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Effect of high-intensity curing lights on the polymerization of bulk-fill composites

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ABSTRACT

Objectives. The purpose of this study was to investigate the effect of high-irradiance light-curing-units (LCUs) on the depth-of-cure (DoC) and degree-of-polymerization (DoP) of bulk-fill composites (BFCs).

Methods. The DoC of composites (Beautifil-Bulk, SHOFU; Filtek-Bulk-Fill, 3 M ESPE; Tetric-EvoCeram-Bulk-Fill, Ivoclar; Sonic-Fill-2, Kerr; Venus-Bulk-Fill, Heraeus; Z250, 3M-ESPE) were measured according to ISO-4049 using high-irradiance LCUs (FlashMax-P3, CMS-Dental; SPEC3, Coltene) and conventional LCU (Paradigm, 3M-ESPE) for exposure times: 3/9-s, 3/20-s, and 10/20-s respectively. Using FTIR, the DoP per composite was measured at the bottom surface as a function of post-curing times for the LCUs at the same exposure times. Data was analyzed with nonlinear regression and ANOVA/Tukey.

Results. Significant differences in DoC were found amongst the LCUs for the various exposure times. All BFCs failed to meet the DoC claimed by manufacturers and failed to satisfy ISO-4049 with the high-irradiance LCUs with 3-s exposures. Standard irradiance and 20-s exposures outperformed all other irradiance-exposure combinations for maximizing the DoC and DoP of BFCs. A minimum of 15.3 J/cm^2 radiant exposure was required to achieve an adequate maximum polymerization rate. Venus Bulk exhibited the highest DoC and DoP for any LCU-exposure-time combination.

Significance. Among the different combinations of BFCs and LCUs, DoC and DoP were always increased with longer exposure time, but there exists a theoretical radiant-exposure limit beyond which DoP or DoC remains unchanged. However, high DoC or DoP are not always associated with one another. Thus, the exposure-reciprocity law must be approached thoughtfully since irradiance and exposure can independently affect DoP and DoC.

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1. Introduction

Dentistry has witnessed significant innovation of resin-based restorative materials in the last three decades. The success of this ongoing evolution appears to have been promulgated from new treatment strategies based on scientific evidences and practical constraints imposed by our clinical practices, patient demands, and empirical research. Especially for restorative dentistry, a paradigm shift toward light cured materials and away from amalgams is driven partially by the post-handling of mercury and its environmental concerns, partly by the gradual clinical success of RBCs, and by the increasing patient demand for esthetics. RBC is presently a routine armamentarium for dental operative procedures with approximately 146 million RBCs placed annually in the United States [1,2]. Placing these RBCs is an intricate process that often poses many challenges such as adequate isolation, etch-and-bond treatment of dentin and enamel surfaces, incremental or bulk placement, and adequate light curing (photo-polymerization). Proper execution of these steps can minimize iatrogenic errors and can enhance the longevity of the restoration. However, the role of the dental LCU in photo-polymerization has often been overlooked, perhaps because of its presumed simplicity in application relative to all of the other challenging requirements when restoring a tooth.

Photo-polymerization is an important process because it serves as a "rate-limiting" factor, controlling the outcome of a RBC restoration. For example, a RBC requires a synergistic combination of intrinsic and extrinsic factors to achieve photo-polymerization efficiency [3]. The former includes the filler content/morphology, monomer ratios/chemistry, or photoinitiator concentrations/types, and the latter is involved with curing parameters such as exposure times, source-to-object distance, or standard-versus-high irradiance mode [2]. Although controlling, manipulation, and formulation of intrinsic factors can have a direct and significant impact on the final physical properties of a RBC, they are very much dependent on the extrinsic attributes. It has been shown that the energy and spectral wavelengths of a LCU must match that of the RBC's manufacturer photo-polymerization requirements [4,5]. Without proper delivery of the required photon energies by the LCU, the predictive course of photo-polymerization reaction can be jeopardized in which suboptimal quantum yields and monomer-to-polymer conversions are incurred and cascaded across each of the photopolymerization kinetic steps such as free-radical initiation, chain-propagation, and chain-termination mechanisms. The aberrant products from these inchoate steps are ultimately reflected in the final outcomes of the RBC's physical properties and clinical performance [3]. Furthermore, of these two factors, the former is governed by the proprietary manufacturing formulations which are neither changeable nor controllable by the end user. In contrast, the latter is most susceptible to operator error, particularly involving their light-delivery techniques. There are other extrinsic factors like LCU's beam profile, spectral emission, and irradiance, which are strictly set forth by the manufacturer as well.

When a curing light tip is placed over a resin-based composite, the dentist must be confident that the chosen LCU can properly initiate polymerization within the recommended curing time. Today, the standard in most dental practices is the LED (light-emitting diode) LCU. The LED LCU exploits the electronic nature between two dissimilar semiconducting materials to produce light. They differ from the quartz-tungsten-halogen (QTH) LCUs in which light production is based on the scientific principle of electroluminescence rather than incandescence [6]. In comparison to QTH LCUs, the advantages of LED LCUs are high photonic output in relatively short exposure time, energy efficiency, and narrow spectral output [7,8].

The recent introduction of LED LCUs with "high power and short exposure" has raised concerns regarding their role, effectiveness, and safety in operative dentistry [9,10]. Questions have arisen among dental professionals as to whether the Bunsen–Roscoe concept of exposure reciprocity [11] can be applied to aid in the acceleration of dental photo-polymerization when using these new LCUs. There has been a discursive controversy around extrapolating the total energy principle to curing of the dental RBCs [12–15]. The assumption is that the photo-response of a photo-sensitive RBC only depends on the total absorbed energy dose (radiant exposure or H, unit: J/cm^2) rather than the two components, irradiance and exposure time, which their product determines radiant exposure [11]. Furthermore, these extrinsic factors can be complicated by the different manufacturers' claims on the bulk-fill RBC depth of cure. Most are publicized to be bulk placed and cured in 4 mm increments, and few are cured in 5 mm increments [16]. Although reducing the time required to cure these materials has short-term, cost-saving implications, the quality, integrity, and performance of the restoration remains the primary concern. Improperly polymerized RBCs can result in insufficient monomer-to-polymer conversion, a predisposing factor to clinical problems such as marginal discrepancy, secondary caries, and fracture, whereas a properly cured composite will exhibit good physical properties in strength, wear, and toughness [17].

The present study aims to investigate the effect of high-irradiance LCUs on the depth-of-cure (DoC) and degree-of-polymerization (DoP) of bulk-fill RBCs. The null hypotheses were:

(1) There are no significant differences in DoC and DoP amongst various commercial bulk-fill RBC brands cured by a LCU having a high irradiance (i.e., $\geq$2000 mW/cm^2) with either a short ($\leq$10 s) or an ultra-short exposure time ($\leq$5 s) versus a LCU having a conventional irradiance (<2000 mW/cm^2) and standard exposure time (20 s).
(2) Given the same radiant exposure (energy dose), there is no significant difference in DoC and DoP amongst various commercial bulk-fill RBCs.

2. Materials and methods

2.1. LCU and bulk-fill RBC characteristics

Three LED LCUs, having different irradiances, were studied: FlashMax-P3 (CMS Dental, Copenhagen, Denmark), Paradigm (3M ESPE, St. Paul, MN, USA), and SPEC3 (Coltene, Cuyahoga

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