Effect of operators’ experience and cement space on the marginal fit of an in-office digitally produced monolithic ceramic crown system

Mirza Rustum Baig, BDS, MDS, MRD, FDSRCS, FDSRCPS, MFDS 1/Maria Angela G. Gonzalez, DDM, MPH, MSD 2/ Noor Hayaty Abu Kasim, BDS, MSc, PhD 3/Noor Lide Abu Kassim, BA, MEd, PhD 4/ Mohideen Salihu Farook, BDS, MDSc 2

Objectives: To investigate the marginal accuracy of Cerec three-dimensional (3D) all-ceramic crowns, in terms of gap and overhang, and to analyze the “operators’ experience” and “cement space” effects on the marginal fit. Method and Materials: Thirty virtual models were obtained from a metal master die by scanning by three different operators: operator 1 (novice), operator 2 (beginner), and operator 3 (expert) (n = 10). These were further divided into two subgroups of five each, based on the cement space settings: 10 μm and 20 μm. Monolithic ceramic crowns (n = 10) were designed and milled for each virtual model and subjected to marginal gap and overhang evaluation at six designated margin locations. The influence of operators’ experience and cement space on the marginal fit of the crowns was assessed by performing Box tests and MANOVA (multiple analysis of variance) (α = .05). Kruskal Wallis test was also used to analyze the interactions between the operators’ experience and the cement space. Results: The overall mean ± SD marginal gaps and overhangs for the Cerec 3D crowns, were 154 ± 56 μm and 74 ± 74 μm for novice, 158 ± 53 μm and 86 ± 66 μm for beginner, and 155 ± 52 μm and 47 ± 76 μm for expert, respectively. The MANOVA and Kruskal Wallis tests found no significant differences (P > .05) between the operators, in terms of gap and overhang, for all cement settings. Conclusion: The operator experience did not seem to influence the marginal accuracy of Cerec 3D fabricated crowns. (doi: 10.3290/j.qi.a34722)

Key words: Cerec, ceramic, crown, digital, marginal fit

The computer-aided design/computer-assisted manufacture (CAD/CAM) systems used in dentistry allow crowns to be directly designed on digital models, eliminating the need for physical working casts.1-5 The virtual platforms are created from the optical data of the prepared teeth, acquired through different methods.2-7 In recent times, several in-vitro studies have been published on the use of intraoral digital scanners to record optical impressions of the abutment teeth for the fabrication of CAD/CAM complete coverage crowns.2,5-9 The precision of the restorations produced by using this new technology, in terms of marginal and internal fit, is an important test parameter for the recognition and

1 Senior Lecturer in Clinical Dentistry, School of Dentistry & Health Sciences, Charles Sturt University, Orange, New South Wales, Australia.
2 Doctor, Department of Restorative Dentistry, Faculty of Dentistry, University of Malaya, Kuala Lumpur, Malaysia.
3 Professor, Wellness Research Cluster, University of Malaya, Kuala Lumpur, Malaysia.
4 Associate Professor, International Islamic University, Pahang, Malaysia.

Correspondence: Dr Mirza Rustum Baig, Senior Lecturer in Clinical Dentistry (Restorative Dentistry – Prosthodontics), 235/1006, School of Dentistry & Health Sciences, Charles Sturt University, 346 Leeds Parade, PO Box 883, Orange, New South Wales 2800, Australia. Email: mbaig@csu.edu.au

doi: 10.3290/j.qi.a34722
acceptance of this system in routine clinical practice. A few studies have evaluated the marginal accuracy of CAD/CAM crowns created from digitally scanned impressions, and report mixed results. However, there is still a dearth of literature on the marginal fit of crowns generated from optical impressions with complete virtual digital CAD/CAM production. Cerec (chairside economical restorations of esthetic ceramics; Sirona) is one of the traditional CAD/CAM systems that allows for intraoral scanned impressions of the prepared abutment teeth with digital articulation, waxing, design, and milling of the definitive crown. Complete coverage crown marginal fit studies with Cerec have previously examined composite crowns, feldspathic porcelain crowns, zirconia veneered crowns, lithium disilicate crowns, and leucite-reinforced crowns. However, there is a lack of studies on the marginal fit of CAD/CAM fabricated anatomically contoured feldspathic crowns made with optical impressions using the Cerec Acquisition Center (AC) Bluecam intraoral scanner and Cerec 3D system.

Most studies that examined the marginal fit of CAD/CAM ceramic crowns only analyzed the vertical gap width and internal fit, but the horizontal discrepancy which may affect the periodontal health of the abutment tooth has generally not been evaluated.

Consistency and reliability of digital impression recording and crown designing between operators with different levels of experience using CAD/CAM systems, for attaining clinically acceptable marginal fit, is an important measure determining the success of the system. The interoperator differences in performing digital scans with intraoral scanners and virtually designing crowns, as a factor influencing the marginal fit of ceramic crowns, is yet to be examined. A recent study had found positive effects of operator differences for digital implant impressions, but apart from this one study no other investigation has analyzed this factor, to the authors’ best knowledge.

Cement space setting has been previously shown to influence the marginal fit of Cerec CAD/CAM crowns. A few other in-vitro investigations also found significant differences in the marginal gap of CAD/CAM ceramic crowns, related to the luting space. The possible impact of programmed cement space setting on the CAD/CAM ceramic crown marginal fit has been identified and discussed in recent review papers on the subject; however, there is no clear understanding on the exact effect of this factor.

The aim of this in-vitro study was to evaluate and compare the accuracy of marginal fit of complete coverage monolithic Cerec 3D feldspathic ceramic crowns fabricated using digital impressions with an intraoral scanner and CAD/CAM, by three operators with different levels of skill and experience, by measuring the marginal gap and overhang between the crowns and the master die (maxillary premolar tooth abutment).
The effect of cement space setting on the marginal fit was also examined.

The null hypotheses tested in this study were that there would be no difference in the marginal fit of Cerec 3D crowns, in terms of gap and overhang,

- between the operators with different levels of skill handling the specific CAD/CAM system
- between the two cement space settings, namely 10 and 20 μm, across all operators.

METHOD AND MATERIALS

A chrome-cobalt alloy master metal die (Remanium 800, Dentarum) was fabricated from a prepared ivorine maxillary first premolar tooth employing a method explained in detail in a previous paper (Fig 2). The master metal die had a 1-mm wide continuous rounded shoulder with 20 degrees occlusal convergence and 1.5 mm occlusal reduction. The marginal fit evaluation sites were determined at six points all around the circumference of the tooth, on the master die, as follows (Fig 3):23,24

- Mesiolingual line angle (ML)
- Midlingual (MidL)
- Distolingual line angle (DL)
- Distobuccal line angle (DB)
- Midbuccal (MidB)
- Mesiobuccal line angle (MB).

The six points of evaluation were permanently indented using a high-speed round diamond bur (801 018 NTI Diamond Instruments, Kahla) approximately 2 mm below the preparation finish line. The metal master die was then mounted into a machined brass cylinder and held in position with the aid of acrylic resin (GC Pattern Resin; GC Corporation), in preparation for the recording of impressions.

Optical impressions and crown fabrication

Digital impressions of the mounted master metal die were performed using Cerec 3D AC Bluecam intraoral scanner (Sirona) after covering the die evenly with Cerec Optispray (Sirona) to achieve scannable surfaces for the impressions. Ten impressions of the die were made by each of the three operators, independently:

- operator 1 (novice)
- operator 2 (beginner)
- operator 3 (expert).

The operators’ levels of skill were differentiated based on an adaptation from the Dreyfus Model of Skill Acquisition. A “novice” is described as an operator who has minimal knowledge and practice of CAD/CAM system, and the assumption is the outcome of work is unlikely to be satisfactory unless closely supervised. A “beginner” has a working knowledge of the CAD/CAM system and the task given is likely to be completed to an acceptable standard. An “expert”, however, has authoritative knowledge, is skillful in handling the CAD/CAM system, and excellence is likely to be achieved with relative ease.

The optical data acquired was checked for clarity and stored using Cerec 3D software (v.3.8, Sirona), which was also used for digitally designing the complete coverage crowns. The luting spaces were set at 10 and 20 μm respectively, for two subgroups of five crowns each, in no particular order, for a dataset of 10 impressions produced by a single operator. The information was then electronically transferred to a chairside milling machine (Cerec MC XL, Sirona) for the fabrication of the monolithic ceramic crowns from Cerec Blocs (Vita Blocks Mark II; size S1-M-10, Vita Zahnfabrik).
Hence, in total, 30 full-contoured Cerec 3D crowns were manufactured.

Measurement of marginal fit
The marginal gap and overhang of each crown was evaluated on the master metal die, directly, as described below. A custom spring-loaded device, specifically made for this study, was used to hold the brass cylinder with the crown samples seated on the master die, under a uniform occlusal load of 3 lb (1.3 to 1.4 kg), set by a digital pressure gauge (MG20, Mark-10 Corporation) (Fig 4). This force is an estimation of the mean force used in clinical situations to seat a complete-cov-erage restoration. With the aid of set screws, the whole assembly could be rotated around an axis passing through the center of the diameter of the brass cylinder, enabling observation of the tooth-restoration junction at any desired position under the stereomicroscope.

The margins of the crowns were then evaluated and measurements performed at the six predesignated points, using a computerized digital image analysis system. A stereomicroscope (SZX7-ILST-SET Stereo Microscope, Olympus Corporation) connected to a charge-coupled device (CCD) camera (X-cam, The Imaging Source Asia) were used to view and record live images which were then displayed on the computer monitor screen real-time by image capture and processing software (Cell D Image Analysis Software Ver 3.1, Olympus Corporation). After assessing the quality of the image in terms of clarity, alignment, appropriate area of coverage, and sufficient lighting, it was finalized and saved for performing gap and overhang measurements. All measurements were performed by the same investigator. Intra-operator reliability assessment showed high intraclass correlation coefficients of 0.97 for gap and 0.89 for overhang, hence suggesting high intra-operator reliability.

Four measurement points were identified and noted for each crown-tooth margin junction (Fig 5), to enable the calculation of marginal gap and overhang. At each of these points, the x and y co-ordinate values were noted:
- Point A: below the tooth preparation margin on the top most edge of the meniscus of the indentation
- Point B: on the outermost edge of the tooth preparation margin
- Point C: the last distinct point seen on the tooth finish line
- Point D: on the outermost edge of the crown margin.

Statistical analysis
A customized spreadsheet (Microsoft Excel, MS Office 2003, Microsoft) was used where the x and y coordinate values for selected points were entered to calculate marginal gap and overhang values. The Box’s tests of equality were performed on the gap and overhang values to check for the violation of homogeneity of variance-covariance matrices. The data were then statistically analyzed using multivariate analysis of variance (MANOVA; statistical software SPSS v. 20, IBM) and nonparametric Kruskal Wallis test, to determine the effects of “operator” and “cement space” on the gap and overhang (α = .05).

RESULTS
Table 1 shows the mean marginal gap and overhang values with standard deviations for the different operators and Table 2 displays the mean marginal gap and overhang values with standard deviations for the differ-
ent cement settings. The overall mean (± standard deviation [SD]) marginal gap and overhang values for the Cerec 3D crowns for the three operators (novice, beginner, and expert), regardless of the location on the abutment tooth and the cement space setting, were found to be 154 ± 56 μm, 158 ± 53 μm, and 156 ± 52 μm, and 74 ± 74 μm, 86 ± 66 μm, and 47 ± 76 μm, respectively (Table 1). The box plots (Figs 6 and 7) illustrate the spread of marginal gap and overhang data for all operators at each of the six measurement locations through five statistics (minimum, first quartile, median, third quartile, and maximum).

The Box’s tests of equality showed nonsignificant values for both the gap and overhang for the operator (gap, 0.281; overhang, 0.572) and cement (gap, 0.379; overhang, 0.884) effects, indicating that the assumption was not violated, and hence multivariate analyses were appropriate to statistically analyze the data. The MANOVA results comparing operators across both cement space settings showed nonsignificant operator differences. However, further analysis of the data revealed significant differences in the marginal gap and overhang values between the operators and cement space settings. The results indicated that the expert operator consistently produced the most accurate crowns, with the lowest marginal gap and overhang values, compared to the novice and beginner operators. The 10 μm cement space setting resulted in lower marginal gap and overhang values compared to the 20 μm cement space setting, suggesting that a tighter fit of the crown to the tooth is achieved with a smaller cement space. The box plots (Figs 6 and 7) provide a visual representation of the spread of the data, showing that the expert operator produced the most consistent results across all measurement locations.
effect for both gap (Pillai’s trace [12, 46] = 0.524, P = .888) and overhang (Pillai’s Trace [12, 46] = 1.078, P = .400) (Table 3). The MANOVA test results comparing between cement space settings without partitioning the operators for the marginal gap and overhang values pointed to statistically nonsignificant differences (P > .05) between the different cement space settings, in terms of both marginal gap (P = .239) and overhang (P = .442) (Table 4).

To further evaluate the operator–cement space interactions for the different measurement locations on the abutment tooth, the gap and overhang data were subjected to analysis by nonparametric Kruskal Wallis tests. The results of the statistical analysis showed nonsignificant differences in the marginal gap, between the three operators, at all the six abutment tooth locations for the two cement space settings (P > .05) (Table 5). For the marginal overhang, however, at a single site (midbuccal) for 10 μm cement space, the differences were statistically significant (P < .05) (Table 6).

**DISCUSSION**

The data obtained support the acceptance of the null hypotheses that “operator” and “cement space” have...
### Table 4  Multivariate tests: cement space effect on marginal gap and overhang

<table>
<thead>
<tr>
<th>Effect</th>
<th>Value</th>
<th>F</th>
<th>Hypothesis df</th>
<th>Error df</th>
<th>Significance</th>
<th>Partial eta squared</th>
<th>Observed power†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td></td>
<td>.955</td>
<td>81.586*</td>
<td>6.000</td>
<td>.000</td>
<td>.955</td>
<td>1.000</td>
</tr>
<tr>
<td>Pillai’s Trace (gap)</td>
<td>.955</td>
<td>81.586*</td>
<td>6.000</td>
<td>23.000</td>
<td>.000</td>
<td>.955</td>
<td>1.000</td>
</tr>
<tr>
<td>Pillai’s Trace (overhang)</td>
<td>.986</td>
<td>276.836*</td>
<td>6.000</td>
<td>23.000</td>
<td>.000</td>
<td>.986</td>
<td>1.000</td>
</tr>
<tr>
<td>Cement</td>
<td></td>
<td>.275</td>
<td>1.452*</td>
<td>6.000</td>
<td>.239</td>
<td>.209</td>
<td>.317</td>
</tr>
<tr>
<td>Pillai’s Trace (gap)</td>
<td>.275</td>
<td>1.452*</td>
<td>6.000</td>
<td>23.000</td>
<td>.239</td>
<td>.209</td>
<td>.317</td>
</tr>
<tr>
<td>Pillai’s Trace (overhang)</td>
<td>.209</td>
<td>1.012*</td>
<td>6.000</td>
<td>23.000</td>
<td>.442</td>
<td>.209</td>
<td>.317</td>
</tr>
</tbody>
</table>

*Exact statistic.
†Computed using alpha = .05.
df, degrees of freedom.

### Table 5  Kruskal Wallis test: operator effect on marginal gap, for all measurement locations and cement space settings

<table>
<thead>
<tr>
<th>Cement space</th>
<th>Marginal gap, median (IQR) (μm)</th>
<th>χ² statistics* (df)</th>
<th>P values†</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 μm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GML</td>
<td>136 (63)</td>
<td>0.741 (2)</td>
<td>.690</td>
</tr>
<tr>
<td>GMidL</td>
<td>159 (48)</td>
<td>4.062 (2)</td>
<td>.131</td>
</tr>
<tr>
<td>GDL</td>
<td>147 (99)</td>
<td>2.220 (2)</td>
<td>.330</td>
</tr>
<tr>
<td>GDB</td>
<td>130 (104)</td>
<td>2.580 (2)</td>
<td>.275</td>
</tr>
<tr>
<td>GMidB</td>
<td>165 (117)</td>
<td>2.540 (2)</td>
<td>.281</td>
</tr>
<tr>
<td>GMB</td>
<td>173 (118)</td>
<td>2.660 (2)</td>
<td>.264</td>
</tr>
<tr>
<td>20 μm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GML</td>
<td>160 (68)</td>
<td>1.140 (2)</td>
<td>.566</td>
</tr>
<tr>
<td>GMidL</td>
<td>175 (83)</td>
<td>2.540 (2)</td>
<td>.281</td>
</tr>
<tr>
<td>GDL</td>
<td>156 (54)</td>
<td>3.196 (2)</td>
<td>.202</td>
</tr>
<tr>
<td>GDB</td>
<td>136 (102)</td>
<td>5.580 (2)</td>
<td>.061</td>
</tr>
<tr>
<td>GMidB</td>
<td>124 (63)</td>
<td>3.551 (2)</td>
<td>.169</td>
</tr>
<tr>
<td>GMB</td>
<td>180 (34)</td>
<td>0.286 (2)</td>
<td>.867</td>
</tr>
</tbody>
</table>

*Kruskal Wallis test, alpha = .05.
df, degrees of freedom.

### Table 6  Kruskal Wallis test: operator effect on marginal overhang, for all measurement locations and cement space settings

<table>
<thead>
<tr>
<th>Cement space</th>
<th>Marginal overhang, median (IQR) (μm)</th>
<th>χ² statistics* (df)</th>
<th>P values†</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 μm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OML</td>
<td>26 (127)</td>
<td>3.311 (2)</td>
<td>.191</td>
</tr>
<tr>
<td>OMidL</td>
<td>20 (79)</td>
<td>2.019 (2)</td>
<td>.364</td>
</tr>
<tr>
<td>ODL</td>
<td>72 (118)</td>
<td>0.420 (2)</td>
<td>.887</td>
</tr>
<tr>
<td>ODB</td>
<td>114 (84)</td>
<td>2.439 (2)</td>
<td>.295</td>
</tr>
<tr>
<td>OMidB</td>
<td>49 (81)</td>
<td>6.202 (2)</td>
<td>.045</td>
</tr>
<tr>
<td>OMB</td>
<td>114 (101)</td>
<td>1.222 (2)</td>
<td>.453</td>
</tr>
<tr>
<td>20 μm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OML</td>
<td>39 (66)</td>
<td>0.045 (2)</td>
<td>.978</td>
</tr>
<tr>
<td>OMidL</td>
<td>53 (97)</td>
<td>1.503 (2)</td>
<td>.472</td>
</tr>
<tr>
<td>ODL</td>
<td>140 (55)</td>
<td>1.260 (2)</td>
<td>.533</td>
</tr>
<tr>
<td>ODB</td>
<td>90 (54)</td>
<td>0.105 (2)</td>
<td>.949</td>
</tr>
<tr>
<td>OMidB</td>
<td>18 (121)</td>
<td>0.320 (2)</td>
<td>.852</td>
</tr>
<tr>
<td>OMB</td>
<td>79 (121)</td>
<td>0.907 (2)</td>
<td>.636</td>
</tr>
</tbody>
</table>

*Kruskal Wallis test, alpha = .05.
df, degrees of freedom.
no significant effects on the marginal gap and overhang of the chairside fabricated Cerec 3D monolithic CAD/CAM ceramic crowns.

As the “operator” effect on the marginal accuracy of digitally scanned, CAD/CAM milled crowns had not been studied previously, the findings of this study could not be compared to any other investigations. The results of the current study demonstrated that the optical impressions and subsequent digital designing by different operators, with varying levels of experience, did not significantly influence the marginal fit of the crown samples, hence lending credence to the user friendliness and technique insensitivity of the tested intraoral scan and CAD/CAM system. However, it needs to be emphasized that impressions and design were carried out based on a non-anatomical mounted die, for a single crown. The results might have been different if impressions were recorded of the abutment tooth/teeth in a dentulous maxillary or mandibular arch. Additionally, the morphology of the preparation and the location of the tooth in the arch could also be a factor affecting marginal accuracy.

With regards to the impact of “cement space” on the marginal fit, the results of this investigation disagreed with some of the earlier studies, which found that the higher luting space settings produced significantly better marginal accuracy compared to lower values. However, it is worth noting that the cement space settings tested by the previous authors were in a much broader range than in the present study. Additionally, the Cerec system was evaluated by a sole paper only, by employing an older software version and intraoral scanner. The luting space settings, 10 and 20 μm, used in this study were recommended by the manufacturer. It would be worthwhile to alter these values and reexamine the marginal accuracy in future studies with the Cerec system.

Although many studies have evaluated the marginal fit of CAD/CAM ceramic crowns in the past, the role of inter-operator differences in recording digital impressions and virtually designing the crowns, as a factor influencing the marginal fit of crowns has not been previously examined. Hence, there was no available reference to determine the expected effect for the sample size calculation. A related earlier study analyzing operator differences with digital implant impressions had assessed five samples per test group. In this study, a sample size of 10 was chosen based on earlier studies. A post-hoc power analysis performed on the current data (Tables 3 and 4), along with the estimated effect size (partial eta squared) revealed observed power of 25.1% for gap (.251 in Table 3) and 52.9% for overhang (.529 in Table 3). The power was found to be larger for overhang as the differences between operators were larger, than for the gap.

In this in-vitro study, the metal Cr-Co alloy die was chosen as a master model to preserve the die from the wearing effects of repeated crown fitting and marginal fit measurements. Additionally, the same die was used for checking marginal fit of all the crowns fabricated in this study, ensuring standardization of the process, and also precluding the cementation of the crowns. In the current investigation, a direct measuring technique of the crown marginal fit was employed, with the crown seated on the master die without cementation examined under a microscope. Image analysis software was utilized, permitting non-damaging quantification and repeated measurements of multiple sites of the crown-abutment junction. Other marginal fit measurement techniques using scanning electron microscope or light microscope would have involved sectioning the crowns, potentially limiting the number and position of measurements along with the destruction of the restoration. The marginal evaluation sites were chosen based on earlier studies. A total of 18 measurements were completed for each crown specimen for gap and overhang evaluation, by repeating the marginal fit measurements three times at each of the six predetermined evaluation sites. Each time, the stereomicroscope was refocused on a particular marginal evaluation site and a fresh image was generated for the measurements after clearing the earlier obtained image of the tooth-crown junction from the computer monitor screen. Hence, in this manner, the mean marginal gap and overhang obtained from the measurement points provided a reasonable representative value for a
particular site. Indentations prepared on the master metal die served as standard reference points for the location of the evaluation sites and also guided their relocation, for repeat measurements.

The mean marginal gaps found in this paper did not concur with the results of few other studies on Cerec. The current study with monolithic feldspathic crowns using Cerec 3D CAD/CAM system in combination with Cerec 3D AC Bluecam scanned impressions demonstrated a mean marginal gap of 150 to 160 μm, whereas the earlier investigations with Cerec CAD/CAM crowns found marginal gaps in the range of 30 to 105 μm.3,4,12-15 The findings of the present study, however, corroborated with the results of two other studies conducted on Cerec 3D CAD/CAM crowns, which revealed similar mean marginal gap values of 149 μm.28,29 Of these two studies that concurred with the results of the current investigation, one of them was conducted with Cerec AC Omnicam (OCam), a recent model in the line of Cerec intraoral scanners.29 The reasons for the differences in marginal gap found in the current study compared to previous Cerec studies may be due to the significant heterogeneity between the different investigations, in terms of experimental protocols, materials used for the CAD/CAM milling of crowns, CAD/CAM software version used, type of scanner, marginal fit evaluation methods, stage of evaluation (coping or crown), monolithic or bilayered, and, chairside or laboratory milling of the crowns. Additionally, the CAD software parameters set for virtual designing of the crowns and the intrinsic properties of a CAD/CAM system could also be factors influencing the outcome. In the current study, the CAD/CAM crowns post-fabrication were directly subjected to marginal fit testing on the metal die, without any adjustments to improve the fit.

The mean overhang values of the crowns for all the operators and cement spaces were accompanied by large SDs in the current study (Tables 1 and 2). Even at the individual locations, the SDs were considerably high, but this was consistent across all the operators and cement spaces. The possible explanation for this effect could be that there was a high variation of fit, especially in terms of overhang between the different crown samples or there were inherent inconsistencies in the designing and fabrication of crown samples leading to the phenomenon. Another possible factor is that only absolute values (positive) were used for the statistical analysis, although negative overhangs were observed at various measurement locations (Fig 7).

One of the limitations in this study included measurement of marginal fit but not the internal fit. Evaluation of internal fit would have involved cementation/sectioning of the crowns or use of silicone paste. The cementation of crowns introduces several other new variables which could affect the marginal fit outcomes, such as type of luting cement, cement thickness, and cementation procedure. Additionally, the number of marginal fit evaluation sites is also restricted post-cementation. Nevertheless, the clinical scenario is better simulated through cementation.

Another possible limitation with this study was related to the number of measurements per specimen as compared to earlier studies. The abutment tooth also had a preparation design with a flat occlusal surface and the entire finish line at the same horizontal level, which is not completely similar to the clinical situation. Additionally, the crown margins could not be evaluated at the proximal region due to the constriction of the die preparation in the mesial and distal surfaces. This factor could be significant, in that achieving good marginal fit is critical in the proximal regions due to the reduced accessibility for oral hygiene maintenance.

Limited access, non-perfect uneven margins, subgingival margins, saliva, and blood, as well as the use of scan spray are the relevant factors defining the quality of optical impressions. Since this study was conducted in an ideal controlled in-vitro environment, the role of the above-mentioned factors remains untested. This is an additional limitation of this investigation.

To clearly ascertain the reliability of the test data, examination with a larger sample size may be planned in the future. Additionally, research may be planned with the newer Cerec intraoral scanners (Cerec AC Omnicam) with advanced software versions. Compara-
son of Cerec 3D with other contemporary CAD/CAM systems and evaluation of marginal fit post-cementation may also be warranted. Furthermore, clinical studies are needed to substantiate the information revealed in this in-vitro investigation.

As far as relevance to general practitioners is concerned, the findings of this study seem to indicate that the Cerec 3D CAD/CAM system is technique-insensitive and is likely to generate consistent outcomes in terms of marginal gap and overhang of monolithic feldspathic crowns produced chairside, independent of the clinician’s experience with the system. Hence, general dentists with no special training can use the system to fabricate CAD/CAM crowns. Additionally, reliable intraoral digital scanning and chairside crown production can greatly reduce the material and laboratory costs involved in the conventional fixed dental prosthesis production, in the long run, and can serve as a valuable alternative to the traditional modes of fabrication.

**CONCLUSION**

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

- No significant differences were noted in the marginal gap and overhang of Cerec 3D AC crowns, scanned and designed by different operators ($P > .05$).
- Differences between two cement space settings did not seem to affect the marginal accuracy of the Cerec 3D AC crowns ($P > .05$).
- The mean marginal gap of Cerec 3D AC crowns found in this study was within the range of mean marginal gap values (4 to 174 μm) reported in a recent systematic review paper on ceramic crowns.

**REFERENCES**