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Effect of the irradiance distribution from light curing units on the local micro-hardness of the surface of dental resins

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ABSTRACT

Objective. An inhomogeneous irradiance distribution from a light-curing unit (LCU) can locally cause inhomogeneous curing with locally inadequately cured and/or over-cured areas causing e.g. monomer elution or internal shrinkage stresses, and thus reduce the lifetime of dental resin based composite (RBC) restorations. The aim of the study is to determine both the irradiance distribution of two light curing units (LCUs) and its influence on the local mechanical properties of a RBC.

Methods. Specimens of Arabesk TOP OA2 were irradiated for 5, 20, and 80 s using a Bluephase® 20i LCU in the Low mode (666 mW/cm^2), in the Turbo mode (2222 mW/cm^2) and a Celalux® 2 (1264 mW/cm^2). The degree of conversion (DC) was determined with an ATR-FTIR. The Knoop micro-hardness (average of five specimens) was measured on the specimen surface after 24 h of dark and dry storage at room temperature.

Results. The irradiance distribution affected the hardness distribution across the surface of the specimens. The hardness distribution corresponded well to the inhomogeneous irradiance distributions of the LCU. The highest reaction rates occurred after approximately 2 s light exposure. A DC of 40% was reached after 3.6 or 5.7 s, depending on the LCU. The inhomogeneous hardness distribution was still evident after 80 s of light exposure.

Significance. The irradiance distribution from a LCU is reflected in the hardness distribution across the surface. Irradiance level of the LCU and light exposure time do not affect the pattern of the hardness distribution – only the hardness level. In areas of low irradiation this may result in inadequate resin polymerization, poor physical properties, and hence premature failure of the restorations as they are usually much smaller than the investigated specimens. It has to be stressed that inhomogeneous does not necessarily mean poor if in all areas of the restoration enough light intensity is introduced to achieve a high degree of cure.

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1. Introduction

Visible light cured (VLC) resin based composites (RBCs) are commonly used as restorative materials [1]. Adequate curing of these materials depends on the initiator receiving sufficient energy at correct wavelengths [2]. Adjusting the optimum curing conditions by choosing correct light exposure time and irradiance level, precise positioning of the light curing unit (LCU) over the restoration site and not attempting to cure too much resin at one time make the difference between a resin that is properly cured and an inadequately cured restoration [3–5]. The irradiance from the LCU has a significant influence on the surface hardness as well as on depth of cure (DoC) and degree of conversion (DC) [6–9].

The reactive radicals are created by the exposure of VLC RBCs. A photo-sensitive initiator, such as camphor quinone (CQ), absorbs light energy and changes into an excited state. The excited state is transferred to a reducing agent, usually an amine molecule e.g. dimethylaminobenzoate (DABE). The CQ–DABE-pair (exiplex) creates two free radicals. They attack the free carbon double bonds of the monomers and start the photo-polymerization. The number of generated radicals depends on the emitted irradiance of a LCU and affects thus directly the attainable DC [2,10–13].

The highest reaction rates and highest changes in DC were observed as long as the resin is below the glass-transition temperature (T_g) [2]. During the curing process T_g increases because it is linked to the degree of polymerization of the resin molecules or the corresponding molecular weight, respectively. Therefore, T_g exceeds the polymerization temperature after some time [14]. The matrix transfers to the glassy state in which the mobility of the radicals and monomers is drastically reduced and the reaction rate tends to zero [15–18]. Therefore, the existing radicals are trapped in the cured polymer matrix [19]. After the exposure the trapped radicals either react very slowly with remaining carbon double bonds or deactivate over termination reactions over a long period of time. This effect known as “post-curing” [20–22] leads to a further and slow increase of DC. It depends on the numbers of trapped radicals in the cured polymer matrix. Halverson et al. showed that the photo-polymerization process has an energy absorption limit. Over a specific energy level no improving of the mechanical behavior was observed [10].

Mechanical properties such as hardness, Young’s modulus or shrinkage depend directly on the DC [13,23]. Several studies showed that a high DC corresponds to high hardness, high Young’s modulus, and high shrinkage [15,24–26]. Therefore, possible irradiance distributions of LCU may produce inhomogeneous shrinkage resulting in internal stress distributions and/or debonding [18,27–30].

Several authors have described the problem of inhomogeneous irradiance output from LCUs, the effect on the curing of VLC RBCs and the consequences of the light output measurement as part of the quality management [31–34]. Currently two different types of light-emitted diode (LED) LCUs are in use: Firstly, monowave blue-LED units emitting a relatively sharp blue light peak and secondly, polywave LED units emitting a broader spectrum with at least two peaks at different wavelengths. Some studies reported higher curing efficiencies in terms of hardness, elastic modulus or DC for polywave LCUs with the same or lower irradiance than for monowave LCUs [35–38].

Tungsten halogen lights and plasma arc lights also emit a broad range of wavelengths that cover the effective spectra of the commonly used photo-initiators [6,39]. However, the classical tungsten halogen lights are being rapidly replaced by LED units due to convenience reasons and higher irradiances [1,7].

The surface hardness (Knoop or Vickers) has been used to characterize the mechanical properties of VLC RBCs [39]. The DC within the resin was determined using Fourier transform infrared spectroscopy (FTIR) [40]. Arikawa et al. and Price et al. found a correlation between the irradiance distribution and the hardness distribution [31,41].

However, the effects of prolonged exposure times on the hardness distribution requires further study as it is assumed that additional curing will occur in areas of lower DC as initiator radicals will have a slightly higher mobility there. This allows additional cross-links to be created in these areas leading to a more homogeneous polymer network. In most cases the exposure time will be between 5 and 40 s [31,41]. The primary problems of current RBCs are inadequate polymerization, shrinkage and corresponding shrinkage stress as well as elution of low molecular substances. This restricts the durability of restorations and may induce allergies or other health implications [26,42,43].

Therefore, the hypotheses of this study were the follows:

1. Each LCU has a specific irradiance distribution leading to a corresponding pattern of the hardness distribution of a dental composite surface.
2. The number of radicals depends on the irradiance level and/or on the exposure time. A higher irradiance creates sufficient radicals to activate all carbon double bounds forming a more homogeneous network and longer exposure times provide radicals over a longer period. Thus, the effects of differences of irradiance distributions of LCUs are compensated by longer exposure time.

2. Materials and methods

2.1. Materials and sample preparation

A camphorquinone based VLC RBC – the micro-hybrid composite Arabesk TOP OA2, VOCO, LOT 1114471 (in the following text abbreviated Arabesk) – containing 22 wt.% bisphenol A glycidyl methacrylate (Bis-GMA), triethylene glycole dimethacrylate (TEGDMA), and urethane dimethacrylate (UDMA), and 77 wt.% of bi-ceramic system filler was used in this study [44,45].

2.2. Methods

2.2.1. Measurement of power and beam-profiles of the LCU

Two LED LCU with different emission spectra were used in this study, Fig. 1: