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Effect of Operator Experience on Ability to Place Sequential, 2-mm-thick Increments of Composite

RJ Sword • W Bachand • B Mears • L Quibeuf • S Looney • RB Price • FA Rueggeberg

Clinical Relevance

Because an operator has only about one chance out of three to place a composite increment within this clinically acceptable range, clinicians are advised to use an instrument (e.g., a periodontal probe with a 2-mm mark) to estimate the thickness of each increment of composite they place.

SUMMARY

Objective: To measure and compare the effect of operator experience in their ability to place composite in increments that are 2 mm thick.

Methods and Materials: Fifteen volunteers from each class of freshmen, sophomores, juniors, and senior dental students and 15 clinical faculty (total number of volunteers = 75) were asked to restore a Class I preparation that was 5 mm in diameter and 8 mm deep from the cusp tips using three increments of composite that were each to be 2 mm thick. Once completed, the models were sectioned, and the thickness of each increment was measured. A repeated-measures analysis of variance (pre-set α=0.05) was used to compare the mean increment thickness with respect to operator experience level and increment sequence number. In addition, the proportion of operators placing clinically acceptable increments (between 1.75 and 2.25 mm thick), as well as the proportions from each group who placed increments that either were thinner

*Rhoda J Sword, DMD, Department of Restorative Sciences, Dental College of Georgia at Augusta University, Augusta, GA, USA

William Bachand, DDS, Department of Restorative Sciences, Dental College of Georgia at Augusta University, Augusta, GA, USA

Brian Mears, DMD, resident, Department of Periodontics, Dental College of Georgia at Augusta University, Augusta GA USA

Lindsey Quibeuf, DMD, Graduate of Dental College of Georgia at Augusta University, Augusta, GA, USA

Stephen Looney, PhD, Department of Population Health Sciences, Department of Oral Health and Diagnostic Sciences, Dental College of Georgia at Augusta University, Augusta, GA, USA

Richard B Price, DDS, MS, PhD, Department of Dental Clinical Sciences, Faculty of Dentistry, Dalhousie University, Halifax, NS, Canada

Frederick A Rueggeberg, DDS, MS, Department of Restorative Sciences, Dental College of Georgia at Augusta University, Augusta, GA, USA

*Corresponding author: Department of Restorative Sciences, Dental College of Georgia at Augusta University, 1120 15th Street, GC4330, Augusta, GA 30912, USA; e-mail: RSWORD@augusta.edu

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or thicker than this range, was determined using nonparametric analyses.

Results: Overall, there was an increasing trend for groups with a higher experience level to provide mean incremental thickness values close to 2 mm. However, the likelihood of placing an increment that was thicker or thinner than the manufacturer-recommended thickness was not significantly different. Regardless of the increment value, only about one-third of the increments placed fell within the desired range of 1.75 to 2.25 mm.

Conclusions: Operator experience had no overwhelming significant influence on the ability to place increments of composite that were between 1.75 and 2.25 mm thick. An operator has only about one chance out of three to place a composite increment within this clinically acceptable range when using no external measurement system.

INTRODUCTION

When restoring a deep cavity preparation using photo-cured resin-based composites (RBCs), the RBC must be placed in increments. For many RBCs, the recommended maximum thickness of each increment ranges from 1.5 mm[1] to 2.5 mm,[2] depending on the material translucency, shade, and manufacturer. These increment limits are due to the inability of sufficient light to reach beyond this depth. Within this depth range, the exposure duration specified by the manufacturer will provide adequately polymerized RBCs.[3] Failure to provide sufficient radiant energy to these depths can produce inadequate polymerization in the RBC at depths beyond the recommended increment thickness: the "depth-of-cure" issue.[4] This failure may explain why the median longevity of approximately seven years[5-12] for posterior RBCs placed in dental offices is far less than their potential to last at least twice as long, a value that has been reported in controlled trials.[9,13]

When placing photo-cured materials, clinicians must estimate the thickness of each increment and try to balance the need to complete a restoration using the least amount of chairside time, with the maximum allowable increment thickness recommended by the manufacturer. Few practitioners will use instruments to judge the thickness of each increment before light-curing, and once the pulpal floor of a preparation is covered with composite, it becomes difficult to evaluate the thickness of each increment. However, it is not known if the operator experience plays a factor in determining the ability to place increments of RBC that are within thickness specified by the manufacturer.

The longevity of the restoration appears to be influenced more by the operator's experience than by the choice of material.[11,14] As novice dental students become more familiar with judging the dimensions within which they work, it seems reasonable to expect that their ability to predictably place a specified thickness of RBC would increase. In addition, one would anticipate that experienced faculty would be able to judge and place increments of RBC that are within the desired limits. The clinical relevance and importance of these target values relate to the fact that if the increment thicknesses are less than those suggested by the manufacturer, more chairside time will be spent placing the restoration.[15] If thicker increments are placed, less chairside time is needed, but the polymerization of the RBC will likely be compromised, leaving the integrity of the total restoration in question.[16-19] Because less than optimal polymerization and suboptimal properties are likely to result when the RBC is placed in increments that exceed the manufacturer's instructions, it is important to evaluate the ability of clinicians to place increments within a controlled range of values.

The purpose of this study was to measure and compare the ability of dental students (having varying degrees of experience) and more experienced faculty clinicians, when placing three sequential, 2.0-mm-thick increments of RBC. In addition, the proportion of participants who successfully placed increments that fell within, lower than, or above a clinically realistic and acceptable range of 1.75-2.25 mm was determined.

The following research hypotheses were considered. With respect to the thickness of each increment of RBC:

1. The percentage of operators meeting the increment target range would not significantly improve with experience at any increment level.
2. The likelihood of placing an increment of RBC that was either thicker or thinner than the target range (1.75-2.25 mm) would not be significantly different among experience levels.

METHODS AND MATERIALS

Fifteen students from each of the four years of training at the Dental College of Georgia at Augusta University volunteered for the study: freshmen (D1), sophomores (D2), juniors (D3), and seniors (D4), as well as 15 experienced clinical faculty from the Department of Restorative Sciences. The volunteers were solicited via e-mail and represented a diverse group having no targeted ability equivalence. Before starting, the participants were asked to read and sign an informed consent. The list of participants was kept only for record-keeping purposes.

A 3D printed, toothlike molar model, adapted from freeware (https://www.thingiverse.com/thing:1485531), was modified to meet the requirements of the specific project (OpenSCAD version 2017.01.20, https://www.openscad.org/about.html). A filament-based 3D printer (Model 30M, Hyrel 3D, Norcross, GA, USA) was used to fabricate individual models made from 1.75-mm black PLA filament (PN: 88855, 3D Universe, Algonquin, IL, USA). This model tooth was of similar dimensions as a human molar tooth and included an attached base portion. The final product simulated an occlusal Class I preparation that was 5 mm in diameter and 8 mm deep from the cusp tips (see Figure 1). The base section of the model contained two vertical slots that engaged another 3D printed part such that the filled tooth model could be safely held vertically while pressed against the face of a dental laboratory model trimmer to remove half of the tooth model (sectioned longitudinally mesiodistally).

Working under ideal conditions with unobstructed access to the model on a laboratory bench, the participants were asked to fill the simulated tooth preparation. They were instructed to place three, 2-mm-thick increments of RBC using their usual technique and to light-cure each increment. Participants were not told the dimensions of the simulated preparation, nor were they given any instrument to measure the dimensions of the preparation. The only items provided to each participant were a gold-tipped composite instrument (TINPF3, Brasseler USA Dental, Savannah, GA, USA), a light-curing unit, and blue blocker glasses. The room was well lit by overhead fluorescent lighting. The use of dental loupes was encouraged, as well as headlamps, if they were part of the participant's customary loupe/light apparatus.

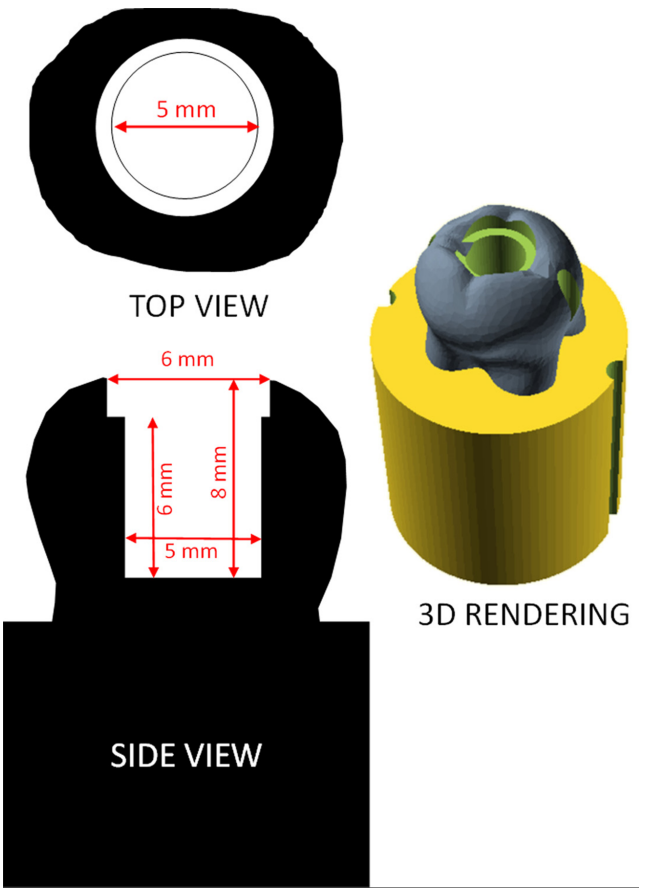

Figure 1. *2D and 3D rendering of the printed mold used to provide the standardized tooth/preparation for restoration.*

All participants used the same commercial light-cured RBC (Premise, Kerr Corporation, Orange, CA, USA). This material was available in a compule delivery form in a light (B1) shade (item #32655, Lot #5881365) that was used for the bottom and top increments. A dark (C4) shade (item #32662, lot #5943632) was used for the middle increment. The use of different shades allowed the boundaries between each increment to be identified.

After completing the restoration, the molds were coded and sectioned occluso-gingivally using a model trimmer (Whip Mix Corporation, Louisville, KY, USA) to expose the cross-section of the filled preparation. The cut surface was then lightly finished using a fine-grit SiC wet paper abrasive strip (#320, Leco Corporation, St. Joseph, MI, USA). Digital images of the sectioned specimens were taken using a calibrated binocular microscope (SM2-B microscope, 10x digital camera [MU-1000] AmScope, Irvine, CA, USA).

Microscopic Image Analysis

Using a standard method, the thickness of each increment was measured along a vertical axis at the center of the restoration. Before capturing a digital image of the sectioned tooth, the X-Y focal plane was calibrated using a precision microscope stage calibration slide that included a 1-mm-long scale in increments of 0.01 mm (MR095, AmScope). Image recording and dimensional analyses were made using the same software program (AmScope V 3.7.3980, AmScope). Figure 2 shows how each increment layer could be clearly identified by the stark contrast in the shades of RBC that had been used.

Statistical Analyses

Statistical interpretation of the data consisted of two separate analyses. The first analysis addressed only the measurement of increment thickness (dependent variable) as affected by operator experience (between-subjects factor, five levels) and the different incremental layers placed (within-subjects factor, three levels). The

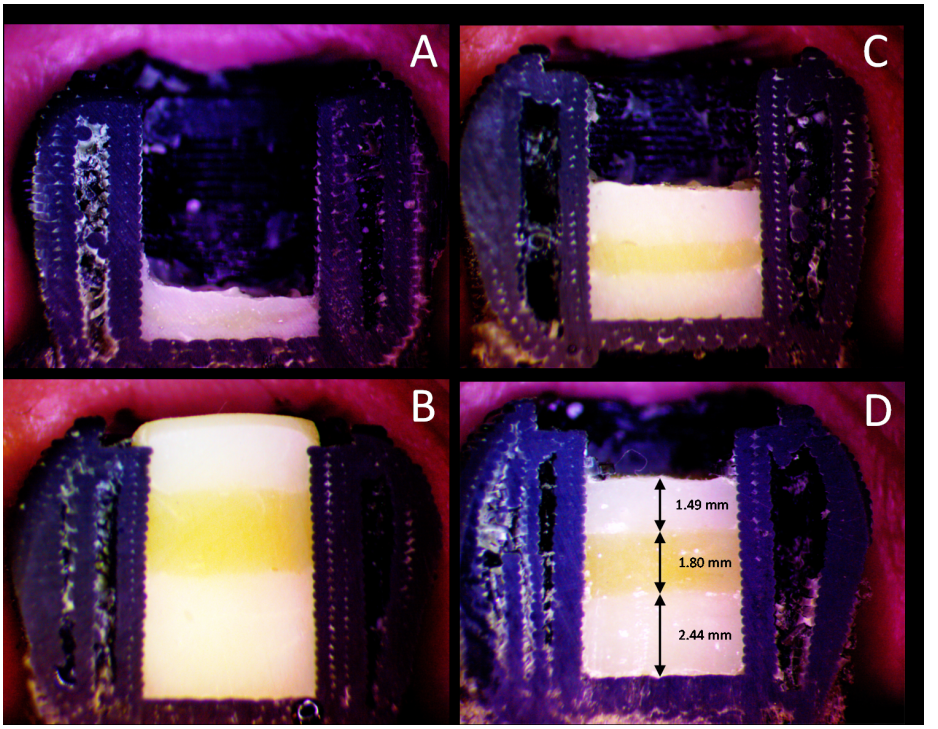

Figure 2. *Representative images of the variety of incremental thickness patterns observed. (A) All increments grossly underestimated, (B) first increment too thick, (C) all increments too thin, (D) illustration of how the increment layer thickness was measured.*

Shapiro-Wilk test was used to assess the normality of the repeated measures data. A repeated-measures analysis of variance with one between factor ("Experience") and one within factor ("Increment") was performed. The Tukey-Kramer test was used to perform pairwise comparisons among the levels of the Increment factor and levels of the Experience factor. Where the data was not normally distributed, appropriate rank-based methods were used. All statistical tests were two-tailed, using a pre-set alpha of 0.05.

The second analysis was designed to examine the influence of operator experience on the ability to provide an increment thickness (dependent variable) relative to a target range of 1.75 to 2.25 mm, categorized at three levels (less, meets, or exceeds) for each of the increments (first, second, and third). The multinomial test was used to compare the five experience levels in terms of the frequency falling within each "filling" category (i.e., less, meets, or exceeds) separately for each increment. Within each increment, a Bonferroni adjustment was made to control the family-wise error rate at 0.05 for all 30 comparisons among the experience levels ([10 pairwise comparisons among five experience levels] x [three ability categories]). Thus, an adjusted significance level of 0.05/30 = 0.0017 was used for all tests performed within each increment. All multinomial tests were two-tailed. Statistical analyses were performed using commercially available software (SAS 9.4, 2012, SAS Institute Inc, Cary, NC, USA).

No previously published or pilot data could be used to reliably estimate an appropriate sample size required for this study. Assuming a coefficient of variation of 55% or less, a sample size of 15 participants in each experience level group would yield an 80% power to detect the anticipated differences in mean increment thickness among the five groups using a two-sided significance level of 0.05. Similarly, with 15 participants in the experience level group, this would yield 93% power for detecting the anticipated differences among the groups illustrated using the multinomial test with alpha = 0.05 (nQuery 8.4.1, 2019, Statistical Solutions Ltd, Cork, Ireland).

RESULTS

Comparison of Mean, Raw Incremental Layer Thickness Values

Figure 2 illustrates an example of the variety of increment thicknesses that was observed, as well as a representative image showing how the thickness of each increment of RBC was measured.

The Shapiro-Wilk test indicated that the assumption of normality was reasonable for the repeated measures

data. Thus, a standard repeated measures analysis was used to examine the effects of Experience and Increment factors, as well as their interaction. The interaction term (Experience x Increment) was significant (p=0.020) as were the Experience (p=0.025) and Increment factors (p=0.001).

Due to the presence of significant interaction effects between the Experience and Increment effects, separate Tukey-Kramer post hoc, pairwise mean comparisons were carried out on the Experience and Increment main effects, as well as on the Experience x Increment interaction. The mean increment thickness placed by the least experienced operators (freshmen) was just barely significantly thinner than those of both the seniors (p=0.043) and the faculty (p=0.046); these were the only significant differences among the levels of the Experience factor (Figure 3). Ignoring the effect of operator experience, the increment thickness tended to decrease with each layer; in particular, the third (top-most and last) increment was significantly thinner ($\bar{x}$ =1.63 mm) than that of the first and deepest increment (p=0.001) and the second (p=0.021) increment (Figure 4).

Figure 5 displays the overall test results reflecting the parameters. In this figure, the solid, horizontal green line represents the 2-mm increment thickness goal. The only experience level demonstrating significant differences in thickness among the increments were the seniors (bottom>top; p=0.018). Within the first increment, the only significant difference was seniors > freshmen (p=0.005). Within both the middle (second) and the top (third) incremental layers, there were no significant differences noted among experience levels (p=0.562 and p=0.136, respectively).

Comparison of Ability to Provide Increment Thicknesses Between 1.75 and 2.25 mm

The study sought to compare operator experience level groups (freshman, sophomore, etc) in terms of the percentage of participants who either placed an increment within the clinically relevant target range (1.75-2.25 mm) or under- or overfilled that increment. The horizontal light green shaded rectangle in Figure 5 represents the upper (2.25 mm) and lower (1.75 mm) boundaries that were considered as clinically acceptable tolerance values for the requested 2-mm incremental thickness for this portion of the study analysis.

Anticipated Results

Figure 6 is a representation of the expected findings had the second research hypothesis proven true. This expected trend was anticipated to hold true for all increments placed by each level of operator experience. Estimated values from this figure were used to help support the sample size to deliver adequate power to the statistical analysis. With increasing operator experience, it was anticipated that the percentages of observed over- and under-range values would decrease,

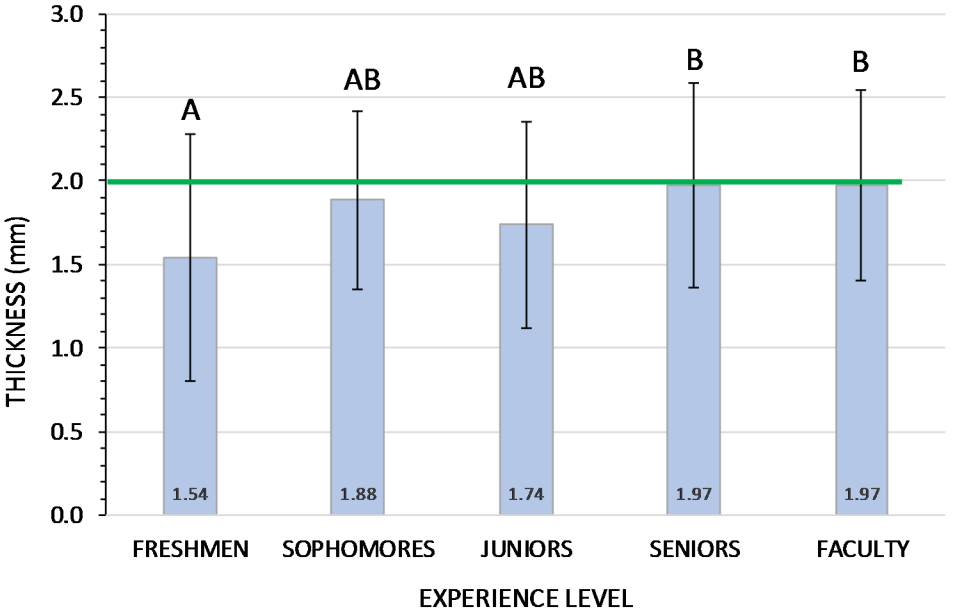

Figure 3. *Mean increment thickness among experience levels (disregarding the influence of increment). N = 45 values per group. Vertical bar = ±1 standard deviation. Thickness layers of groups identified by similar uppercase letters are not significantly different. Horizontal green line represents the 2-mm target thickness.*

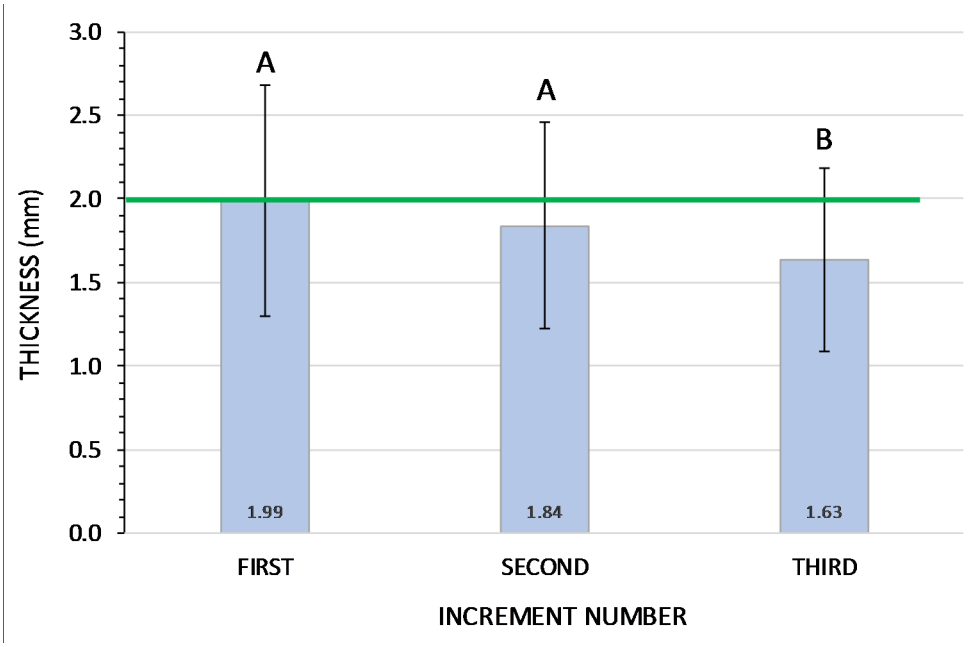

Figure 4. *Mean increment thickness among increment placement sequences (disregarding the influence of experience). N = 75 values per group. Vertical bar = ±1 standard deviation. Thickness layers of groups identified by similar uppercase letters are not significantly different. Horizontal green line represents the 2-mm target value.*

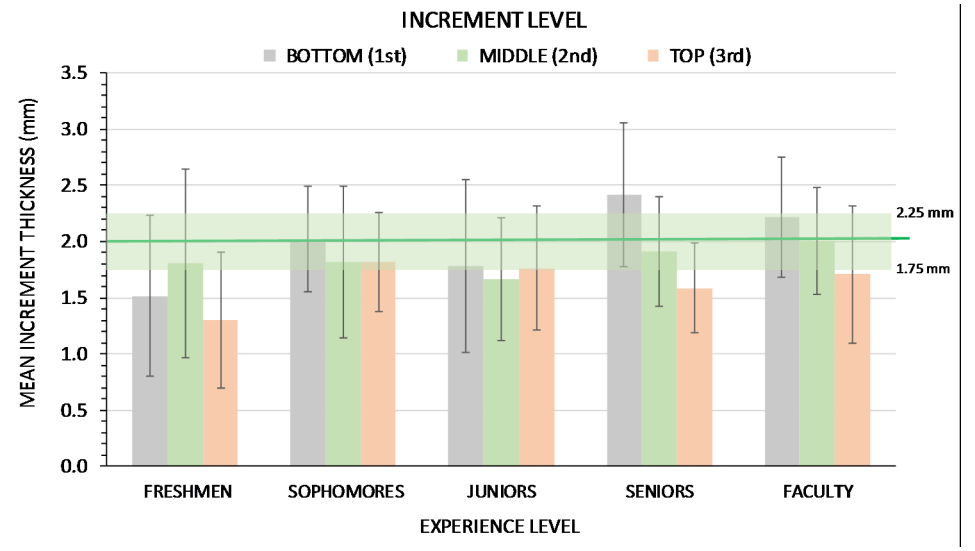

Figure 5. *Mean increment thickness with respect to increment sequence number and operator experience level. N = 15 values for each increment. Vertical bar = ±1 standard deviation.*

while the percentage of participants demonstrating increment thickness values within the clinically acceptable range (1.75-2.25 mm) would increase.

The percentage of study participants whose incremental thicknesses were within the three different filling categories as a function of operator experience for the first increment layer is shown in Figure 7. There were no statistically significant differences among the operator experience levels within any of the three filling categories. Figure 8 depicts the differences in the ability to reach the target range among the operator experience levels for only the second increment. Again, there were no statistically significant differences among the operator experience levels within any of the three filling categories (less, meets, or exceeds). Figure 9 displays the operator's ability to place the last (top) composite increment within the target range by level of experience. As seen previously, there were no statistically significant

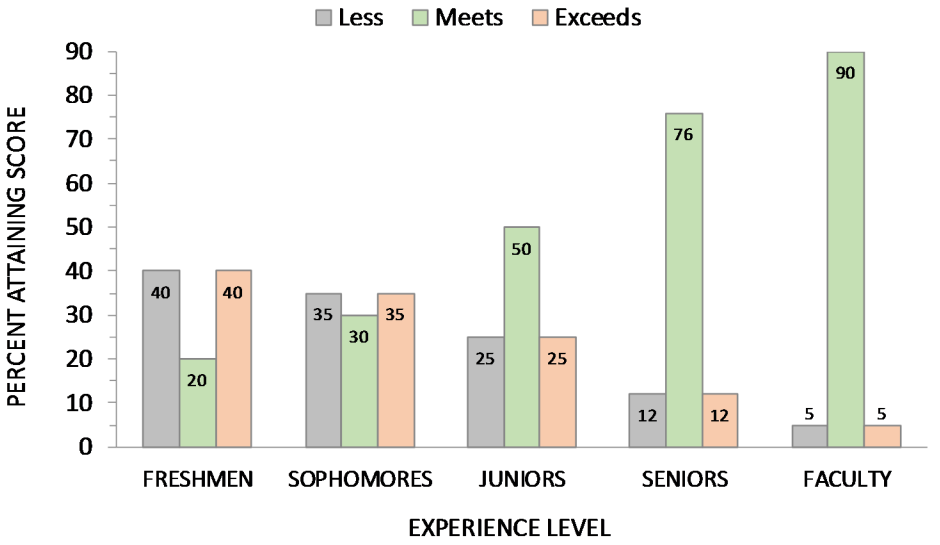

Figure 6. *Graph of anticipated trends of over- and underestimating and values falling within the clinically acceptable increment thickness range, as a function of experience level, regardless of increment sequence, had the research hypothesis proven true.*

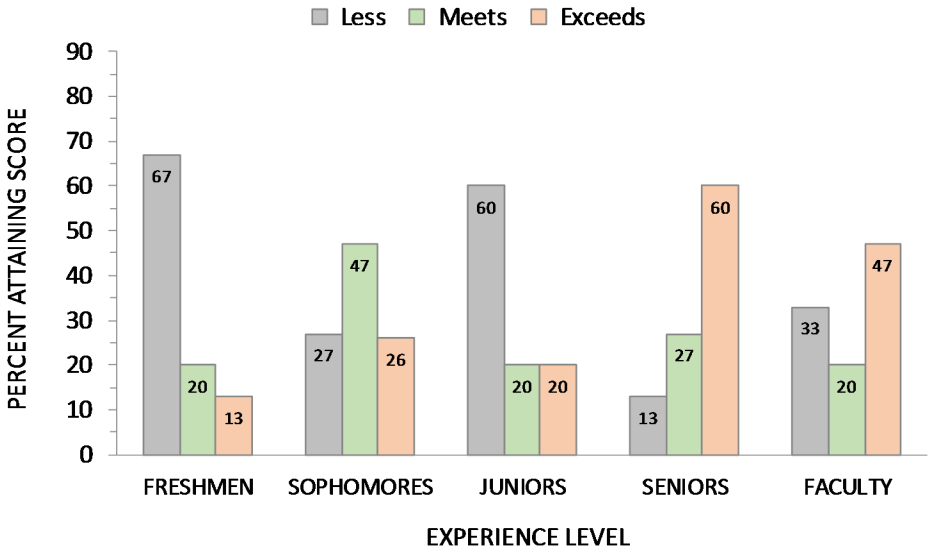

Figure 7. *Percentage of each operator experience group able to meet the target increment range value for the first (bottom) increment.*

differences among the operator experience levels within any of the three filling categories. However, visually, there appears to be a trend for all experience levels to place increments of RBC that were less than the target range thickness (range from 80% of the least experienced (freshmen) to a low of the sophomore dental students at 40%). Interestingly, in both the senior students and faculty (groups considered as having the most experience), 60% of the participants placed increments of RBC that were less than 1.75 mm thick. Only 20% of the faculty provided increment thickness falling within the 1.75 to 2.25 mm range, whereas the sophomore and junior students produced acceptable increment thicknesses at twice that rate: 40%. However, none of the differences among the experience level groups were statistically significant.

Because there were no significant differences among the operator experience levels in terms of their ability to place increments of RBC within the desired target range, the operator experience categories were collapsed

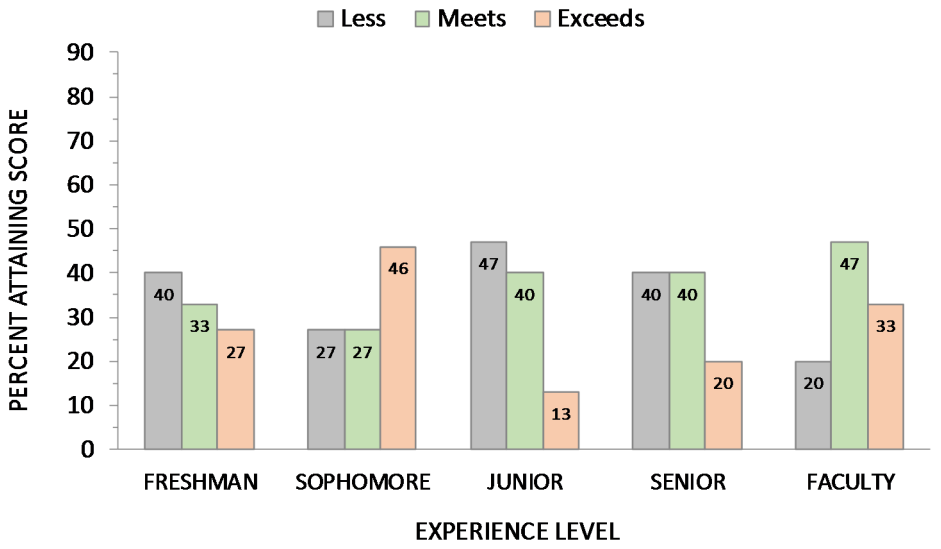

Figure 8. *Percentage of each operator experience group able to meet the target increment range value for the second (middle) increment.*

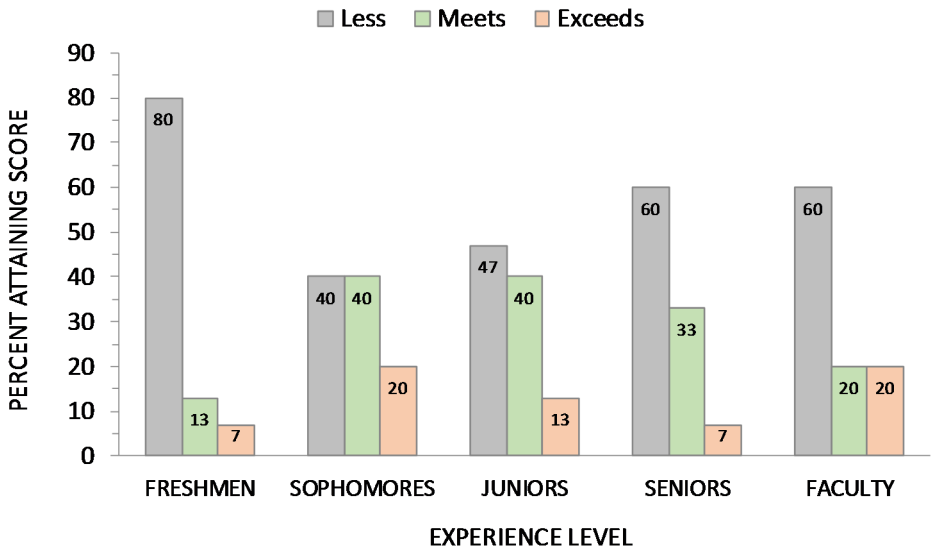

Figure 9. *Percentage of each operator experience group able to meet the target increment range value for the last (top) increment.*

into one. The data were then evaluated in terms of percentage of all participants placing incremental thicknesses that fell outside of, or within, the desired range. Figure 10 summarizes these data. When this step was performed, the results were almost equally distributed among the three increment categories for the first and second increments.

Removing the effect of discriminating between increments that were less than 1.75 mm or greater than 2.25 mm thick, and only categorizing the ability of operators to reach the desired composite thickness for each increment or not, provides additional insight into the results. In general, the data indicate that, regardless of the increment, only about one-third of the increments placed fell within the desired range. The percentage of operators providing increment thicknesses falling outside the desired range was significantly greater than the percentage falling within the desired range for both the first and third increments ($p<0.001$ for both comparisons).

When the data for the increments were pooled, the percentage of participants who either met the

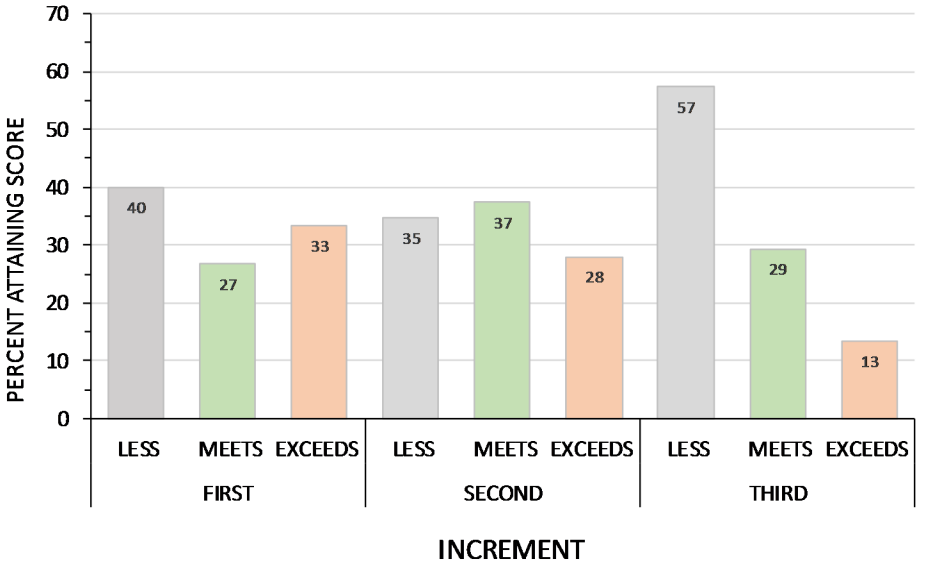

Figure 10. *Percentage of operators providing increment thicknesses that were either less than, met, or exceeded the target thickness between 1.75 and 2.25 mm after collapsing the experience level categories. N = 75 participants for each increment layer.*

incremental thickness range or did not showed that only about 33% of the time was a composite increment placed that ranged between 1.75 and 2.25 mm; furthermore, the percentage of outcomes not meeting the desired thickness was significantly different from the percentage that did ($p<0.001$). Interestingly, if only the most experienced group (clinical faculty) was analyzed, among all increments, 33% overfilled, 39% underfilled, and only 29% provided increments falling within the desired range. These data, for the highest level of operator knowledge and experience, indicate that 72% did not place increments of RBC to an acceptable thickness, and only 29% were—numbers very much like the overall trend observed when all study participants were pooled together.

DISCUSSION

The first research hypothesis was partially validated. There were no statistically significant differences among the operator experience levels within any of the three filling categories. However, as seen in Figure 5, in general, there was an increasing trend for groups with higher experience levels to place the RBC in mean increment thickness values that were close to 2 mm. Notwithstanding, at all exposure levels and for all increments, there was a large degree of variability in the results. The smallest increment thickness (0.3 mm) was placed as the middle increment by a freshman, and the thickest increment value (3.5 mm) was observed at the bottom increment placed by a junior student. In general, freshmen tended to underfill each increment. Perhaps this trend reflects the inability of novice American practitioners to judge small differences in metric-unit values. An improved ability to deliver appropriate thickness values was seen in the sophomore and junior students. This increase might be because these students had become more familiar using the metric system to such small values, as well as their enhanced ability to discriminate small visual differences, perhaps arising from their greater experience of placing restorations in dentoforms (sophomores), as well as in clinical patients (juniors). The first increment thickness placed by senior students was commonly the thickest (Figure 5). This increased thickness might result from senior students trying to refine skills and save clinical time during the restoration process. However, this small amount of time saved will likely result in a much less polymerized foundation for the overlying layers of composite yet to be placed. The group showing the least variability in placing a 2-mm increment of RBC was the dental faculty. This result was expected because of their degree of clinical experience, as well as their clinical understanding of the importance of following the manufacturer's instructions and the consequences of not doing so.

The second research hypothesis was rejected, as seen in Figure 4. Even though the thickness of the first RBC layer might have been the most difficult to judge visually, because it was deepest and furthest away from visual examination, its mean thickness value matched the desired 2-mm target value. However, there was a considerable amount of variation in the data. Overall, the thickness of the last (third) increment was

significantly lower than that of the first. This finding might have resulted from participants realizing, with previous increments of unknown thicknesses, a fear of overfilling the restoration, even though no upper limit was ever defined.

With the exception of the sophomores, participants restoring the first increment within the anticipated, acceptable range varied from only 20% to 27%, and there were no statistically significant differences among the experience levels of the participants. The correct thickness of the first increment might be the most important because the RBC at this location is furthest away from the light tip and is more likely to be in a shadow. Proper polymerization of this specific increment is required to provide adequate strength to support all the subsequent overlying increments and to bond to the tooth. If this initial increment is not optimally polymerized, the potential for leaching uncured resin toward the pulpal floor is increased, and the bond strength and flexural strength are lowered. Monomer leaching resulting from undercuring within the deepest restoration layers has significant biological implications.[20] Decreased increment flexural strength provides less reliable support for overlying cured composite increments, perhaps allowing them to flex under occlusal load and potentially lead to interfacial debonding over time. This situation might cause postinsertion pain and may result in premature restoration failure. At the top-most increment (Figure 9), the most experienced participants (seniors and faculty) tended to produce a lower percentage of increments that fell within the acceptable range. Still, those values were not significantly different from any other experience group.

In general, it appears that, regardless of experience level, an operator is just as likely to place a composite increment of the desired thickness range (1.75-2.25 mm) than he or she is to over- or underfill that increment (Figure 10). For the first increment of RBC, there was a preponderance of freshmen and juniors who provided less than desirable thickness values, whereas the seniors and faculty produced most of the excess thickness values (Figure 8). For the second increment, the freshmen, juniors, and seniors had the highest percentages of participants generating less than the target range thickness. At the same time, the sophomores and faculty produced the highest amounts of overfilling (Figure 9). At the third increment (Figure 9), all operators tended to show higher levels of underfilling, with 80% of the freshmen falling within this category. Interestingly, as experience levels increased past that of the freshmen, there was a tendency for the top increment to be less than the target range, with senior and faculty participants producing the same high proportions of underfilling: 60% (Figure 9). However, the third increment showed a definite difference in these trends. There was a much greater incidence of operators placing increments that were less than the desired thickness compared with more than the desired thickness (57% vs 13%; $p<0.001$). In addition, there were significantly more operators placing increments that were less than the desired thickness range than those who met the desired thickness range (57% vs 29%; $p=0.009$). The accumulation of the thicknesses of the first two increments appeared to influence the operator to err on the side of underfilling than on overfilling. The last increment also demonstrated the lowest frequency of participants placing an excessively thick RBC layer: 13%.

The clinical implications of the study imply that, regardless of experience level, an operator has only about one chance in three of placing a composite increment within the manufacturer's recommended thickness of 1.75 to 2.25 mm. These findings have profound clinical significance, in that the long-term durability and biocompatibility of a photo-activated resin composite rests on the adequate extent of monomer conversion of each increment placed. For the deepest increments, which are furthest from the light source and provide the foundation for strength for all subsequent increments placed, the variation of increment thickness may have the greatest implications and might demand the closest scrutiny to operator attention. In light of these findings, it may be advisable to place a first increment that is thinner than that recommended by the manufacturer.

This study was subject to several limitations. First, the work was conducted under ideal conditions, where there was full access to the tooth to be restored and a relatively small number of participants in each experience level group (n=15 per group and a total of 75 participants). The 15 participants in the faculty group ranged in experience from less than five to more than 30 years. However, due to the small sample size of dentists (n=15), their ability to provide increments of desired thicknesses was not evaluated with respect to their years of experience. Another limitation was that only a horizontal layering technique was used to fill the cavity. Different results may be achieved using other methods such as nonhorizontal, diagonal types of placement.

Future studies should include placing restorations in a more challenging location, such as a mannequin head attached to a dental chair. Bulk-fill RBCs could be used to evaluate how well participants can estimate the 4- to 5-mm thickness recommended for that class of products. A 3D-printed Class II preparation could also be fabricated to further evaluate increment thickness

accuracy in a larger, more complex preparation. Lastly, future studies could examine the efficacy of using a depth-gauging instrument during composite placement. Such a gauge could be incorporated in the composite delivery system or as a separate instrument.

CONCLUSIONS

Within the limitations imposed, the following conclusions may be reached:

1. There were no statistically significant differences among the operator experience levels within any of the three filling categories. However, in general, there was an increasing trend for groups with higher experience level to provide mean RBC incremental thickness values close to 2 mm thick.
2. In general, regardless of experience level, an operator is just as likely to place an increment of RBC that is within the desired thickness range (1.75-2.25 mm) than he or she is to over- or underfill that increment.
3. In general, regardless of the increment number, only about one-third of the increments placed fell within the desired range of 1.75 to 2.25 mm.

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Regulatory Statement

The project was determined to be a minimal risk project by the Augusta University Internal Review Board (IRB) and was assigned protocol 910480.

Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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