IN BRIEF

- Direct placement light-activated resin-based composites are increasingly being used as an alternative to dental amalgam.
- One of the factors critical to the success of such restorations is adequate material polymerisation.
- Achieving correct stable light guide positioning for curing becomes more difficult in posterior locations.
- This pilot investigation reports on the influence of operator variability during the simulated curing of a posterior restoration.

A pilot investigation of operator variability during intra-oral light curing

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Objective To test the hypothesis that operator experience influences the efficacy of light curing in a typical posterior intra-oral location. To investigate whether short cure cycles affect performance.
Design A cross-sectional single-centre study designed to assess the efficacy of experienced and inexperienced operators when undertaking simulated intra-oral curing.
Setting An *in vitro* laboratory based investigation conducted in a dental school during 2001.
Materials and methods A computer-based technique was used to monitor light intensity in a clinical simulation. Dentists and student operators were tested for their ability to cure a posterior restoration effectively. Relative light intensity was assessed against time for each operator and test run.
Results Experienced (qualified) operators produced more effective and consistent cure results than less experienced undergraduate students. Operator performance was not affected by variations in irradiation time.
Conclusions This cross-sectional pilot investigation demonstrates that operator experience is a factor in successful clinical photo-curing of posterior restorations. Stable and accurate light guide positioning are required throughout the entire irradiation cycle to optimise intra-oral cure of light-activated restorations. Further investigations are planned to assess the potential of this novel method of assessment for use as a routine teaching aid in clinical practice.

Direct placement resin-based composites are increasingly being used as an alternative to dental amalgam for the restoration of cavities in posterior stress bearing situations.[1-4] Whilst the rate at which dentistry is entering the post amalgam-age varies according to country[1-4] the trend is set to continue as clinicians are increasingly being asked to satisfy the expectations of patients who seek safe, biocompatible and affordable tooth-coloured restorations.[3,5] Favourable clinical results have been reported from controlled clinical studies for posterior composite restorations but these are not necessarily predictive of general practice as the results are highly dependent on patient selection, individual clinical skills and the care taken in placing the restoration.[6] Successful use of resin-composite in extensive posterior cavities is significantly affected by operative competence and diligence, with failure rates being greatest in the molar region.[5,9] Practice-based research studies and opinions report disappointingly low success rates for posterior composites.[5,7,8] There is a need for techniques and materials that will accommodate the variable demands of clinical practice whilst allowing successful use of posterior resin-composite in large cavity preparations.[5]

Visible light-activated materials have effectively replaced their chemically-cured precursors because they offer the operator significant clinical advantages.[10] However, a significantly lower survival rate has been reported for endodontically treated posterior teeth restored with light-activated resin-composites in comparison with chemically-activated materials.[11] The authors of this practice-based study attributed the poor results to inadequate polymerisation of the initial increment of light-activated composite in deep cavities. Even with modern high intensity light activation units there is a high degree of inefficiency in the transmission of visible light into and through aesthetic restorative materials.[12] There is an exponential decrease in light energy as composite or dentine thickness increases.[13] Thus deep or undercut cavity preparations pose difficulties for effective light activation of restorative materials.[5] Incomplete curing of the deeper portions of restorations increases the risk of restoration fracture or failure.[14,15]

Depth of cure depends on many factors including material composition, light source characteristics, irradiation time and distance of the light guide exit window from the material surface.[16-18] When curing the initial increment of material in a tunnel restoration or a deep box-shaped proximal cavity in a molar tooth, a distance of 6 mm frequently occurs between the cusp tips and the cavity surface.[17,18] Problems may also arise *in vivo* in ensuring normal and stable alignment of the light guide relative to the composite surface throughout the entire irradiation period. Access is further restricted in posterior locations and patients vary in their ability to obtain and sustain a wide-open mouth position. Lengthy irradiation times and the requirement for repeated sequential light applications may influence operator performance. Whilst clamps, jigs and other fixtures are routinely used in the laboratory to assure optimal light guide

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position and alignment relative to *in vitro* prepared test specimens, such methods are not practical clinically. Clinically, operators often work unassisted and have to ensure adequate means of eye protection from the intense light source, frequently by using a hand-held light blocking paddle/shield.

In an effort to increase efficacy and reduce curing times, manufacturers have introduced high intensity halogen lights fitted with turbo tip light guides.These operate by gathering the light via the light guide entry window near the light source and concentrating it at the smaller diameter exit window.[19] High-energy plasma-arc lamps have also been introduced to the market[20] providing short bursts of light in a narrow wavelength band around 470 nm at an energy level in excess of 1,000 mW/cm^2. They feature wand type handpieces with a relatively narrow light guide exit window diameter (5 mm) and manufacturers have recommended curing times of 3 s or less.[21] A 90% time saving has been estimated and improved co-ordination of incremental build-up has been reported by dentists using these fast lights.[21] Their appeal to practitioners is obvious despite initial reports questioning the effectiveness of these extremely short cure times.[22–24] It has not been established whether operator variability is reduced by short cure cycles. A momentary lapse in concentration will have a more profound impact with a short cure cycle whereas there may be less risk of operator fatigue with multiple sequential irradiations. Because very little curing occurs lateral to the area covered by the light guide exit window, the need for stable and accurate positioning of the guide normal to the composite surface increases as the light guide diameter approaches the cavity diameter.[18,20]

The potential loss of efficiency associated with intra-oral curing in posterior locations has not been investigated. In particular, the influence of operator variability on efficacy of cure has not received attention to date. The objective of this pilot study was to develop an *in vitro* test method to allow the effectiveness of operators curing a standardised posterior restoration under simulated clinical conditions to be assessed. The aims of the investigation were to determine:

1) Whether operator experience influences effectiveness of cure.
2) Individual operator reproducibility when undertaking sequential cure cycles.
3) Whether short (3 s) vs. long (30 s) cure times influence operator performance.
4) The influence of operating unassisted vs. assisted on cure performance.

MATERIALS AND METHODS

The experimental set-up consisted of a laboratory simulation of a typical clinical scenario. A phantom head (Frasaco, Tettnang, Germany) was used to simulate working intra-orally in a posterior location. The restorative simulation represented the curing of an occlusal restoration in an upper first molar tooth. A fixed inter-incisal distance of 35 mm was established between the two dental arches. An axially aligned parallel walled cylindrical cavity (Ø = 4 mm) prepared in the occlusal surface of a typodont upper first molar had an optical fibre set into the cavity base. The distance between cusp tips and the cavity base was 6 mm. The optical fibre relayed light intensity readings during the entire irradiation period of 30 s to a photosensitive diode interfaced to an analogue to digital converter (ADC). The ADC was connected to a computer to allow light intensity to be recorded against time. Relative light intensity (RLI) as a percentage of the maximum dose attainable for any given time (energy density) was calculated for each operator and test run. Light output was monitored throughout the entire experiment to ensure stability of output and re-calibration was performed at the start of each individual series of tests. Cure cycles were repeated five times for each operator and test series. Operators were not allowed feedback on their performance during testing.

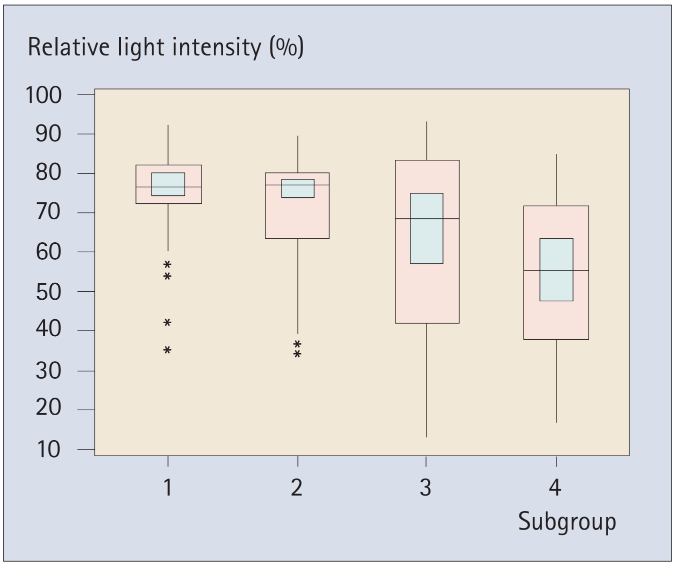

Fig. 1 Box and whisker displays of the raw data for the four subgroups of individuals tested. Staff (1), GDPs (2), Clinical students (3) and Pre-clinical students (4). Subgroups 1 and 2 represent 'experienced' operators and 3 and 4 'inexperienced' operators. Medians, interquartile ranges (outer box) and 95% confidence intervals (inner box) are shown with outlier results indicated by asterisks

The two groups of subjects tested in this work were either qualified dentists (group I; $n = 16$) familiar with posterior composite use or undergraduate students (group II; $n = 16$) with little or no clinical experience of posterior composite restorations. The dentists in group I (designated as 'experienced' operators) were either clinical teaching staff (subgroup 1; $n = 8$) or general dental practitioners (subgroup 2; $n = 8$). The 'inexperienced' operators (group II) consisted of students with either six months clinical experience of placing light activated restoratives (subgroup 3; $n = 8$) or students with no prior clinical experience of light curing (subgroup 4; $n = 8$). Half the operators in both groups were tested working assisted and the remainder worked unassisted. In the former situation a single trained assistant performed the tasks of holding the light shield and artificial cheek retraction in a standardised manner. When operators worked unassisted they held the light protective shield with one hand whilst simultaneously gaining access, and positioning the light guide with the other. Rubber dam was not used. A light activation unit (Heliomat H2; Ivoclar Vivadent, Schaan, Liechtenstein) with a stable output against time and a wand type handpiece with a light guide exit window diameter (Ø = 5 mm) matching that of a plasma arc curing unit was used in this work. An individual who was responsible for monitoring and recording the data on a computer initiated the irradiation sequence on the verbal command of the operator. Subjects were not informed about their individual performance until all tests were completed.

The five mean energy density readings (RLI %) obtained for each subject were averaged to obtain an overall score for each individual for purposes of inter-group comparison.

The number of results in each series of tests ($n = 80$ per group) where any individual RLI score fell below 50% was also noted and such results were arbitrarily categorised as failures.

Non-parametric statistical techniques were used for data analysis. Confidence interval analysis was used for the binary data representing the differences between group proportions. All statistical testing was performed at a 95% level of confidence.

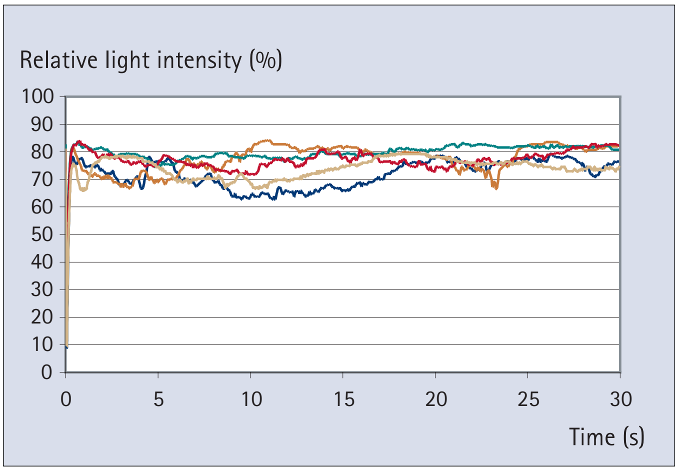

Fig. 2 Representative series of traces for an experienced operator

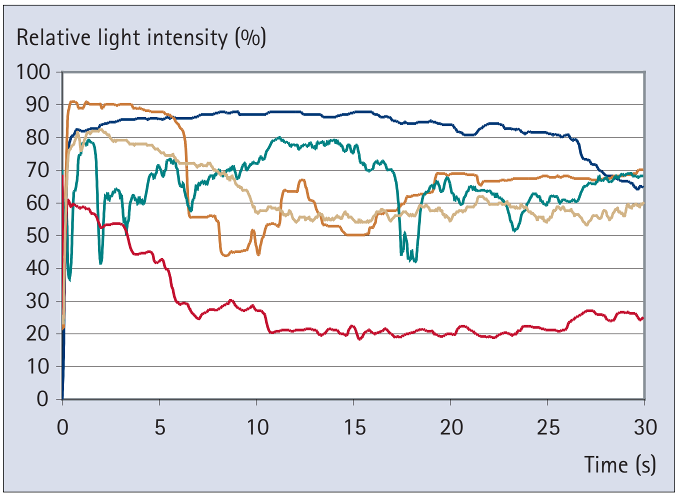

Fig. 3 Series of traces for an inexperienced operator. The fourth trace in this series was scored as a failure as it had a mean RLI < 50% over the 30 s irradiation time

RESULTS

1. Operator experience

Box and whisker plot displays summarising the individual scores for all the four subgroups of subjects are shown in Figure 1. A Kruskal-Wallis one-way ANOVA based on the overall score for each individual revealed that there was no significant difference between any of the four test subgroups (H = 7.43, DF =3, *P* = 0.06). The spread of results for the experienced operators (subject medians based on the five test runs ranged from 45.6% to 88.7%) was narrower than for inexperienced operators (medians ranged from 28.9% to 90.0%). The data for each individual run of the subjects in both groups was compared using a two-way mixed-model non-parametric ANOVA25, with the independent variables being operator experience (two levels) and subject test run (five levels). A significant effect was determined for operator experience (Mann-Whitney *U*-test for inter-row variation / n = 16 / p = 0.01). No significant effect was noted for subject test run (Friedman test / Sum Chi(R)-square = 8.60 / DF = 4 / *P* = 0.07) and there was no significant interaction (Friedman test / Chi(R)-square = 8.15 / DF = 4 / *P* = 0.09). There were 26 failures (mean RLI < 50%) recorded out of the 80 trials for inexperienced operators and nine failures out of 80 for experienced operators. The difference between the proportions of failures was analysed using a two sample unpaired case confidence interval test based on Newcombe's method.[26] The 95% confidence interval for the difference between these two proportions ranged from –0.333 to –0.085. A minority of operators accounted for the failures in group I (three out of 16 individuals) whereas a majority of individuals in group II (11 out of 16) had at least one score out of five test runs below 50% RLI. When a more stringent pass level was set (RLI > 75%) the number of failures increased to 32 (from 13 individuals) and 60 (from 15 individuals) out of 80 trials for experienced and inexperienced operators respectively. A representative series of traces for an experienced operator is displayed in Figure 2 whilst Figure 3 displays a series of traces for an inexperienced operator.

2. Operator variability over successive cure cycles

Experienced operators were more consistent across the five test runs (Fig. 4a) in comparison with inexperienced operators (Fig. 4b). No trend of increased failure rate with successive cure cycles ($n = 5$) was apparent.

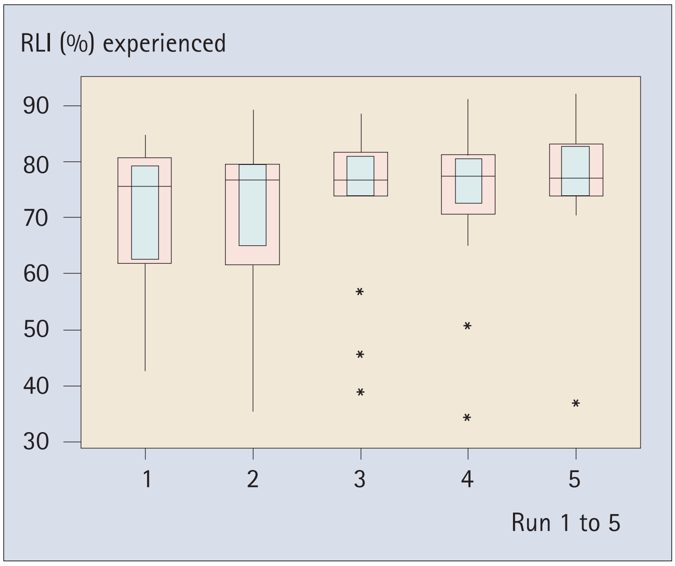

Fig. 4a Distribution of results for experienced operators according to the experimental run

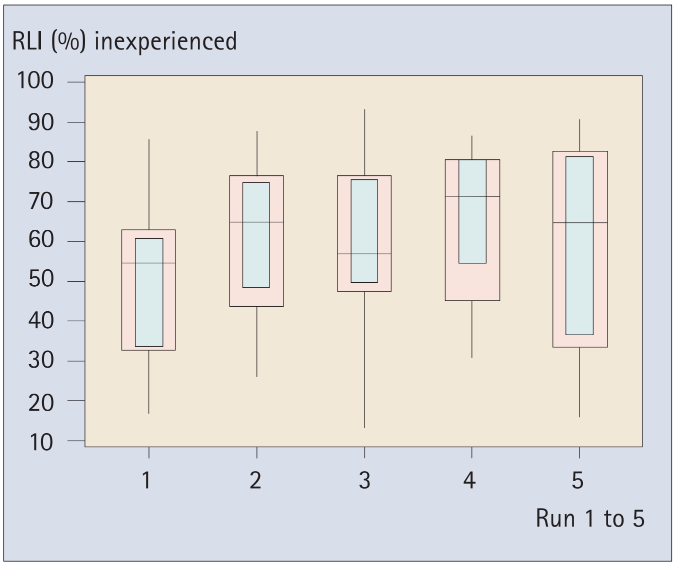

Fig. 4b Distribution of results for inexperienced operators according to the experimental run

3. Irradiation time and operator performance

No significant difference in RLI (%) was noted between the first (0–10 s) middle (10–20 s) and final periods (20–30 s) of the entire irradiation period for any of the four test subgroups (Friedman test / DF = 2 / *P* = 0.17). There was also no significant difference in RLI (%) between short (0–3 s) and conventional (0–30 s) irradiation times for any test subgroup (1-sample Wilcoxon test / *P* > 0.44).

4. Assisted vs. unassisted operating

The overall median for the assisted operators was 74.0% versus 69.8% for the unassisted operators and no significant difference was found between them (Mann Whitney *U* test / *P* = 0.61).

DISCUSSION

Direct placement resin-based composites are increasingly being used as an alternative to dental amalgam for the restoration of extensive class I and II cavities in posterior teeth.[4] They offer excellent aesthetics, are less costly and more conservative of tooth tissues than ceramic or gold inlays.[5] However the clinical technique required for routine success with such restorations is demanding and operator competence and diligence may have a profound influence on results.[27]

Adequate polymerisation of photo-activated resin-based posterior composite restoratives is important to ensure clinical success.[30] The performance of light-activated restorative materials is related to the effectiveness with which they are polymerised. Depth of cure has been related to a logarithmic function of the total amount of exposure — the product of light intensity and irradiation time.[29,30] Some manufacturers have introduced materials they claim to be capable of being adequately polymerised to depths up to 5 mm with a 40 s exposure. Independent research has been unable to validate these claims and effectiveness of polymerisation decreased significantly with increased cavity depth regardless of exposure time.[31] Operator controlled factors governing extent of cure includes light source characteristics, irradiation time, increment thickness and correct light guide position during irradiation. The minimum energy density needed for effective cure of a standard increment thickness will depend on material composition and light source factors.[32]

Inadequate polymerisation may adversely influence the mechanical and biological properties of resin-based restoratives. Aesthetics, wear resistance and clinical longevity may all be reduced. Surveys of practitioners have established that dentists frequently use lights of lower output intensity and/or shorter irradiation times than those recommended by manufacturers and/or research workers.[33,34] It is the responsibility of all practitioners to ensure that they adopt appropriate protocols for ensuring effective and efficient curing of their photo-activated restorations.[35] This investigation is the first report of which the authors are aware documenting individual intra-oral variations in light curing ability. Other investigators have documented the effects of operator ability on dental procedures. Sano *et al.*[36] tested students and dentists and demonstrated that operator experience may have an effect on the ability of the individual to produce consistently good tensile bond strengths to dentine. They found that the dentists produced more consistent results than the students when using a multi-step bonding system. Also, simulated clinical handling in combination with intra-oral curing in the molar region has been reported to result in a significant reduction in the flexural strength of two commercially available posterior composites in comparison with laboratory-quality specimens.[37] Access for light guides is increasingly restricted posteriorly. The radiant emittance of modern guides, made of random fibres, is reduced towards the exit window periphery.[38]

The current results show that whilst operator experience has an effect on efficacy of light activation, operator variability is a critical issue. It is intended to extend the current work to identify the causative factor(s) behind individual variations in performance. The findings reflect significant variations between individual operators, which may be found in clinical practice. The results of this pilot *in vitro* simulation study conducted on a phantom head cannot be directly extrapolated to the situation where restorations are cured in cavities *in vivo*. However, the experimental set-up employed was considered to be an appropriate standardised simulation of the problem posed when irradiating the initial increment of material in deep posterior cavities. Where access is restricted, small changes in light guide alignment may result in considerable reduction in energy density applied to the cavity floor. Such situations are likely to occur with increasing frequency as dentistry moves progressively into the post-amalgam era.

The assistance of all the individuals who generously volunteered their time to allow this survey to be undertaken is acknowledged.

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