Marginal fit and short-term clinical performance of porcelain-veneered CICERO, CEREC, and Procera onlays

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Statement of problem. Onlay preparations are very complex surfaces for computer surface digitization, CAD, and CAM of all-ceramic onlay cores.

Purpose. This study tested the hypothesis that onlays can be fabricated with CICERO, CEREC, and Procera core technologies.

Material and methods. Fifteen mandibular and 10 maxillary molars were prepared for onlays in 17 patients (11 women and 6 men). The onlay design was experimental. Molars were prepared with deep gingival chamfers in the proximal boxes and around the functional cusps. The nonfunctional cusps were prepared with broad bevels. Eight stone dies of preparations were measured with a laser beam (CICERO), 10 dies with a light beam (CEREC), and 7 dies with a contact probe (Procera). Two onlay cores were produced for the same stone die. One core was used to analyze fit on the stone die, and the other core was porcelain veneered for optimizing anatomy, esthetics, and fit of the onlay and cemented. The fit of the onlay core on the stone die and the cement width on a stone cast were measured by a microscopic digital imaging system. The onlays were evaluated for function every 6 months for 2 years.

Results. Measurements of the margins by the CICERO system were (1) precise (error <4%) and (2) accurate with an SD of less than 9 µm. The proposed onlay preparation design met the requirement that all points of the surface be visible from a single point of view for optical 3-dimensional mapping by the CEREC system. For the surface measurements by the Procera contact probe, the orientation of the sapphire tip toward the preparation surface was critical, and it was necessary to apply wax to smooth internal edges. The marginal gaps of the CICERO, CEREC, and Procera cores on the stone dies were 74 µm (SD 15), 85 µm (SD 40), and 68 µm (SD 53), respectively. The cement width was 81 µm (SD 64). No fractures occurred.

Conclusion. Marginal gaps for the onlay cores were no more than 85 µm. The cement width of the semicomputer-produced onlays of 81 µm was a favorable measurement value for a clinically acceptable, strong all-ceramic onlay. However, this value as well as anatomy and esthetics of the onlay depended on the craftsmanship of the porcelain veneering by the dental technician. (J Prosthet Dent 2000;84:506-13.)

CLINICAL IMPLICATIONS
The findings of this study showed a cement gap width of 81 µm for semicomputer-produced all-ceramic onlay restorations.

Cast gold onlays have been very successful restorations. An onlay restores the entire occlusal surface but covers only part of the vestibular and lingual or palatal surfaces. The favorable periodontal, functional, and material aspects of cast gold onlays are adversely affected by the color of gold and the laborious production technique. The cosmetic aspect of dental restorations has always played an important role in dental treatment planning. Today, esthetics has become such a dominating factor that even more preference is given to tooth-colored all-ceramic restorations.

Computer technologies have enriched dentistry with new ways of producing ceramic cores for full crowns. The goal of porcelain veneering these cores is to improve anatomy and esthetics. Computer technology entails computer surface digitization (CSD) of the preparation on the stone die, CAD of the core, and CAM of the core.
It may be advantageous for onlays to combine a computer-produced ceramic core veneered with porcelain. The Computer Integrated CEramic RecOnstruction (CICERO) system (CICERO Dental Systems BV, Hoorn, The Netherlands), the CEramic REConstruction (CEREC) system (Sirona Dental Systems, Bensheim, Germany), and the Procera system (Nobel Biocare, Göteborg, Sweden) have been developed for core production.

The aim of this study was to determine whether the CICERO, CEREC, and Procera systems are capable of producing all-ceramic cores veneered with porcelain for an experimental onlay design. The criteria for acceptance were (1) fit for prevention of periodontal disease and caries, (2) esthetics for a pleasing result, and (3) no fractures in function.

MATERIAL AND METHODS

An experimental group of 17 patients (11 women and 6 men) with large defective amalgam or composite fillings in mandibular or maxillary molars was selected for onlay therapy (Fig. 1). One female patient received 4 onlays, and 5 female patients received 2 onlays. The patients were between 25 and 55 years of age. Endodontic treatment was not an exclusion criterion. There was group function during articulation present in all patients. Molars were only excluded when vestibular lingual or palatal restorations or caries were present in the gingival third of the selected teeth. In such cases, a full crown was indicated. Assignment of the teeth to the 3 CAD/CAM systems was randomized; the distribution is presented in Table I.

The experimental preparation protocol was as follows: The occlusal surface was reduced 1.5 to 2 mm, and the proximal boxes and the seat were prepared with a bullet-shaped diamond bur (Horico 198 F 025; Horico, Berlin, Germany). Deep (≥1 mm) gingival chamfers were prepared with a smaller bullet-shaped bur (Horico 289 F 018) in the proximal boxes and around the functional cusps (buccal of mandibular and palatal of maxillary molars). Broad (≥1 mm) bevels were prepared on the nonfunctional cusps (lingual of mandibular and buccal of maxillary molars) with a diamond disk (Horico 068 F 041). The axial walls were prepared at the same time, and the transitions from the gingival to proximal and occlusal were rounded and smoothed with the same bullet-shaped bur and diamond disk. The gingival finish lines ended if possible in enamel (Figs. 2 and 3).

Impressions were made with hydrocolloid material (Van R Dental Products, Maarssen, The Netherlands). For CICERO cores, the impressions were poured in a white stone (New Fuji-rock, Hasumuma Cho, Japan). For CEREC cores, a special brown reflective type of stone (CAM-base, Dentona, Wipperfürth-Hämmern,
Germany) was used; consequently, reflective powder on the stone model was not necessary for scanning. For Procera cores, both stone materials were used.

The CICERO method for the manufacture of onlay cores used laser scanning, ceramic sintering, and computer-integrated milling techniques. The unprepared region of the die below the finish line was painted black; consequently, only the (white) preparation surface was measured by the laser beam. The measurements were calculated by triangulation into a 3-dimensional representation. The 1-mm thick core was produced of Synthoceram, a high-strength Al$_2$O$_3$-based ceramic (CICERO Dental BV). Porcelain veneering was performed with Syntagon porcelain (CICERO Dental BV).

For the manufacture of the CEREC cores, a CEREC 2 unit was used with Crown 2.1.x software (Sirona Dental Systems, Bensheim, Germany). The system uses a light beam for the measurement of the preparation surface. VITA Blocks Mark II were used for the milling process (VITA Zahnfabrik H. Rauter GmbH & Co KG, Bad Säckingen, Germany). These blocks were composed of SiO$_2$ (60%-64%), Al$_2$O$_3$ (20%-23%), Na$_2$O (7%-9%), K$_2$O (6%-8%), CaO (0.3%-0.6%), and TiO$_2$ (0.0%-0.01%). The blocks were ground to cores with an anatomic-shaped occlusal surface with a minimal thickness of 1.5 mm. Porcelain veneering was performed with Vitadur Alpha porcelain (VITA Zahnfabrik H. Rauter GmbH & Co KG).

The procedure for the Procera core was as follows. The internal edges in the preparation at the sides of the boxes and seat were smoothed by the addition of wax. Isolating fluid was brushed on for separation, and a wax coping was made. The Procera scanner (Model Mod 40) measured the onlay preparation surface on the stone die with a contact probe device. Thereafter, the wax coping was placed on the stone die, and its surface was measured in the same way. The optimal orientation of the stone die in the clamping device of the Procera scanner was such that the sapphire tip contacted the preparation surface during all scanning movements. When the angle to the surface of the die was reduced to 30 degrees, the accuracy was reduced. The best angle between probe and preparation surface was between 30 and 150 degrees. A 1-mm thick core was produced by Sandvik Hard Materials AB (Stockholm, Sweden). The internal surface of the core was porcelain veneered at the sides of the smoothed edges in the boxes and the seat to optimize fit (DUCERA porcelain, Nobel Biocare, Stockholm, Sweden). Thereafter, the external surface of the core was porcelain veneered (Fig. 4).

Two onlay cores were produced for the same stone die. One core was used to analyze fit on the stone die. The other core was porcelain veneered to optimize anatomy, esthetics, and fit and tried in the mouth of the patient and rated according to surface, color, and anatomic form as suggested by the California Dental Association’s (CDA) quality evaluation system. These ratings were performed independently by 2 examiners. When there was a disagreement on the rating of a given onlay, collaborative examination resolved the disagreement. The rating by both examiners for the onlays had to be excellent before cementation. Otherwise, porcelain veneering was adjusted or redone, and the onlays were reevaluated in the mouth of the patient until they were excellent.

Porcelain veneering of the onlay cores was adjusted 6 times and completely redone by the dental technician 2 times to achieve excellent ratings by the examiners. A rubber dam was applied, and Panavia cement (Kuraray Co Ltd, Osaka, Japan) was used for cementation. The insertion technique was as follows: The onlays were cleaned in the ultrasonic cleaner for 5 min-
utes and dried. Thereafter, the internal surface of the onlay was etched with phosphoric acid (37%), rinsed, and dried. The pretreatment of the molar was as follows: Cleaning was performed with pumice and a primer (Panavia ED Primer, Kuraray Co Ltd, Osaka, Japan) was applied with a brush on the preparation surfaces and left in place for 60 seconds. Evaporation of the volatile components of the primer was performed with a gentle airflow until the surface was completely dry and glossy. Panavia base paste and catalyst were mixed with a spatula for 20 seconds, and the onlay was seated within 40 seconds. Excess cement was removed with a tapered suction tip, brush, dental floss, and explorer. The cement was then cured along the margins in several sections by visible light for 20 seconds. The rubber dam was removed, and the occlusion and articulation were checked.

After cementation, there was no clinical difference among the onlays manufactured by the 3 systems (Fig. 5). Porcelain veneering and staining masked the core ceramic and optimized the anatomy, esthetics, and fit of the onlays. Differences in anatomy and esthetics depended on the creativity of the porcelain technician (Fig. 6).

A hydrocolloid impression was taken 3 weeks after cementation and poured in stone for analysis of the marginal cement width at baseline. Clinical evaluation took place every 6 months for 2 years.

The analysis system for measuring the light microscopic marginal gap on the stone dies and the cement width dimensions was composed of a light microscope (Olympus BX 60, Olympus Optical Co Ltd, Tokyo, Japan), a CCD color video camera (Model DXC-930P, Sony Inc, Tokyo, Japan), a digital image processing computer (Hewlett Packard, Vectra VL, series 4, 5/100, Palo Alto, Calif.), computer screen (Trinitron, Multiscan 17 sf II, Sony Inc), and Kontron software (Kontron Elektronik Imaging System KS 100 version 2.00, Kontron Elektronik GmbH, Eching bei München, Germany).
Reproducibility (precision) of an instrument is reflected in the ability to reproduce the same measurement results in repeated measurements. The reproducibility of the marginal gap measurements of the onlay core on the stone die by the digital microscopic image processing computer was tested as follows: A light microscopic image of the boundary surfaces of the core and the tooth preparation on the stone die was obtained with the video camera, digitized, and processed. Ten measuring points were painted on a 0.5-mm section of the finish line of the preparation on the stone die. The opposite corresponding measuring points on the margin of the core were painted as well. The distance (marginal gap) between 2 corresponding points was defined and calculated by the computer. The procedure was repeated 4 times. Five marginal gaps were measured (Fig. 7).

For the precision error of the marginal gap measurements by microscopic digital imaging, the mean and corresponding SD were calculated using the 5 measurements of each marginal gap. The coefficient of variation in percent (CV[%]) was calculated for each of the 5 measured marginal gaps. The reproducibility error of the measurements was expressed as the mean CV(%) and calculated.

The mean marginal gaps and the SDs were calculated for the CICERO, CEREC, and Procera onlay cores on stone dies. Differences among the 3 systems were tested for statistical significance with an analysis of variance. The 95% confidence level was selected for the comparison.

In surface digitization, reproducibility entails the ability to reproduce the same margins. Instrument precision was also expressed as the CV(%). Instrument accuracy is reflected in the ability to measure the correct dimensions of the margins. Accuracy of the measurement of the margins was estimated by correlating their measurements to the measurement of the margin of a spherical calibration phantom with known dimensions. Accuracy was expressed as the SD.

In case of fractures of the onlays, the Kaplan-Meier statistics would have been used for analysis of the fracture rates.

RESULTS

The precision analysis of the microscopic digital measurement system showed that the average measurement error for a marginal gap between 15 and 50 µm was 3% or 0.45 and 1.5 µm (Table II).

The results of the marginal gap measurements for the cores on the stone dies and the cement width on the stone casts are presented in Table III.

The precision errors for the CICERO measurements of the box- and cusp-chamfered margins and cusp-beveled margins were 3.9%, 3.4%, and 2.4%, respectively. In regard to accuracy, the SDs of the measurements of the box- and cusp-chamfered margins and cusp-beveled margins were 19 µm, 21 µm, and 24 µm, respectively, compared with 15 µm for the phantom.

The proposed onlay preparation design met the requirement that all points of the surface must be visible from a single point of view for optical 3-dimensional mapping by the CEREC system. For the surface measurements by the Procera contact probe, the orientation of the sapphire tip toward the preparation surface was critical even with the applied wax to smooth the internal edges.

Fig. 5. Onlays for molars shown in Figure 1. A, Procera. B, CICERO (mirror image). C, CEREC.
No fractures occurred in the follow-up period 2 years after cementation.

DISCUSSION

This study was done in the framework of research and the development of a completely computer-produced onlay. It describes the results of the first phase to achieve this aim; that is, to computer produce the strong core of the onlay with CICERO, CEREC, and Procera technologies. The cores were veneered with porcelain by the dental technician.

Clinical studies report favorable results for teeth needing an all-ceramic crown. Odén et al\textsuperscript{19} reported that only 3 Procera crowns of the remaining 97 of 100 crowns had experienced a fracture through the veneering porcelain and the Al\textsubscript{2}O\textsubscript{3} coping material after 5 years. Two additional crowns were replaced as a result of fractures of only the veneering porcelain. Scotti et al\textsuperscript{20} in a study of 63 In-Ceram full crowns, reported a success rate of 98\% for periods up to 44 months.

Multiple factors, such as the internal adaptation of the ceramic to the tooth surface, contribute to the clinical result. Tuntiprawon and Wilson\textsuperscript{21} reported that the best gap dimension in regard to compressive strength for all-ceramic crowns was 73 µm. When the gap was increased to 122 µm, a lower failure strength occurred without improvement in seating. The reported marginal gap opening in vitro for Procera full crowns, measured as the closest approximation between the epoxy die and the margin of the crown, was 63 µm ± 13 µm SD for molars.\textsuperscript{22} This definition of marginal gap is not the absolute marginal gap that is the distance between the margin of the crown and the finish line of the tooth preparation.\textsuperscript{23} The absolute marginal gap is reported in most studies of crown fit using marginal gap as a generic term. The accuracy of the surface digitization, the design, and the manufacturing process showed that the 3 systems were capable of producing onlay cores with a mean range for marginal gap dimension on stone dies of no more than 85 µm.

Berg and Dérand\textsuperscript{24} reported in a 5-year study on CEREC inlays that the measured marginal defects showed a mean width and depth (SD) of 373 (147) and 111 (67) µm, respectively. Only 3 of 115 inlays were found to be fractured. Heymann et al\textsuperscript{12} studied cement width at occlusal margins of 50 CAD-CAM-generated ceramic inlays and found no related inlay or enamel chipping through the 4-year recall interval. The adjusted means (plus or minus their SDs) for depth of cement loss at baseline and at each recall in micrometers were 0 ± 0 (baseline), 9 ± 19 (6 months), 32 ± 37 (1 year), 53 ± 40 (2 years), 61 ± 48 (3 years), and 44 ± 39 (4 years).

Panavia cement was chosen for cementation of the onlays because it is pulp-friendly and bonds strongly to enamel and dentine.\textsuperscript{25} The bonding is enhanced by the primer irrespective of the substrate being Al\textsubscript{2}O\textsubscript{3}, SiO\textsubscript{2}, or a combination. Others have recommended microfilled dual-cure cements.\textsuperscript{12} These cements necessitate the etching of the internal surfaces of the onlay to preferentially dissolve the SiO\textsubscript{2} matrix and coating with silane coupling agent. However, CICERO and Procera cores cannot be etched because they are made of Al\textsubscript{2}O\textsubscript{3}. The CEREC core was composed of 20\% to 23\% Al\textsubscript{2}O\textsubscript{3} and 15\% Na\textsubscript{2}O and K\textsubscript{2}O.

To date, no known reports have been published on CICERO and Procera onlays. For the CEREC system, mostly inlay type restorations have been described in clinical studies.\textsuperscript{12,24} A mean cement width of 81 µm was measured for the onlays. If 100 µm is regarded as a cut-off point of marginal fit,\textsuperscript{22,26} this measurement value was favorable for a clinically acceptable, strong, semicomputer-produced all-ceramic onlay.

Fig. 6. Aspects of anatomy, esthetics, and fit of porcelain-veneered onlay cores. A, Vestibular view of onlays on first and second molars. B, Lingual view of onlay on first molar.
Eight CICERO, 10 CEREC, and 7 Procera all-ceramic onlays were placed on 15 mandibular and 10 maxillary molars in 17 patients and evaluated over a period of 2 years. Within the limits of this short-term study, the following conclusions were drawn.

1. Measurements of chamfer and bevel margins by the CICERO system are (1) precise (error < 4%) and (2) accurate with an SD of less than 9 $\mu$m compared with optimal measurements of the spherical margin of a phantom. The proposed onlay preparation design met the requirement that all points of the surface be visible from a single point of view for optical 3-dimensional mapping by the CEREC system. For the surface measurements by the Procera contact probe, the orientation of the sapphire tip toward the preparation surface was critical, and it was necessary to apply wax to smooth internal edges.

2. The mean marginal gaps for the CICERO, CEREC, and Procera cores on the stone dies were 74 $\mu$m (SD 15), 85 $\mu$m (SD 40), and 68 $\mu$m (SD 53), respectively. There was no statistical difference among the materials.

3. The mean cement width of the onlays was 81 $\mu$m (SD 64).

**CONCLUSIONS**

Eight CICERO, 10 CEREC, and 7 Procera all-ceramic onlays were placed on 15 mandibular and 10 maxillary molars in 17 patients and evaluated over a period of 2 years. Within the limits of this short-term study, the following conclusions were drawn.

1. Measurements of chamfer and bevel margins by the CICERO system are (1) precise (error < 4%) and (2) accurate with an SD of less than 9 $\mu$m compared with optimal measurements of the spherical margin of a phantom. The proposed onlay preparation design met the requirement that all points of the surface be visible from a single point of view for optical 3-dimensional mapping by the CEREC system. For the surface measurements by the Procera contact probe, the orientation of the sapphire tip toward the preparation surface was critical, and it was necessary to apply wax to smooth internal edges.

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3. The mean cement width of the onlays was 81 $\mu$m (SD 64).
4. The anatomy and esthetic aspect of the semi-computer-produced onlays were the result of conventional porcelain veneering. No fractures occurred up to 2 years after placement.

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