fit. The improvement of margin discrepancy seen with fit adjustments in both digital groups raises the question of whether a conventionally or digitally manufactured cast should be produced as a standard laboratory procedure in order to verify the fit of digital restorations and permit intaglio adjustments before clinical evaluation.

An additional finding was noted in the milled group, as 2 of the specimens did not fit properly because of surface roughness on the occlusal aspect of their intaglio surfaces. A closer inspection of these areas revealed spiral tags of alloy coinciding with the milling lines the bur had left during the milling process. This incomplete tag removal is defined as chip-and-tear formation (Fig. 7)[42] and requires adjustment to permit complete seating of the retainer. This occurrence might be related to premature aging and wear of the milling bur or to an excessive service life expectation before programmed tool replacement.

This study supports the results reported by authors who compared digital versus cast restorations. In a recent study by Johnson et al,[43] a comparative analysis was performed between milled and cast gold copings with different marginal designs. The authors concluded that for chamfer preparations, milled copings had a significantly smaller vertical marginal discrepancy than cast copings before adjustment, while cast copings had better adaptation after adjustment.

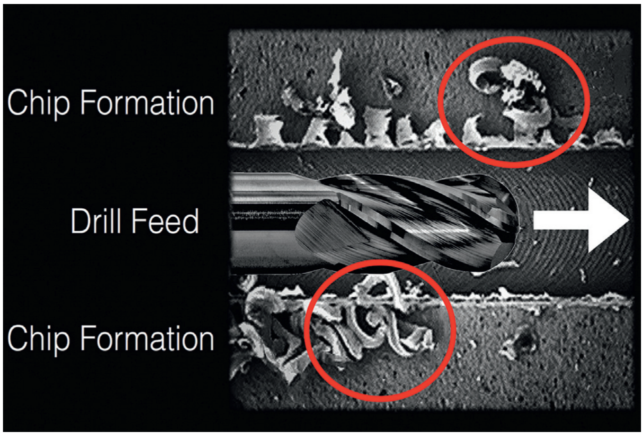

Figure 7. Mechanism of chip formation in milling process.

Although this study does not appear to support the results reported by other authors, directly comparing results with conflicting studies is difficult because of the variations in measuring techniques, alloys used, and the CAD-CAM systems used. In a study by Nesse et al,[31] data revealed that the best marginal adaptation occurred with the milled group followed by the cast group, whereas the poorest fit was in the DMLS group. In that study, pre-adjustment marginal discrepancies for the DMLS group were found to be less than those of the milled or cast group. In addition, the type and dimensions of the sintered alloy particles and the sintering system used can account for some of the differences. In another study, Örtorp et al[33] concluded that the best fit was found in the DLMS group, followed by cast groups, and finally the CAD milled group. The authors suggested that the inferiority of the milled group could be attributed to the wear of the milling burs in milling such as a hard material like Co-Cr. In this study, the noble metal alloy used was less hard than Co-Cr and may account for the different result.

This study has several limitations. The test cast impressions were made at room temperature and would be expected to create more accurate definitive casts than impressions made at mouth temperature.[44] Only the vertical discrepancy analysis for each group was evaluated. The required fit adjustments on the internal surfaces are influenced by the skill of the operator. The findings of this study are limited to pre-cementation marginal adaptation only. In addition, all frameworks were produced and tested under ideal conditions by using ideal tooth preparations, which may not reflect conditions in daily clinical practice. Finally, the alloy used for the milled group was different from that used for the cast and DMLS groups.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn:

1. Noble alloy frameworks for metal–ceramic 3-unit FDPs fabricated by using both CAD-CAM workflows had significantly smaller vertical marginal discrepancies than those of cast frameworks, with the subtractive group (milled) having the best marginal fit among the 3 test groups.
2. Manual adjustments significantly enhanced the marginal fit of all test groups (*P*<.001).
3. The milled group required the least number of adjustment cycles, followed by the DMLS group, and the cast group (*P*<.001).
4. All 3 groups demonstrated marginal discrepancies in the range of clinical acceptability according to the ADA specification No.8.
5. No significant difference in marginal discrepancy was found between premolar and molar retainers before (*P*=.982) or after adjustment (*P*=.835).

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