Utilizing CAD/CAM to Measure Total Occlusal Convergence of Preclinical Dental Students’ Crown Preparations

Keith A. Mays, DDS, MS, PhD; H. Alex Crisp, DDS; Paul Vos, PhD

Abstract: Traditionally, faculty assessment of preclinical crown preparations occurs by visualizing preparation features. However, contemporary CAD/CAM tools have the ability to more precisely evaluate preparation features, which is beneficial for psychomotor development. Taper is one of the most challenging features to objectively assess. The aim of this study was twofold: first, to validate the software’s ability to distinguish differences in taper, and second, to compare traditional faculty assessment with digital assessment of taper. In the study, 30 all-metal crown preparations were created on typodont teeth with varying degrees of axial reduction and placed into three groups based on amount of taper (minimum, moderate, or excessive). Each tooth was scanned with the D4D scanner, and the taper was analyzed using E4D Compare. A second experiment used 50 crown preparations of tooth #19, which were done as a formative exercise. A comparison faculty assessment with CAD/CAM assessments of taper was performed. The results showed that when the taper was varied, E4D Compare was able to distinguish those differences; the Tukey post-hoc test revealed a significant difference \( p=0.001 \). The qualitative analysis comparing faculty grading to CAD/CAM grading demonstrated a trend for CAD/CAM to be more precise. These results suggest that E4D Compare is an effective means of quantitatively measuring the amount of total occlusal convergence or taper on a crown preparation and that digital assessment may be more precise than faculty visual grading.

Dr. Mays is Associate Dean of Academic Affairs, School of Dentistry, University of Minnesota; Dr. Crisp was a dental student, East Carolina University School of Dental Medicine at the time of this study; and Dr. Vos is Professor and Chair, Department of Biostatistics, East Carolina University. Direct correspondence to Dr. Keith A. Mays, University of Minnesota Academic Health Center, 15-238 Moos Health Science Tower, 515 Delaware Street, SE, Minneapolis, MN 55455; 612-624-6588; kmays@umn.edu.

Keywords: dental education, prosthodontics, computer-assisted instruction, preclinical assessment

Submitted for publication 5/5/15; accepted 6/12/15
translate into challenges for faculty grading student performance and for teaching students how to evaluate their own work. However, CAD/CAM software can improve the objectivity of the grading process for both students and faculty. In addition, one of the challenging elements of managing a fixed prosthodontic course is having adequate time to meet with students during and outside of scheduled laboratory sessions to provide feedback. Finding time to meet with students can be difficult when the students have competing academic responsibilities. However, the use of digital evaluation of preclinical crown preparation with E4D Compare can provide students with instant, objective, and visual feedback. The aim of this study was twofold: first, to validate the software’s ability to distinguish differences in the amount of taper of a preparation, and second, to compare traditional faculty assessment with digital assessment. Therefore, this study evaluated how digital evaluation of preclinical crown preparation can be beneficial to fostering a more objective evaluation process of measuring student performance.

Materials and Methods

The Institutional Review Board at East Carolina University approved this study. Two separate experiments were conducted at the East Carolina University School of Dental Medicine. The first component validated the software’s ability to differentiate preparations with predetermined variations in taper (TOC). The second component was designed to compare faculty assessment of preclinical performance with CAD/CAM evaluation of crown preparations.

Component 1

An all-metal crown preparation was created on 30 #19 typodont teeth (Kilgore International, Coldwater, MI, USA) with varying degrees of axial reduction. To properly align the preparation during scanning, two alignment holes (one occlusal and one buccal) were placed on adjacent teeth #18 and #20 (Figure 1). A sample tooth was prepared by a prosthodontic faculty member, which was used as the standard to compare against all experimental and student preparations in the second component. This tooth was deemed the master preparation and was scanned with a laser scanner on the CAD/CAM digital impression system and then exported into the E4D Compare software. A third-year dental student prepared 30 experimental preparations to achieve the specified amounts of taper on the buccal/lingual surfaces of each tooth. To achieve a consistent uniform result, a putty reduction guide was used to determine axial reduction during preparation with Kerr Extrude (Danaher Corporation, Washington, DC, USA).

The 30 teeth (experimental preparations) were placed into three groups (n=10 each) based upon axial taper (minimum, moderate, or excessive). The margin was placed 1 mm above the gingival margin for all preparations. The preparations were altered at three areas to create the desired variations in taper and to...
provide a consistent measurement location when using the putty reduction guide. To determine the preparation dimensions, the teeth were measured at 1 mm, 3 mm, and 4 mm above the gingival margin. Group 1 (minimum taper) measured 1 mm, 1 mm, and 1.5 mm at each of the respective measurement locations. Group 2 (moderate taper) measured 1 mm, 1.5 mm, and 1.5 mm at the measurement locations, and group 3 (excessive taper) measured 1 mm, 2 mm, and 2 mm at each of the respective measurement locations. Each sample was then placed into the Nissan typodont and individually scanned with the CAD/CAM. Once the scanning was completed, a file was opened in E4D Compare, and the TOC was analyzed for each tooth.

The E4D Compare software was used to compare the difference between the 30 experimental preparations and the master preparation. The teeth were aligned using the dots on the adjacent teeth to achieve proper measurement. The TOC was measured with the tolerance set to 0.25 mm. The isolation and difference tools were used to separate the preparation from the adjacent teeth. This isolation was completed by selecting the “Trim Model” tab, and the angle of convergence was acquired by selecting the “Slice Plane” and “Plot TOC” tabs. All samples were measured on three days to decrease measurement error. In addition, measurements were made on three locations on each sample: the mesio-buccal, mid-buccal, and disto-buccal. A single mean was created from the three measurements, which was compared to a single measurement made at the mid-buccal location (Figure 2). An ANOVA was used to statistically analyze the mean TOC using SPSS 20, performed by one investigator (KM).

**Component 2**

In this part of the study, 50 all-metal crown preparations of tooth #19 performed as a formative exercise in a fixed prosthodontics course were used to compare faculty assessment with CAD/CAM assessments. Although the software is capable of providing information on axial reduction, occlusal reduction, margin location, etc., this study focused only on evaluating computer assessment of the TOC and the faculty assessment of retention/resistance from the grading criteria. Two classes of second-year dental students in the fixed prosthodontic laboratory performed the crown preparations. Two faculty members independently graded each preparation using a standardized grading form that is used for both formative and summative exercises. The two graders had participated in the course for several years and

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**Figure 2. Flow chart of measurement times and locations**

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been calibrated annually on using the criteria sheet. An analysis of interrater reliability was performed for the two graders.

Each preparation was scanned with a laser scanner on the CAD/CAM using the Planmeca E4D digital impression system and then exported into the E4D Compare software, which performs preparation evaluation by comparing student projects to an ideal preparation. Comparisons can be made without any forgiveness or tolerance, which would overlay the student’s preparation on the master preparation and measure the differences in the dimensions. However, by adjusting the tolerance, the system will allow for some degree of forgiveness, which can be helpful in accommodating for differences in faculty members’ grading style. To determine the best fit, tolerance was set at three levels when measuring the preparations (0.2 mm, 0.3 mm, and 0.4 mm). Therefore, each preparation was scanned three separate times at each of the tolerance levels. The relationship between faculty grade and CAD/CAM digital grade was assessed using scatter plots at five tolerance levels. In addition, a scatterplot was used to descriptively analyze the best fit of tolerance levels by evaluating the association between faculty grade and CAD/CAM grade at each tolerance level.

In this analysis, the faculty grades were averaged together for each preparation placed on the x-axis with the CAD/CAM grade on the y-axis. Side-by-side boxplots were used to visualize the relationship between faculty grading of retention form and CAD/CAM grading of TOC. The Inter Quartile Range (IQR) or width of the interval needed to capture the middle 50% of the data was used to descriptively analyze difference in grading. The statistical analysis for this part of the study was performed by a statistician (PV) using R Foundation for Statistical Computing.12

Results

A comparison of measurements made at the mid-buccal location versus the average of six sites on the tooth demonstrated that there was no significant difference in the TOC. For the minimum preparation, the mean (standard deviation) at the mid-buccal was 10.79° (3.34) and at all sites was 10.76° (2.09). For the moderate preparation, the mean (standard deviation) at the mid-buccal was 21.30° (3.46) and at all sites was 22.80° (2.30). For the excessive preparation, the mean (standard deviation) at the mid-buccal was 44.56° (4.61) and at all sites was 46.87° (3.24). Therefore, the remaining analysis focused on the TOC measurement made at only the mid-buccal location. The ANOVA revealed that there was no significant interaction between taper and site (F=1.978, p=0.075), but that there was significant difference for preparation taper (F=1361, p=0.001) and site (F=2.893, p=0.039). The pairwise comparison revealed no significant difference when comparing all sites to the mid-buccal (p=0.125). The Tukey post-hoc test demonstrated that there was a significant difference when comparing the preparation taper (p=0.001) (Figure 3). The results suggested that when the crown preparation taper was varied, the E4D Compare software was able to distinguish differences that grouped preparations into distinct groups (minimum, moderate, or excessive).

The scatter plot analysis of the two faculty members’ visual grading showed that for the most part the grades were grouped around the regression line (Figure 4). There was a general trend for both graders to have a passing or failing grade with both coordinates above or below 70 and with most assessments being within ten units. However, there were a few observations that would have one grader failing and the other passing. The IQR for the differences showed that 50% of the assessments differed by six or fewer units. There were six values on the lower portion of the graph that showed differences of 20 or more; for each of these, grader 1 gave the lower rating.

A scatterplot was used to assess the relationship between averages of the two faculty grades and the CAD/CAM digital grade at five tolerance levels. Figure 5 shows these scatter plots for the three most acceptable tolerance levels with average faculty grade on the x-axis and E4D Compare grade on the y-axis. The scatterplots suggested that setting the tolerance too high or too low would impact how closely the software matched faculty grading patterns. Our results show that the best fit for our faculty was when the tolerance was set at 3 mm. At this tolerance level, the CAD/CAM values were slightly higher (mean difference 0.478, standard deviation 16.14). The linear regression line had slope 0.42 (standard error 0.20) and squared correlation 0.0829. When restricted so that the intercept was zero, the slope was 0.99 (standard error 0.037).

The boxplot data shows that the median CAD/CAM values for all grading categories were roughly equal. Also, the IQR represented by each box height indicated that the spread was similar.
preparations, which may also foster a less than stringent protocol in clinical evaluations. Crown preparations are generally designed to ensure that there is adequate space for the selected material, which requires well-prescribed dimensions. One excellent way to reduce the subjectivity is to use a putty reduction guide that is fabricated prior to starting the preparation. After that, the reduction can be measured using any standard periodontal probe. One limitation of using a putty reduction guide is that the assessment can only be made at the point where the putty has been sliced. In addition, it is not feasible to measure taper or the TOC with a putty reduction guide. Our results demonstrated that E4D Compare had the ability to distinguish the variation in the amount of TOC when preparations of known dimension were scanned. Therefore, one can extrapolate that CAD/CAM grading may be an excellent method to objectively determine the amount of taper on the crown preparation. This finding is consistent with previous studies that found the CAD/CAM software to be a useful tool to help students measure preparations.11,15

Discussion

The assessment of preclinical preparations is essential for restorative laboratory courses. Historically, there has been a significant degree of subjectivity in assessing student performance on crown preparations, which may also foster a less than stringent protocol in clinical evaluations. Crown preparations are generally designed to ensure that there is adequate space for the selected material, which requires well-prescribed dimensions. One excellent way to reduce the subjectivity is to use a putty reduction guide that is fabricated prior to starting the preparation. After that, the reduction can be measured using any standard periodontal probe. One limitation of using a putty reduction guide is that the assessment can only be made at the point where the putty has been sliced. In addition, it is not feasible to measure taper or the TOC with a putty reduction guide. Our results demonstrated that E4D Compare had the ability to distinguish the variation in the amount of TOC when preparations of known dimension were scanned. Therefore, one can extrapolate that CAD/CAM grading may be an excellent method to objectively determine the amount of taper on the crown preparation. This finding is consistent with previous studies that found the CAD/CAM software to be a useful tool to help students measure preparations.11,15
When using the computer to grade crown preparations, one concern is the ability of the evaluator to accurately reproduce the assigned portion of the grading process. Accurate reproduction of the grading process requires that the human evaluator place the cursor in the same location for measurements made on separate days and/or times. Unfortunately, this process can result in the measurements for the student evaluator and the faculty evaluator being slightly different. This difference may become a factor if programmatic needs require students to assess their performance and then have a final conformational evaluation by a faculty member. An additional scenario could manifest itself if CAD/CAM grading was used during a licensure board examination, a student performed an intermediary assessment, and the board found in a subsequent final evaluation that the orientation was slightly different. Therefore, to decrease variability of measurements, we made measurements on three days and at three locations for each tooth (the mesio-buccal, mid-buccal, and disto-buccal). The mean total occlusal convergence was calculated for all measurement locations each day. Our results demonstrated that there was no significant difference when comparing measurement locations and the day of measurement. Therefore, this study suggests that CAD/CAM grading is an effective method to objectively measure the amount of TOC on a preclinical crown preparation.

The advancement in CAD/CAM technology has been rapid, and both software and hardware improvements are continually occurring. One limitation of this study is the need for alignment of the preparations using the small divots placed on the adjacent teeth, even though another study used this method of alignment.11 Most of the time this form of alignment is very effective, but periodically there is a need for some additional fine adjustment that can be accomplished by manually aligning the cast within the system. This is a technique-sensitive process that is subject to differences in measurements between users. The measurement was controlled in...
The second goal of this study was to compare traditional faculty assessment with digital assessment—a particularly critical issue because of the subjective nature of preparation evaluation. One way to address the concern is through faculty calibration, which is extremely challenging and can have limited lasting effect. To augment calibration by using one person to scan all preparations and make alignments. In the future, variations will not be a major concern because the most recent upgrades in the software and hardware have an auto-alignment feature that reduces this limitation and creates reliable measurements between users and measurement times.

![Comparison of Faculty Visual to CADCAM Digital Grade](image)

**Figure 5.** Comparison of faculty visual assessment with E4D Compare assessment at three tolerance levels

![Box plots](image)

**Figure 6.** Comparison of faculty visual assessment of retention/resistance form and E4D Compare assessment of total occlusal convergence
issues, our faculty members generally confer with each other after individual grading has occurred when one faculty member has given a failing grade and the other has not. The lack of objectivity also creates challenges when training students how to evaluate preparations. One significant finding of our study was that the faculty assessment was not necessarily predictive of the CAD/CAM assessment. Our grading criteria suggested that excellent ranged from 6° to 10°, good ranged from 10° to 15°, and acceptable ranged from 16° to 22°. The CAD/CAM demonstrated that faculty scores for the acceptable category correlated to CAD/CAM measurement ranging from 10° to 28°. Even though the faculty graders had been calibrated on the grading criteria for the past three years, the CAD/CAM system was able to more precisely measure the TOC. We suggest that the grading performed by faculty members with the understanding of what is necessary for a crown to fit is difficult to quantify for the novice student and lacks the real level of precision we desire. This finding is also consistent with a study that found hand-grading was not as precise as computer grading.11 We also believe that this would be a useful feedback tool for teaching students to self-assess and understand preparation dimensions.

One feature of the E4D system has the ability to alter the tolerance level or relative preciseness with which the system compares the faculty preparation to the student preparation. Shifting the tolerance is a useful tool for developing psychomotor skills in that the tolerance can be higher for the novice and then shifted to tighter parameters for the more advanced student. When using the system as a grading tool, it is important to determine which tolerance level most closely matches the faculty’s grading ranges. Our study compared three tolerance levels (0.2 mm, 0.3 mm, and 0.4 mm). Adjustment of the tolerance can help students at different levels accommodate for faculty grading styles and account for minor errors between typodonts. This study found that the 0.3 mm tolerance level was the most appropriate for the grading faculty. We recommend that each faculty grading group be made aware of its grading pattern and then set the tolerance based on that profile. Shifting the tolerance too low or high can deflate or inflate the grade assigned. Further studies should be conducted to determine how to best manage the tolerance in order to benefit the student and provide accurate feedback.

Conclusion

The results of this study suggest that the Planmeca E4D Compare software may be an effective means of quantitatively measuring the amount of TOC or taper on a crown preparation. The measurement of the TOC can be accomplished by a single measurement in the mid-buccal/mid-lingual area of the tooth. Our findings also suggest that digital assessment is more precise than faculty grading.

REFERENCES