Clinical Evaluation of CAD/CAM Metal-Ceramic Posterior Crowns Fabricated from Intraoral Digital Impressions

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Purpose: The aim of this in vivo study was to evaluate the accuracy of metal-ceramic crowns fabricated using computer-aided design/computer-assisted manufacturing (CAD/CAM) in conjunction with intraoral digital impressions. ***Materials and Methods:*** Fifty patients in a general practice participated in the study. Patients were provided with crowns fabricated from digital impressions taken with an intraoral chairside scanner. Prior to crown insertion, the marginal integrity, esthetics, and occlusal and articulation contacts were evaluated using California Dental Association (CDA) criteria. The precementation space of the crowns was evaluated with the replica technique. ***Results:*** No adjustments were needed for any of the interproximal contact points. Adjustments of occlusion and articulation contacts were needed in 20% of the restorations. Clinical evaluation of the marginal integrity showed satisfactory results according to the CDA criteria. The 50 silicone replicas showed a median precementation space of 46 μm at the marginal measurement location, 94 μm at the midaxial location, and 185 μm at the centro-occlusal location. ***Conclusions:*** The precementation spaces of the crowns were within the acceptable range for CAD/CAM restorations. *Int J Prosthodont 2014;27:331–337. doi: 10.11607/ijp.3607*

Since the introduction of the first digital scanner for dental impressions by Francois Duret in the 1980s, a number of manufacturers have created in-office dental scanners that are user-friendly and produce well-fitting dental restorations.[1]

Different methods are available to fabricate computer-aided design/computer-assisted manufacture (CAD/CAM)-based crowns and fixed partial dentures (FPDs). Most common is the optical scanning of stone casts to provide digital images for the design and manufacturing stages. However, this technique has some of the disadvantages associated with conventional impressions, such as patient discomfort, distortion of impression materials, and dimensional instability. The use of a direct intraoral digital impression can overcome most of these disadvantages.

Various CAD/CAM systems are available on the market. Two of these systems, CEREC AC Omnicam (Sirona Dental Systems) and E4D Dentist (D4D Technologies), offer in-office design and milling. Two other systems, iTero (Cadent) and Lava Chairside Oral Scanner C.O.S. (3M ESPE), produce digital impressions that require design and milling at a dental laboratory or commercial milling center. All of these systems can be used to produce casts for further production of dental restorations.[2]

Poor marginal fit of a dental restoration increases the risk of biologic complications such as caries and gingival irritation.[3] Felton et al[4] found no significant correlation between marginal discrepancy and pocket depth; however, there was a correlation between marginal discrepancy and periodontal parameters (eg, Gingival Index and crevicular fluid volume). Furthermore, misfit may also affect the retention of the crown and reduce longevity.[5]

Several factors may decrease the accuracy of fit between the crown and abutment tooth. The use of CAD/CAM technologies may minimize these factors compared to traditional impression and crown fabrication procedures. A marginal gap of 26 to 138 μm has been reported in the literature for metal-ceramic

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crowns fabricated using conventional impression techniques and traditional framework fabrication (lost-wax technique).[6–8] Favorable bond strength was achieved in conjunction with a cement thickness of 50 to 100 μm. A marginal gap of 150 μm or more resulted in a significantly higher washout of the cement compared to a gap of 25 to 75 μm.[9]

Several in vitro and in vivo studies have examined the marginal and internal fit of CAD/CAM restorations.[10–17] The generally accepted marginal discrepancies for CAD/CAM restorations are between 50 and 100 μm.[11,14] Clinical studies have shown that the accuracy and function of CAD/CAM frameworks are acceptable,[13,16] and the long-term survival rates of CAD/CAM single-tooth restorations have been shown to be comparable to those of conventional restorations.[17–19]

The majority of studies evaluating dental restorations fabricated from the CEREC system have focused on composite resin or ceramic restorations. Bindl and Mörmann[10] reported a significantly improved marginal fit for crowns fabricated with the CEREC 2 system (207 ± 60 μm) compared to crowns fabricated with CEREC 1 (308 ± 95 μm). A marginal gap of 53 to 105 μm for crowns produced with CEREC 3 has been reported.[12,15]

With the evolution of intraoral scanners, more clinical investigations are needed to determine the clinical accuracy of new intraoral digital impression systems in combination with CAD/CAM restorations. Therefore, the aim of this in vivo study was to evaluate the accuracy of metal-ceramic crowns fabricated using CAD/CAM techniques and intraoral digital impressions.

Materials and Methods

Fifty patients (32 women, 18 men; mean age: 56.7 years) in a general dental practice agreed to participate in this study. All patients needed rehabilitation with single crowns in the posterior region. Informed consent was provided by each participant. The study protocol was approved by the regional committees of medical and health research ethics (REK-2011/445). The treatment was performed by a specialist in prosthodontics according to a standardized protocol. Inclusion criteria were loss of tooth structure, indicating crown therapy in a posterior tooth (premolar or molar); no need for additional extended treatment (eg, endodontic or periodontal treatment); and acceptable oral hygiene.

The abutment teeth were prepared for metal-ceramic crowns. To serve as a finish line, a distinct chamfer was prepared using Komet burs (no. 8850 314 018, Lemgo). The circumferential reduction of tooth substance was between 1.2 and 1.5 mm, depending on the remaining hard tissue. Occlusal reduction was approximately 1.5 mm using Komet burs (no. 8379 314 023). The retentive surface of the prepared teeth had to be at least 4 mm in height with a convergence angle of approximately 6 to 18 degrees.[18,19]

The preparation finish lines were placed at gingival level and did not exceed a subgingival depth of 0.5 mm. Before the impression was taken, retraction cords of two different sizes (GingiBraid+, Dux Dental) soaked in aluminum chloride (Styptin, Dux Dental) were placed with a double cord technique.[20] Scanning of the preparation commenced immediately after removal of the upper retraction cord and rinsing and air drying of the prepared tooth. The intraoral scanning procedure was performed according to the iTeroTM manual.

A provisional restoration was placed on the prepared tooth using Protemp 4 Garant (3M ESPE) and cemented with TempBond NE (Kerr).

The completed digital impression data were coded and sent via the internet to the Cadent facility and dental laboratory. In cooperation with the dental laboratory, a polyurethane master cast was fabricated and articulated using the iTero articulator at Straumann's facility in Leipzig, Germany.

The frameworks of the crowns (Coron) were milled (CHIRON FZ08 S, CHIRON Werke) based on the data acquired through the digital impression. Coron is a cobalt-based nonprecious type 4 dental alloy (ISO 22674) used for high-melting ceramics. The dental laboratory ordered the frameworks using the standard parameters for Coron milled frameworks, ie, a cement gap of 30 μm and a spacer of 60 μm beginning 0.5 mm above the preparation line. The frameworks were veneered with feldspathic porcelain in a dental laboratory in Oslo, Norway.

Clinical Try-in

All clinical procedures were performed by the same specialist in prosthodontics. The provisional crowns were removed, and the prepared teeth were thoroughly cleaned with pumice on a rotating brush.

At the try-in appointment, prior to the cementation, the crowns were seated, and marginal integrity, occlusion and articulation contacts, and interproximal contact points were evaluated. The marginal integrity was evaluated using an explorer with a fine tip (EPD5658XTS, Hu-Friedy) and classified according to the California Dental Association (CDA) quality evaluation system. When applied by standardized examiners, CDA criteria have been found to be precise and accurate in the evaluation of dental restorations and dental care.[21,22] The anatomical form, surface, and color of the crowns were evaluated and classified using CDA criteria.

Occlusal contacts between the restoration and opposing teeth were recorded in maximum intercuspation and in 3-mm excursion as either present or absent using 8-µm occlusion foil (TrollFoil, Trollhätteplast). The occlusion contact was classified as very hard, obvious, slight, or no occlusal contact point. The interproximal contact points were checked with dental floss (Reach Dentotape Waxed Floss, Johnson & Johnson). The time needed for adjustment of the occlusal and interproximal contact points was registered separately and classified into three different categories: adjustment not needed, adjustment time less than 5 minutes, or adjustment time more than 5 minutes.

All crowns were cemented with a resin-reinforced glass-ionomer luting cement (GC Fuji PLUS, GC Europe).

Fig 1 Occlusal view of an unsectioned silicone replica.

Internal Fit (Replica Technique)

The replica technique described by Boening et al[23] and Molin and Karlsson,[24] and validated by Laurent et al,[25] was used to evaluate the internal fit. Prior to any adaptation of the crowns and after evaluating the interproximal contact points and marginal integrity, the crowns were filled with a low viscous A-silicone material (AFFINIS light body, Colténe) and placed on the abutment teeth with maximum finger pressure to simulate cementation.[26] After setting, the impression material adhered to the internal aspect of the crowns was removed together with the crowns. The thin layer of impression material, representing the discrepancy between the crown and abutment tooth, was stabilized with a more viscous silicone material in a different color (Imprint 3 VPS Quick Step Heavy Body, 3M ESPE) to mimic the abutment tooth. After setting, both silicone materials were removed in one piece from the crown (Fig 1).

Measuring Technique

All replicas were cut with a razor blade along the abutment axis, once in the mesiodistal direction and once in the buccolingual direction, into four fragments per crown. At each cross section, the following four measurements were taken, resulting in 18 data points per replica (Figs 2 to 4):

- *The marginal precementation space:* the shortest distance from the internal surface of the crown to the prepared tooth surface close to the finish line of the preparation.[27]
- *The midaxial precementation space:* the distance between the die and inner surface of the crown in the middle of the axial wall.[28]
- *The centro-occlusal precementation space:* only measured after the first cut (mesiodistal), resulting in two measurements per replica, one measurement for each piece.[28]

All analyses of the replicas were performed by one author, who was not involved in either the clinical treatment or try-in. Prior to the measurements, the cross sections were mounted on needles in a plaster block and adjusted horizontally to the microscope's plate to achieve a vertical observation angle.

Replica film thickness was measured under a microscope (Leica) at ×25 magnification with an external light source (Olympus Europe Highlight 2001, Olympus Optical). The microscope was connected to a digital camera (Olympus DP50), and the software program CELLB 2.6 (Build 1175, Olympus Soft Imaging Solutions) was used for measurement. The measuring instruments were calibrated at regular intervals.

Statistical Analysis

Replica data were tabulated and analyzed using SPSS 16.0 software (SPSS). Correlations were calculated using the Student *t* test for paired samples. A *P* value < .05 was considered statistically significant.

To evaluate the intrapersonal reliability within space measurements, the intraclass correlation coefficient (ICC) was determined. The ICC describes the precision of the measurements by comparing each measured space in one of the replicas with its mirror in the other part of the same replica. The closer the ICC is to 1, the more similar the measurements. An ICC of 0.75 or above is usually considered to be good. An ICC above 0.9 is considered to be excellent.

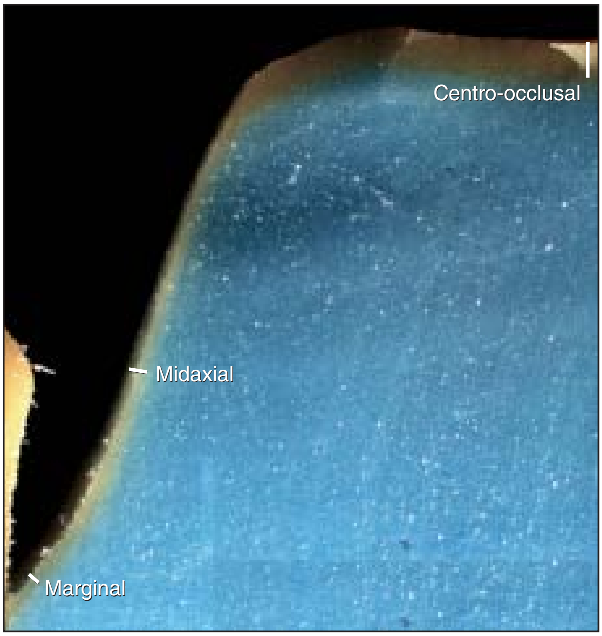

Fig 2 Cross section of a silicone replica with locations of the measured precementation spaces.

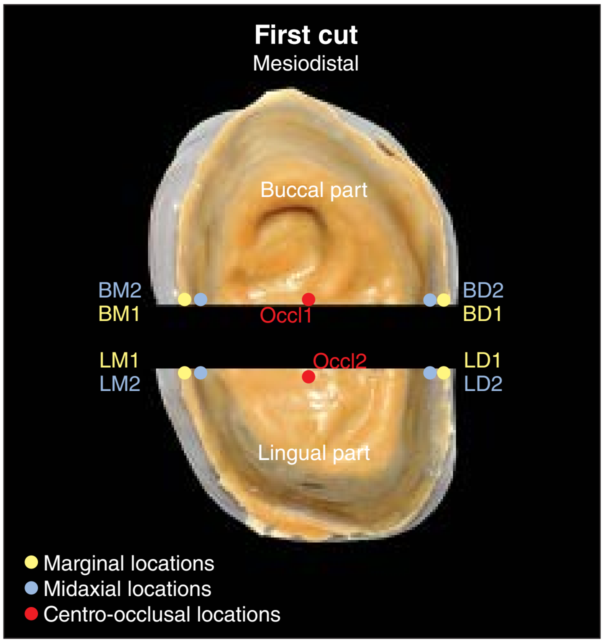

Fig 3 Measuring locations after the first cut of the replica. L = lingual; B = buccal; M = mesial; D = distal.

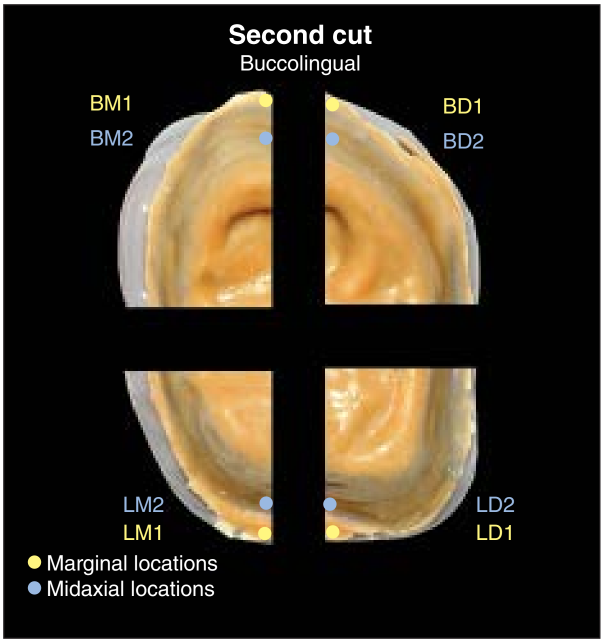

Fig 4 Measuring locations after the second cut of the replica. L = lingual; B = buccal; M = mesial; D = distal.

Results

For the 50 patients in this study, 47 quadrant scans and 3 extended scans were produced.

Clinical Try-in

At the clinical try-in, all examined crowns were evaluated in terms of marginal integrity, surface quality, color, and anatomical form according to CDA classification. All crowns were rated as satisfactory overall (R or S ratings).

None of the restorations had to be adjusted at the interproximal contact points.

Forty crowns (80%) showed perfect fit in occlusion and articulation contacts, and only 10 crowns (20%) had to be adjusted. The time needed for adjustment was less than 5 minutes for each crown.

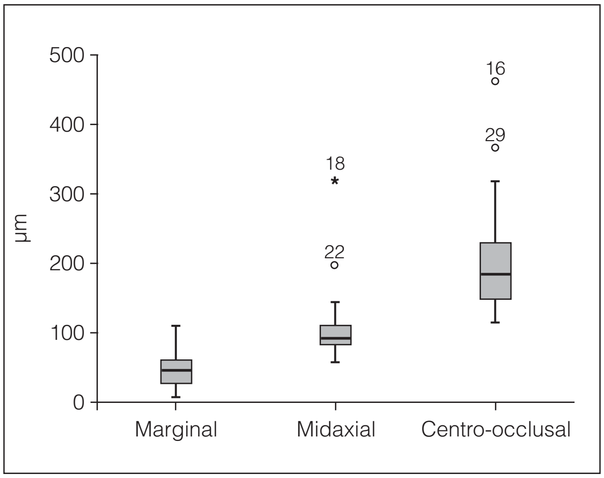

Fig 5 Measurements of the precementation spaces and comparison between the different localizations (boxplot with whiskers). The numbers within the boxplot indicate the case numbers.

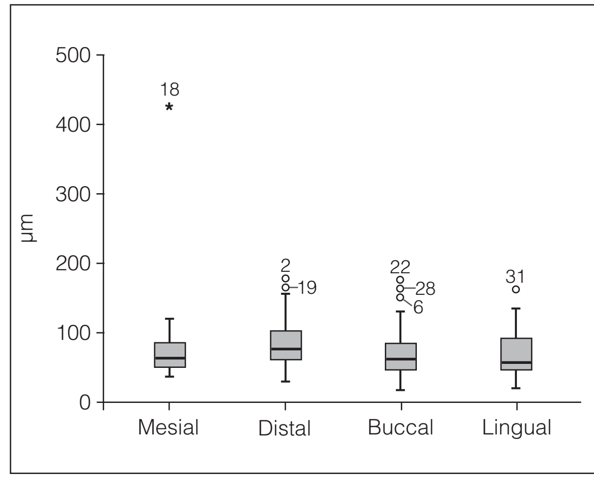

Fig 6 Comparison between the different tooth surfaces at the marginal measuring location. The numbers within the boxplot indicate the case numbers.

Internal Fit

A total of 900 measurement points (50 patients × 18 points) were checked. The lowest mean and median values were found at the marginal location, with a mean of 46 µm (SD: 24) and a median of 46 µm. The mean width at the midaxial location was 102 µm (SD: 40), with a median value of 94 µm. For the centro-occlusal location, a mean value of 198 µm (SD: 68) and median value of 185 µm were found (Fig 5).

The largest value for the marginal location was observed for the distal surface, with a median value of 77 µm. The lowest value was observed for the lingual surface, with a median value of 57 µm. The largest average marginal space was found at the distal surface, and the lowest average space was found at the buccal surface (Fig 6).

There was a significant difference between mesial and distal surfaces (P = .044), distal and buccal surfaces (P = .011), and distal and lingual surfaces (P = .038).

No systematic discrepancies of the marginal precementation space correlated to individual abutment tooth types (eg, premolars) were observed.

The intrapersonal reliability test revealed no significant differences. The intraclass correlation coefficients (ICC) was ≥ 0.8 in all cases, indicating that the accuracy of the measurements was *good* to *excellent* (Table 1).

Table 1 Intraclass Correlation Coefficients

	Marginal location		Midaxial location	
First cut (mesiodistal)	BM1–LM1 BD1–LD1	0.80 0.84	BM2–LM2 BD2–LD2	0.94 0.81
Second cut (buccolingual)	BM1–BD1 LM1–LD1	0.91 0.80	BM2–BD2 LM2–LD2	0.86 0.91

L = lingual; B = buccal; M = mesial; D = distal.

Discussion

The marginal precementation spaces for the metal-ceramic crowns, with mean and median values of 46 µm, were found to be equivalent or smaller than those reported in other studies evaluating digital impression systems. Syrek et al[19] examined all-ceramic crowns (alumina) fabricated from intraoral digital impressions as well as crowns fabricated from conventional silicone impressions. They found a significantly better marginal fit for the crowns produced from intraoral scans (median: 49 µm) compared to those produced with conventional impressions (median: 71 µm). A recent clinical study of zirconia crowns reported a median marginal gap of 38 µm.[29] Tsitrou et al[12] found a mean marginal gap of 91 to 105 µm for ceramic crowns produced with the CEREC 3 system. All of these studies used a replica technique similar to that applied in this study. The silicone replica technique allows three-dimensional evaluation of the space between the crown and abutment tooth. The marginal gap cannot be evaluated as precisely with an explorer as with the silicone replica technique, particularly at the interproximal and subgingival areas.[19]

The shortcomings of the replica technique may include defects in the silicone impression at the measuring points and the precision of the measuring procedure. However, all impression replicas in this study were checked under dental loupes, and new replicas were made before cementation if any possible errors were detected. All measurements for the intrapersonal reliability test were collected separately and not analyzed until all measurements were assembled.

The Coron crowns ordered by the dental laboratory had the standard specifications, with a cement gap of 30 µm and a spacer thickness of 60 µm, beginning 0.5 mm above the margin of the preparation line. In the present study, the median marginal space was 46 µm, resulting in a difference of 16 µm from the cement gap ordered by the dental laboratory. The midaxial discrepancy showed the closest value to the standard parameter, with a median of 94 µm. The range of the measured spaces was widest at the occlusal location A significantly larger marginal space was observed at the distal location.

The observed differences likely result from a combination of factors. First, there may be inaccuracies in the digital models created from the digital impressions.[30–32] Another factor may be the shape of the bur related to the bur accessibility in the copings during milling. The manual veneering of the Coron frameworks by a dental technician may also have influenced the results. In vitro studies comparing the marginal adaptation of crowns with different veneering techniques demonstrated a significantly smaller mean marginal gap for pressed porcelain restorations with a metal substructure compared to traditional metal-ceramic restorations fabricated from feldspathic porcelain.[33,34]

Ender and Mehl[31] reported distortions in the distal part of conventional full-arch impressions made using polyvinyl siloxane. It is unlikely that the difference between the mesial and distal marginal gap is caused by an incorrect digital scan. The software for the digital scanner used in the present study will not produce a complete digital model of the abutment teeth if the image of the distal surface shows defects. The operator will, if necessary, be given the opportunity to adjust the incorrect scan of the preparation line. The minimal time needed for adaptation of the crowns (< 5 minutes for each of the 10 crowns requiring adjustment), indicates the accuracy of the digital models.

Precise abutment tooth preparation is very important for CAD/CAM restorations. The restorations can be optimally milled only when the tooth preparation provides a smooth, flowing surface with no sharp angles. The goal is to achieve a shoulder and/or chamfer margin with rounded internal angles, thus facilitating accuracy of the digital imaging and milling procedures.[35] Previous studies have investigated the convergence angle and digitally defined cement space for CAD/CAM frameworks fabricated from either an intraoral scanning system or scanned casts.[15,36] The findings were in contrast to each other. For the frameworks fabricated from an intraoral scanning system, good fit was achieved when the luting space was set to a defined value regardless of the occlusal convergence angle of the abutment.[15] For the frameworks fabricated from scanned casts, the internal spaces decreased as the convergence angles of the abutments increased.[36]

In the present study, the convergence angles of the prepared abutment teeth varied between 6 and 18 degrees according to the remaining tooth substance. More in vitro studies are needed to investigate the effect of the convergence angle on the internal fit of crowns fabricated using digital impression systems.

CAD/CAM framework fabrication will eliminate some sources of error compared to the traditional lost-wax fabrication procedure by increasing both the accuracy and quality of the restoration. In an in vitro study, Ortorp et al[37] compared different methods for the fabrication of three-unit cobalt-chromium (Co-Cr) FPDs: the conventional lost-wax technique, milled wax in combination with the lost-wax technique, milled Co-Cr, and direct laser metal sintering. The metal sintering technique was found to be favorable.

Only milled Co-Cr crowns generated from the digital impression system were examined in this study. However, several other studies have examined the marginal and internal fit of crowns fabricated using conventional impression techniques[7,19] and crowns fabricated with digital impression techniques.[1,12,19,29]

Different digital acquisition technologies may lead to different levels of precision during scanning; studies of this issue are needed and should preferably be performed in combination with different digital framework fabrication methods. The cost and time benefits of using intraoral digital impression scanners are not discussed in the present study; further studies related to this issue are also needed.

Conclusions

Within the limitations of this study, the marginal spaces of the crowns evaluated were found to be within the acceptable range for CAD/CAM restorations.

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References

1. Birnbaum N, Aaronson H. Dental impressions using 3D digital scanners: Virtual becomes reality. Compend Contin Educ Dent 2008;29:494, 496, 498–505.

2. Sakaguchi RL, Powers JM. Digital imaging and processing for restorations. In Sakaguchi RL, Powers JM, eds. Craig's Restorative Dental Materials. St Louis, MO: Mosby, 2011:349–353.
3. Gardner FM. Margins of complete crowns—Literature review. J Prosthet Dent 1982;48:396–400.
4. Felton DA, Kanoy BE, Bayne SC, Wirthman GP. Effect of in vivo crown margin discrepancies on periodontal health. J Prosthet Dent 1991;65:357–364.
5. Tuntiprawon M, Wilson PR. The effect of cement thickness on the fracture strength of all-ceramic crowns. Aust Dent J 1995; 40:17–21.
6. McLean JW, von Fraunhofer JA. The estimation of cement film thickness by an in vivo technique. Br Dent J 1971;131:107–111.
7. Wöstmann B, Dohle A, Rettberg S. Zur Frage der in vivo erreichbaren Abformgenauigkeit. Dtsch Zahnarztl Z 1994;49:679–685.
8. Fransson B, Oilo G, Gjeitanger R. The fit of metal-ceramic crowns, a clinical study. Dent Mater 1985;1:197–199.
9. Jacobs MS, Windeler AS. An investigation of dental luting cement solubility as a function of the marginal gap. J Prosthet Dent 1991;65:436–442.
10. Bindl A, Mörmann WH. Clinical and SEM evaluation of all-ceramic chair-side CAD/CAM-generated partial crowns. Eur J Oral Sci 2003;111:163–169.
11. Andersson M, Carlsson L, Persson M, Bergman B. Accuracy of machine milling and spark erosion with a CAD/CAM system. J Prosthet Dent 1996;76:187–193.
12. Tsitrou EA, Northeast SE, van Noort R. Evaluation of the marginal fit of three margin designs of resin composite crowns using CAD/CAM. J Dent 2007;35:68–73.
13. Reich S, Wichmann M, Nkenke E, Proeschel P. Clinical fit of all-ceramic three-unit fixed partial dentures, generated with three different CAD/CAM systems. Eur J Oral Sci 2005;113:174–179.
14. Witkowski S, Komine F, Gerds T. Marginal accuracy of titanium copings fabricated by casting and CAD/CAM techniques. J Prosthet Dent 2006;96:47–52.
15. Nakamura T, Dei N, Kojima T, Wakabayashi K. Marginal and internal fit of Cerec 3 CAD/CAM all-ceramic crowns. Int J Prosthodont 2003;16:244–248.
16. Beuer F, Naumann M, Gernet W, Sorensen J. Precision of fit: Zirconia three-unit fixed dental prostheses. Clin Oral Investig 2009;13:343–349.
17. Wittneben JG, Wright RF, Weber HP, Gallucci GO. A systematic review of the clinical performance of CAD/CAM single-tooth restorations. Int J Prosthodont 2009;22:466–471.
18. Karlsson S, Nilner K, Dahl BL. A Textbook of Fixed Prosthodontics: The Scandinavian Approach. Stockholm: Gothia, 2000.
19. Syrek A, Reich G, Ranftl D, Klein C, Cerny B, Brodesser J. Clinical evaluation of all-ceramic crowns fabricated from intraoral digital impressions based on the principle of active wavefront sampling. J Dent 2010;38:553–559.
20. Perakis N, Belser UC, Magne P. Final impressions: A review of material properties and description of a current technique. Int J Periodontics Restorative Dent 2004;24:109–117.
21. Ryge G, Snyder M. Evaluating the clinical quality of restorations. J Am Dent Assoc 1973;87:369–377.
22. California Dental Association. Quality Evaluation for Dental Care: Guidelines for the Assessment of Clinical Quality and Professional Performance. Los Angeles, CA: California Dental Association; 1977.
23. Boening K, Wolf B, Schmidt A, Kästner K, Walter M. Clinical fit of Procera AllCeram crowns. J Prosthet Dent 2000;84:419–424.
24. Molin M, Karlsson S. The fit of gold inlays and three ceramic inlay systems. A clinical and in vitro study. Acta Odontol Scand 1993;51:201–206.
25. Laurent M, Scheer P, Dejou J, Laborde G. Clinical evaluation of the marginal fit of cast crowns—Validation of the silicone replica method. J Oral Rehabil 2008;35:116–122.
26. Kokubo Y, Ohkubo C, Tsumita M, Miyashita A, Vult von Steyern P, Fukushima S. Clinical marginal and internal gaps of Procera AllCeram crowns. J Oral Rehabil 2005;32:526–530.
27. Holmes JR, Bayne SC, Holland GA, Sulik WD. Considerations in measurement of marginal fit. J Prosthet Dent 1989;62:405–408.
28. Reich S, Kappe K, Teschner H, Schmitt J. Clinical fit of four-unit zirconia posterior fixed dental prostheses. Eur J Oral Sci 2008;116:579–584.
29. Scotti R, Cardelli P, Baldissara P, Monaco C. Clinical fitting of CAD/CAM zirconia single crowns generated from digital intraoral impressions based on active wavefront sampling [epub ahead of print 17 Oct 2011]. J Dent.
30. Kim SY, Kim MJ, Han JS, Yeo IS, Lim YJ, Kwon HB. Accuracy of dies captured by an intraoral digital impression system using parallel confocal imaging. Int J Prosthodont 2013;26:161–163.
31. Ender A, Mehl A. Accuracy of complete-arch dental impressions: A new method of measuring trueness and precision. J Prosthet Dent 2013;109:121–128.
32. Guth JF, Keul C, Stimmelmayr M, Beuer F, Edelhoff D. Accuracy of digital models obtained by direct and indirect data capturing. Clin Oral Investig 2013;17:1201–1208.
33. Goldin EB, Boyd NW 3rd, Goldstein GR, Hittelman EL, Thompson VP. Marginal fit of leucite-glass pressable ceramic restorations and ceramic-pressed-to-metal restorations. J Prosthet Dent 2005;93:143–147.
34. Holden JE, Goldstein GR, Hittelman EL, Clark EA. Comparison of the marginal fit of pressable ceramic to metal ceramic restorations. J Prosthodont 2009;18:645–648.
35. Hicklin S. CAD/CAM-based restorations and prosthetic reconstructions: An assessment of what is currently available on the market from a technical point of view. ITI Forum Implantaologicum 2011;7:14–17.
36. Iwai T, Komine F, Kobayashi K, Saito A, Matsumura H. Influence of convergence angle and cement space on adaptation of zirconium dioxide ceramic copings. Acta Odontol Scand 2008;66: 214–218.
37. Ortorp A, Kihl ML, Carlsson GE. A 5-year retrospective study of survival of zirconia single crowns fitted in a private clinical setting. J Dent 2012;40:527–530.