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Curing characteristics of a composite. Part 2: The effect of curing configuration on depth and distribution of cure

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ABSTRACT

Objective. The objective of this study was to examine the effect different configurations of curing would have on the depth and distribution of the cure within each configuration, for a specific resin-based composite (RBC).

Methods. RBC was cured in a variety of configurations, consisting of 6 mm molds of three different colors; large molds that simulated the condition of no mold at all; and 3–6 mm diameter molds to check the effect of size. All specimens were cured for 20 s with a quartz-halogen lamp and were allowed to cure for 24 h in the dark. Transmission measurements were made for these same configurations. Knoop hardness measurements were made across the central plane of some configurations to determine the distribution of curing.

Results. Depths of cure and distribution of curing were significantly affected by changes in configuration. Under the configuration of no mold, the cure extended well beyond the periphery of the light guide due to scattering of the light. When a mold was used, a pronounced effect by the walls resulted in decreased hardness as the mold wall was approached, and the severity of this effect was dependent on the color of the mold. It is believed that this is due to absorption/reflection characteristics of light by the walls, with the white molds showing the least effect. Reducing the diameter of the molds resulted in significant decreases in depth of cure, which are attributed to light absorption by the walls that limits the penetration of light during the curing procedure.

Significance. Configuration of curing has a significant effect on the depth of cure, but also significantly reduces the cure near the mold wall. This can have clinical ramifications for the cure along a stainless steel matrix band for Class II restorations, and for test procedures in general, where there is no standardization regarding configuration or where measurements are made on specimens.

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1. Introduction

There has been a long history of testing light-curable resin-based composite (RBC) materials to establish effective curing conditions for combinations of RBC and related curing lamps. In the conduct of these studies a wide variety of molds have been used in which the RBC is light cured. These have varied in size, depth, shape, color, material and translucency, but for the most part, the mold has been ignored as a factor in the results obtained. However, there has been some evidence that the mold can influence the depth and the distribution of the cure [1–4], so it is unlikely that results from these various molds could be directly compared. Therefore, it would seem reasonable that there should be some standardization of how light-curable RBC materials are tested, and recognize that the mold is an important part of the test methodology. There is a standardized test for depth of cure, which is often referred to as the ISO test [5], which is mandatory for manufacturers to certify their RBC materials and to set their recommendations for cure times relative to RBC increment thickness, which makes it a clinically related test. However, the rationale for this test is unspecified and correlations between the test and clinical applications are lacking.

If a test method is going to be developed it seems reasonable that the configuration for curing the RBC should be understood. The configuration of curing refers to the surroundings of the RBC and the relative positioning or size of the curing lamp, and in its typical form is a cylindrical mold with the lamp directly on top, but it can be more complex than that. Understanding how light is distributed, absorbed, or reflected in the configuration would be an important part of judging the worth of a particular configuration, particularly if the same is done for curing RBC in human teeth. It may be that a test should be designed around a difficult clinical application, such as a deep Class II cavity. For any test configuration that is devised to give clinical guidance on depth of cure, it is important to know what to measure and where to make the measurements and that requires an understanding of how the light and subsequent cure of the RBC is distributed within that configuration.

It might be expected that with configuration changes involving color of opaque molds, that the different amounts of absorption or reflection of the curing light could cause changes in how the material cures, and that was partially confirmed in a study where black molds produced shorter depths of cure than a stainless steel mold when a light shade of composite was cured [1]. However, black molds are still used [6,7] instead of stainless steel molds, as recommended in the ISO test [5]. White molds have also been used, but they have generally been made of Teflon or some other translucent material that can allow more of the curing light to pass through the mold than through the RBC material [1,2]. This results in exaggerated depths of cure, and scrape back surfaces that are concave as opposed to the convex scrape-back surfaces found when using opaque molds [1,2,8,9]. Despite these results, translucent plastic and Teflon molds are still used in determining the depth of cure and other properties [10–12].

Human tooth molds have also been used [2,13,14], but they have varied in size and have not been compared with a 4 mm diameter, stainless steel mold, as specified in the ISO test to determine depths of cure.

The effect of mold size has been examined for opaque cylindrical molds [1,3,4] and the measured or implied depth of cure for RBC materials was found to decrease as the diameter decreased. A change in size would be considered a change in configuration, as would a change in geometry. Most molds used are cylindrical, but other mold geometries have been used: molds with 4 mm square cross section [6,12], a slot mold with 2 mm by 4 mm cross section [15] and a hemi-cylindrical mold of 4 mm diameter [16]. These were used to provide a flat surface on which to make measurements such as hardness. In each case, other than one [15], comparisons with the ISO test [5] were made even though the geometry and/or materials were not what is specified in the ISO test. Also, since the ISO test is relevant to measurements along the central axis, then surface measurements may not be comparable given the evidence above of potential non-uniform curing within specimens.

Given that the walls of a mold may influence the cure distribution within the RBC, then it is of interest to know what the cure distribution is for an unrestricted RBC, which in practical terms means a mold that is large enough that there is no influence on the curing process. Under these conditions, the RBC has been shown to cure laterally beyond the edges of the light guide by a significant amount [17–19], and this lateral cure and depth of cure is dependent on the diameter of the light guide, for the same irradiance [17,18].

In Part 1 [8], unique relationships were found between the internal radiant exposure, H, and both DC and KHN, which were called the energy-conversion relationship (ECR) and energy-hardness relationship (EHR) for the RBC. The internal H values were determined from the incident radiant exposure, H_0, and a measured light transmission relationship as a function of depth, $T(d)$, using fully cured RBC. It was postulated that the ECR and EHR were unique to the material and would apply to any curing configuration of that RBC material, however, the $T(d)$ relationship was expected to vary with the configuration. Using these relationships for a given configuration, it was postulated that the curing characteristics along the central axis of a configuration could be defined. In addition it was postulated that at the scrape-back depth (D_{SB}) the radiant exposure H_{SB} would be nominally the same for all configurations, but the value of D_{SB} would vary as would the $T(d)$ relationship. Depth of cure was defined as the scrape back depth, D_{SB}, in Part 1, and is also defined that way in the present work.

It is the intent of this work to examine in a detailed way the effect of various curing configurations on the distribution and depth of cure for an RBC material in a variety of configurations. The specific goals and hypotheses are to show that for a specific RBC: (1) Each configuration is represented by a transmission relationship specific to that configuration. (2) D_{SB} will also be specific to each configuration. (3) H_{SB} will be nominally independent of the configuration. (4) The distribution of curing will be non-uniform along a plane perpendicular to the central axis for each configuration and will be unique to the configuration. (5) The EHR for the RBC material is independent of the configuration.