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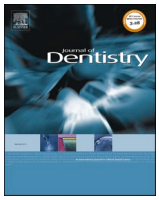

Procedure time and filling quality for bulk-fill base and conventional incremental composite techniques—A randomised controlled in vitro trial

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ABSTRACT

Objectives: The aims of this randomised controlled laboratory trial were to determine the procedure time and immediate quality (surface porosity and marginal gaps) of fillings placed using the bulk-fill base technique and the conventional incremental technique in simulated clinical settings.

Methods: Forty-two dentists and dental students were randomly allocated to use either the bulk-fill base technique or the conventional incremental technique to fill an identical class II disto-occlusal cavity in a maxillary left first molar typodont tooth. We recorded the time the participants used to fill the cavity and evaluated the surface porosity and marginal gaps on the approximal surfaces of the fillings using a stereomicroscope and specific probes according to the FDI criteria for restoration evaluation. Data were analysed using the Mann–Whitney *U*, Kruskal–Wallis, and chi-square tests.

Results: The median time ± interquartile range was 186 ± 80 s for the bulk-fill base technique and 463 ± 156 s for the conventional incremental technique ($p < 0.001$). The quality of the fillings was better for the bulk-fill base technique than for the conventional incremental technique ($X^2 = 9.5$, $p = 0.002$). Neither operator experience nor the usual technique of choice were associated with the procedure time or the quality of the fillings.

Conclusions: Compared to the conventional incremental technique, the use of the bulk-fill base technique shortened the time to fill a cavity by 59.8 % or 4 min and 36 s, and it improved the immediate surface and marginal quality of the fillings, regardless of the operator's experience or technique preference.

Clinical significance: The use of the bulk-fill base technique instead of the conventional incremental technique leads to significant time-savings when placing large class II composite fillings. Additionally, the use of the bulk-fill base technique instead of the conventional incremental technique improves the immediate quality of large class II composite fillings.

1. Introduction

Dentists spend 58 % of their working hours placing fillings [1]. Resin-based composite (hereinafter referred to as 'composite') is the most common material for fillings [2,3]. Although fillings have good longevity in randomized controlled trials, there is a substantial variation in the longevity of fillings among individual general practitioners [4–6]. Consequently, 57 % of fillings are replacement fillings [3].

Bulk-fill composites were introduced at the beginning of the millennium to shorten the time to fill cavities and to lessen the technique sensitivity of the conventional incremental cavity filling technique [7]. Bulk-fill composites can be classified into low-viscosity or bulk-fill base composites, and high-viscosity or full-body bulk-fill composites. Most low-viscosity bulk-fill composites exhibit low wear resistance; consequently, their instructions for use typically recommend a capping layer of a more wear-resistant high-viscosity composite on occlusal surfaces [7,8]. In clinical trials, the success rates for fillings with or without bulk-fill composites are similar [9–12]. In laboratory studies, bulk-fill composites exhibit similar or better chemical-physical properties, including polymerization stress, cuspal deflection, marginal gap, degree of conversion, flexural strength, and fracture strength [13].

The bulk-fill base technique shortens the operation time by 18 % to

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49 % [14–17]. However, the protocols in these laboratory studies could have better replicated real-life settings with larger cavities and multiple general practitioners as operators. Thus, the primary aim of this study was to further clarify the difference in procedure time between the bulk-fill base technique and the conventional incremental technique in conditions that closely mimic clinical settings in general practice. The secondary aim of the study was to compare the immediate quality (surface porosity and marginal gaps) of the approximal surfaces of the fillings placed using the bulk-fill base and the conventional incremental techniques.

2. Methods

The protocol for this study was approved by the Norwegian Centre for Research Data (reference number 399613). The protocol was reviewed by the Regional Committees for Medical and Health Research Ethics which concluded that the study did not qualify as health research and therefore did not require their approval (reference number 158600). A pilot study with seven participants was conducted to test the experimental procedure. Dentists working in Troms County (Norway) and 4th and 5th year dental students were invited to participate in the study. The eligibility criteria included an age between 20 and 60 years and sufficient proficiency in the Norwegian language to understand the written materials of the study. Twenty-four dental students and 18 graduated dentists volunteered to participate in the main study. Each participant received oral and written information about the study, after which they provided written consent to participate in the study. Subsequently, the participants completed a short questionnaire (Table 1). Identity numbers placed on the questionnaire forms and test tubes containing the teeth enabled blinded analysis of fillings and prevented data mismatching.

The experiment was conducted in a laboratory dental office. In the experiment, maxillary left first molar typodont teeth with identical class II disto-occlusal cavities were used (DRSK Group AB, Hässleholm, Sweden). The cavities had a buccal-palatinal width of 5 mm approximately and 4 mm centrally, an occlusal-gingival depth of 6 mm, and a distal-mesial length of 4 mm. The inner angles of the cavities were slightly rounded. The typodont teeth were pre-set to a study model jaw (KaVo, Biberach, Germany) with pre-contoured metal matrices (Orbis, Plandent, Helsinki, Finland) and wooden wedges. Dental adhesive Scotchbond™ Universal Plus adhesive (3M, Neuss, Germany) was applied in the cavity according to instructions provided by the manufacturer. The study model jaw was placed within the dental manikin that was fitted to a dentist chair. Throughout the experiment, the first author prepared the laboratory and provided the oral instructions for the experiment to the participants.

Participants were randomly allocated to use either the bulk-fill base technique or the conventional incremental technique. Participants in the conventional incremental group were instructed to fill the cavity with six oblique increments (up to 2 mm in height) of conventional composite (Ceram.x Spectra ST Universal Composite Restorative, cloud shade A1, Dentsply Sirona, Konstanz, Germany) and light-cure each increment for 10 s. Participants in the bulk-fill base group were instructed to fill the cavity with one increment (up to 4 mm in height) of bulk fill composite (SDR® flow+ Bulk Fill Flowable, universal shade, Dentsply Sirona Konstanz, Germany) and light-cure it for 20 s followed by a capping layer of one horizontal increment of conventional resin-based composite (Ceram.x Spectra ST Universal Composite Restorative, cloud shade A1). All the materials were cured using an LED light-curing unit (Bluephase Style, Ivoclar Vivadent) with a light intensity of 1100 mW/cm^2. The participants were instructed to only fill the cavity, and neither finishing nor polishing was allowed. Before the actual trial, all participants placed a practise filling to familiarize themselves with the study environment.

The time to fill the cavity was recorded in seconds with a handheld stopwatch. We used a modified FDI criteria to evaluate the immediate quality (marginal adaptation and surface porosity) of the approximal surfaces of the fillings. An area 4 mm in apical-occlusal height from the gingival cavity margin was included in the quality evaluations. The final capping layers of the fillings were of the same composite, and therefore the gaps and pores in the occlusal layers were not evaluated. Marginal and central areas were evaluated separately. The marginal area was a 1 mm area adjacent to the cavity margin and evaluated for marginal adaptation. The rest of approximal surface of the filling was deemed "central" and evaluated for surface porosity.

We evaluated the FDI criteria marginal adaptation scores 1–2 as good because of difficulties in distinguishing the scores 1–2 from one another. In practice, marginal adaptation was evaluated good if the marginal gaps were under 0.15 mm in diameter or depth. Marginal areas with gaps between 0.15 mm and 0.25 mm in diameter and depth were evaluated sufficient/satisfactory. Fillings with marginal gaps over 0.25 mm in diameter and depth were classified as non-acceptable. The sizes of the marginal gaps were determined using a stereomicroscope and specific probes (Deppeler, Switzerland) with tip diameters of 0.15 mm and 0.25 mm. We made dents at 0.15 mm and 0.25 mm on the tips of the probes to also enable the depth measurement of the gaps. The use of the specific probes was recommended in the FDI criteria [18].

We evaluated the central area of the filling for surface porosity using the same probes as for the marginal adaptation. Surface porosity for fillings with pores under 0.15 mm in diameter or depth were evaluated good. Fillings with pores between 0.15 mm and 0.25 mm in diameter and depth were evaluated sufficient/satisfactory. Fillings with pores over 0.25 mm in diameter and depth were classified non-acceptable.

The evaluations were performed by the first and the second authors, both of whom are specialist dentists in cariology. The evaluators familiarized themselves with the use of the evaluation protocol in a training session. Both evaluators were blinded with regards to whether the fillings were made using the conventional incremental technique or the bulk-fill base technique and they performed the measurements independently but in the same order. In cases of disagreement, consensus was reached after discussion.

The Shapiro–Wilk test revealed that the data on procedure time were not normally distributed, thus the Mann–Whitney *U* test was used to compare the procedure time between the filling technique groups. Levene's test revealed that the variances for experience and procedure time were not equal, and therefore the Kruskal–Wallis test was used to compare the procedure time between experienced and inexperienced operators within the filling technique groups. The chi-square test of independence was performed to examine the differences in surface porosity and marginal gaps for the filling technique groups and different levels of clinical experience. The chi-square test was also used to compare the usual filling technique of choice and experience of the operator, and whether the usual filling technique of choice was associated with the quality of the filling. All analyses were performed with SPSS version 28 (IBM SPSS Statistics). The significance level was set at p

Table 1
Variables and response alternatives on the questionnaire.

Variables	Response alternatives
Gender	Female Male Non-binary Does not wish to disclose
Age in years	20–25, 26–30, 31–35, 36–40, 41–45, 46–50, 51–55, 56–60, 61–65
For graduated dentists: Working experience in years	0–5, 6–10, 11–15, 16–20, 21–25, 26–30, > 30
For students: Year of study	4th or 5th
Own estimation for the duration of the filling procedure	Reported in minutes and seconds
Usual technique of choice to fill a disto-occlusal cavity in maxillary first left molar	Conventional incremental technique with oblique layers, bulk-fill base technique, other (description)
For students: Number of fillings placed	Free-text number

< 0.05.

3. Results

Among the participants, there were 18 dentists (83.3 % female) and 24 dental students (75.0 % female). Prior to the study, the student participants had placed an average of 126.6 fillings (SD = 63.7, range = 30–275). The median procedure time ± interquartile range was 186 ± 80 s using the bulk-fill base technique and 463 ± 156 s using the conventional incremental technique ($U = 0.00$, $p < 0.001$, Fig. 1).

For the bulk-fill base technique, the median procedure time ± interquartile range was 201 ± 88 s for the dentists and 184 ± 79 s for the dental students ($p > 0.05$). Conversely, for the conventional incremental technique, the median procedure time ± interquartile range was 402 ± 160 s for the dentists and 480 ± 169 s for the dental students ($p > 0.05$). The usual filling technique of choice was not associated with the procedure time ($p > 0.05$, Fig. 2).

Before the experiment, the participants estimated that it would take them 240.0 ± 240.0 s (median ± interquartile range) to fill the cavity using the bulk-fill base technique and 480.0 ± 480.0 s (median ± interquartile range) using the conventional incremental technique. The mean number of layers was 2.2 (SD = 0.9) for the bulk-fill base technique and 6.1 (SD = 0.5) for the conventional incremental technique. All participants, except one participant in the conventional incremental group, followed the instructions for light-curing the composite increments. Participants' adherence to the provided light-curing instructions were recorded in order to determine to what degree participants would deviate from the prescribed guidelines, however the reason why one participant did not follow the light-cure instructions is unknown. The mean light-curing time was 30 s (SD = 0.0) for the bulk-fill base technique and 65.7 s (SD = 26.2, range = 60–180) for the conventional incremental technique.

The proportion of fillings evaluated as good in quality was 76.2 % for the bulk-fill base technique and 28.6 % for the conventional incremental technique ($X^2 = 9.5$, $p = 0.002$, df = 1, Fig. 3). Only two fillings were evaluated as non-acceptable, and both had been placed using the conventional incremental technique. In the bulk-fill base group, the proportion of fillings evaluated as good was 88.9 % for dentists and 66.7 % for dental students ($p > 0.05$). In the conventional incremental group, the proportion of fillings evaluated as good was 33.3 % for dentists and 25.0 % for dental students ($p > 0.05$).

All reported usual filling techniques wherein materials were applied in layers of no more than two millimetres were categorized as the conventional incremental technique. Two participants in the bulk-fill base group reported not having a usual filling technique. One participant in the bulk-fill base group did not answer the question about the usual filling technique, and this participant's data were not included in the subsequent analyses. The conventional incremental technique was reported as the usual technique to fill a class II cavity by 46.3 % of participants, whereas 48.8 % of the participants reported they usually use the bulk-fill base technique ($p > 0.05$). Among the dental students, the bulk-fill base technique was the usual choice for 56.5 %, and the conventional incremental technique for 39.1 % ($p > 0.05$). Conversely, among the dentists, the bulk-fill base technique was the usual choice for only 38.8 %, and the conventional incremental technique for 55.5 % ($p > 0.05$). The reported usual filling technique was not associated with the quality of the fillings ($p > 0.05$).

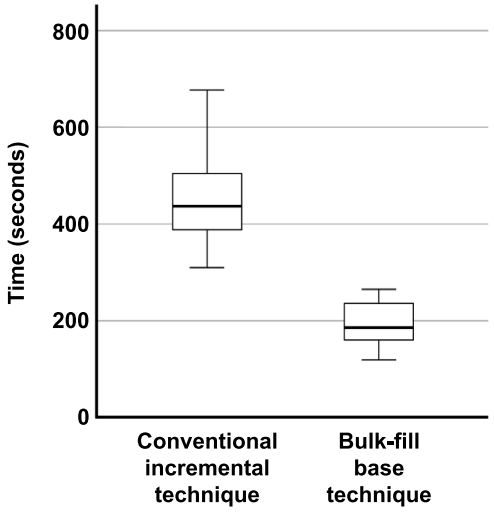

Fig. 1. Boxplot of procedure time to fill the cavity for bulk-fill base and conventional incremental techniques.

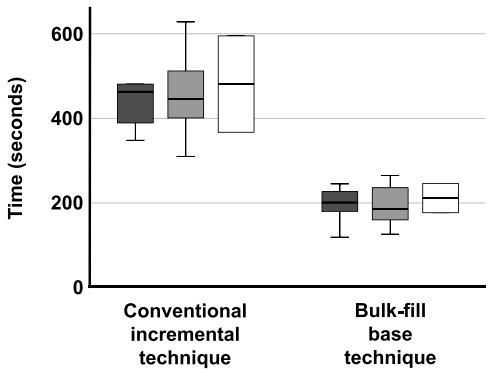

Fig. 2. Clustered boxplot of procedure time to fill the cavity using either conventional incremental or bulk-fill base technique stratified by the usual filling technique of choice.
Dark grey boxes: clinicians who prefer conventional incremental technique; Light grey boxes: clinicians who prefer bulk-fill base technique; white boxes: clinicians who prefer other filling techniques.

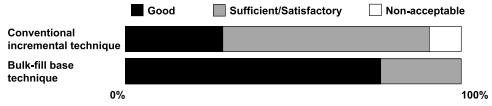

Fig. 3. The proportions of good, sufficient / satisfactory, and non-acceptable fillings for bulk-fill base and conventional incremental techniques.

4. Discussion

This study found that using the bulk-fill base technique shortened the time to fill a large class II cavity by 60 %, or 4 min and 36 s, compared to the conventional incremental technique. We mimicked the clinical setting to a greater extent than the previous laboratory studies. First, this study was performed on identical teeth with identical cavities that mimicked real-life large cavities that would result from operating on cavitated or symptomatic caries lesions instead of small or medium-sized cavities. Second, the teeth were mounted on a dental manikin attached to a dentist chair instead of on a tabletop. Lastly, the fillings were placed by 42 non-specialist operators instead of one or unknown number of operators. Therefore, we consider our results on time savings that come from using the bulk-fill base technique instead of the conventional incremental technique more reliable than the results from previous laboratory studies.

However, our results are in close accordance with a previous laboratory study that reported a 49 % shorter operation time for the bulk-fill base technique compared to the conventional incremental technique [15]. Another laboratory study reported an only 18 % shorter operation time for the bulk-fill base technique compared to the conventional incremental technique, but this study had shallow cavities, resulting in a similar number of increments for both techniques [16]. A recent

randomized controlled clinical trial reported a 57 % shorter time to fill a cavity using the full-body bulk-fill technique compared to the conventional incremental technique [19].

We could not determine how much of the time difference between the two techniques was related to the number of increments and application time. However, there appears to be a correlation between the number of increments and the procedure time. In our study, there were four fewer increments when the participants used the bulk-fill base technique, and the time difference was 60 %. In another study, there were two fewer increments when the participants used the bulk-fill base technique, and the time difference was 49 % [15]. In contrast, a third study had similar number of increments for bulk-fill base and conventional incremental techniques, and the time difference was only 18 % [16]. Hence, the shortening in the time to fill a cavity by using the bulk-fill base technique instead of the conventional incremental technique is highly but not solely dependent on the reduction in the number of composite increments. In our data shortening of the light-curing time accounted for half a minute, which is one ninth of the time saved by using the bulk-fill base technique instead of the conventional incremental technique.

From a patient's perspective, the bulk-fill base technique appears to be an obvious choice as it shortens the time the patient spends mouth wide open in the discomfort of the dentist chair. That is, most if not all patients would prefer to close their mouth after bonding and the three minutes the bulk-fill base technique takes, rather than laying with their mouth wide open for an additional four and a half minutes the conventional incremental technique would require. From the dentist's perspective, even minor time savings in common procedures, such as placing a filling, can lead to considerable chair time savings. We estimate the annual chair time saving of using the bulk-fill base technique instead of the conventional incremental technique to be around 50 h. The estimate is based on 3.6 class I or II restorations per dentist per day for 200 working days in a year [20]. In a typical case of a 30-minute appointment for a class II filling, the use of the bulk-fill base technique would save close to one sixth of the appointment. Additionally, working efficiently reduces a patient's anxiety and increases the well-being of the dentist [21–23]. With fewer procedural steps and less light-curing time needed, the utilization of the bulk-fill base technique can also contribute to environmentally sustainable dentistry [24].

It was previously thought that the conventional incremental technique with thin oblique layers of composite would decrease the cuspal deflection resulting from polymerization shrinkage [25]. However, later studies with improved study protocols have reported that the shape and height of the increments do not worsen marginal quality, cuspal deflection, nor the clinical success of fillings [10,15]. Perhaps because of these later studies, only a few composite manufacturers specifically recommend the use of oblique layers today. We have been unable to find published data on the proportions of dentist who use oblique and horizontal layers. However, we anticipated that our participants were more familiar with oblique layering than horizontal layering and, therefore, asked our participants to use oblique layers when using the conventional incremental technique. Moreover, the conventional incremental technique has a high degree of technique sensitivity [26,27]. In the current study, the bulk-fill base technique improved immediate quality of the fillings compared to the conventional incremental technique.

The threshold of marginal gap size predisposing to the development of secondary caries is elusive [28,29]. If no adhesive is being used, marginal gaps as small as 0.05 mm predispose to secondary caries *in situ* [30]. However, if adhesive is being used, secondary caries lesions are confined to the entrance of 0.04 mm marginal gaps [31]. Furthermore, in occlusal fissures of extracted third molars viable microorganisms and caries are predominantly observed at the entrance of the fissure, whereas in the deeper sections of the fissures, there are but a few viable microorganisms [32]. The FDI criteria considers marginal gaps above 0.25 mm in diameter and depth unsatisfactory based on the finding that only gaps of this extent may harbour large amounts of microbial accumulation [33,34]. When it comes to the surface porosity of a filling, a pore in the middle of an approximal filling does not predispose the tooth to secondary caries but the pore may accumulate cariogenic biofilm and thus cause caries to the adjacent teeth [35].

The low proportion of fillings evaluated as good in the conventional incremental technique group highlights the technique sensitivity of the conventional incremental technique. However, the low proportion of good fillings could result partly from the high threshold for "good" set in the criteria, and partly from us not allowing the participants to finish the filling. Furthermore, the experimental setup, especially the presence of the first author and the overt time measurement, may have been experienced as stressful by the participants, potentially influencing their performance.

To the best of our knowledge no previous data exist on the filling technique preferences of dentists or dental students. Our participants reported using the bulk-fill base and conventional incremental techniques equally often as their usual technique of choice when filling large class II cavity, although they estimated that the conventional incremental technique would take twice as long. The participants also overestimated the time it would take them to fill the cavity by 29 % for the bulk-fill base technique whereas their estimation on the procedure time for the conventional incremental technique was accurate. Surprisingly, for the participants who used a filling technique that was not their usual technique, the procedure time, and the quality of the fillings were similar to those placed using the usual technique of choice. Thus, switching from one technique to another does not appear to introduce undue risks regarding to procedure time or the immediate quality of the filling.

Our finding that the operator's experience was not associated with the procedure time, nor the quality of the fillings is in accordance with a previous study that reported similar quality in the margins of class II composite fillings for operators with varying levels of experience [26]. The student participants in our study had developed good level of routine, having placed an average of 127 fillings on patients in addition to the approximately 25 fillings they had placed during preclinical skills laboratory exercises. However, there are at least two studies that have surprisingly reported better abilities for the less experienced operators. Firstly, dental students performing dental bonding for the very first time achieved higher bond strengths than experienced dentists [36]. Secondly, there is a consistent inverse correlation between the dentist's age and restoration survival rate [37]. Our findings, together with those from the aforementioned studies, suggest that experience per se does not necessarily improve a dentist's performance with regards to fillings.

5. Limitations of the study

The study was conducted in laboratory settings, which should be considered when applying these results to clinical decisions. No previously published or pilot data could be used to reliably estimate an appropriate sample size required for this study. The FDI criteria to evaluate the fillings proved challenging, as it required specific probes and the use of a stereomicroscope. Furthermore, the evaluation method was sensitive to small defects that are unlikely to affect the patient's quality of life.

6. Conclusions

Compared to the conventional incremental technique the bulk-fill base technique shortened the time to fill a large class II cavity by close to 60 %, or four and a half minutes, and improved the quality of the fillings. The time savings and improved filling quality could lead to several additional benefits, thereby improving the quality-of-life for both patients and clinicians.

CRediT authorship contribution statement

Kaisa M. Leinonen: Conceptualization, Investigation, Formal analysis, Data curation, Writing – original draft, Visualization. **Jukka Leinonen:** Conceptualization, Investigation, Writing – review & editing. **Napat L. Bolstad:** Writing – review & editing. **Tarja Tanner:** Writing – review & editing. **Mohammed Al-Haroni:** Writing – review & editing. **Jan-Are K. Johnsen:** Conceptualization, Formal analysis, Data curation, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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