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Cuspal Deformation During Light-Curing of Resin-Based Restorative Materials Measured by ESPI (Electronic Speckle Pattern Interferometry)

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INTRODUCTION: Polymerization shrinkage that occurs during light-curing of resin-based restorative materials inside a cavity may result in cuspal deformation [1], enamel crack propagation [2] or debonding of the restoration [3]. The amount of stress generated depends on the bulk of the composite and the rate at which it polymerizes. In recent years, a curing protocol called exponential curing has been introduced with the hope of reducing stress from polymerization shrinkage and improving composite properties. Exponential curing relies on the concept that an initial, low energy of curing light will start the polymerization reaction and will allow stress to be dissipated by flow of the material before a higher energy light is applied to complete the polymerization. However, the benefits of this curing concept in terms of stress concentration and tooth deformation has always been controversial.

Although different methods have been proposed to measure the polymerization shrinkage of resin composite materials [4-6], none of these has been able to measure the deformation of teeth during the in situ polymerization of the resin. Because Speckle interferometry has the capability to perform contactless, real time and high-sensitivity measurements of displacement on the surface of an object, we have used ESPI to measure the cuspal deformation of teeth during in situ polymerization of the restorative material. Our hypothesis was that the exponential curing mode would cause less stress and deformation during polymerization than the standard curing mode, without reducing the mechanical properties of the cured material.

MATERIALS & METHODS: MOD cavities with average dimensions of 2x3.5x2 mm were prepared in 24 extracted human molars. The adhesive system (AdheSE, Vivadent) was then applied to the cavity walls and the specimen glued onto a heavy metal base used to maximize stability. This also allowed specimens to be accurately mounted in a Michelson speckle interferometer constructed for the measurement of out-of-plane displacement. Briefly, this device illuminates the the tooth surface with a 10 mW He-Ne laser, creating a granular pattern of speckles on the tooth surface. Images of the speckles were captured with a CCD camera with an image array of 756x581 pixels. The displacement of the teeth due to the polymerization shrinkage was calculated by multiplying the total number of observed fringes by d.

$$d = \lambda/2 \qquad (1)$$

where λ is the wavelength of the laser light.

The resin composite material (Tetric Ceram, Vivadent) was inserted into the cavity and bulk cured using either the LED Elipar Freelight 2 (3M-ESPE) or the halogen Swiss Master Light (EMS). For each light source, two curing modes were selected: standard (STD) or time dependent (EXP). For the STD conditions, irradiation times were 20 s at 800 mW/cm^2 for the Freelight 2 and 10 s at 2000 mW/cm^2 for the Swiss Master Light. For the EXP conditions preset programs with intensities increasing exponentially during the first seconds were used. Tooth deformation during light curing was measured in real time for 60s.

For polymerization control, each tooth was sectioned in two halves, and the Vickers hardness of the resin-composite was measured at eight different locations inside the restoration. The indentations were made by applying a 0.5 Kg load with a Hauser micro-indenter. The results were compared with a multifactor analysis of variance followed by a LSD multiple range test ($P< 0.05$)

RESULTS: The mean displacement of the teeth during the polymerization reaction is given as a function of time in the Figures 1 and 2. The Vickers hardness $VH_{0.5}$ is given in the Table 1.

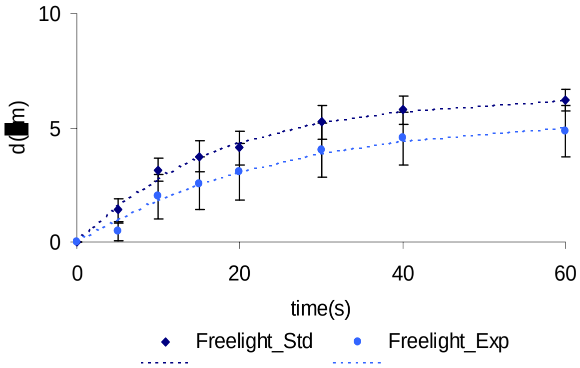

Fig. 1: Mean displacements (µm) of the teeth during the setting reaction obtained with the LED Freelight 2.

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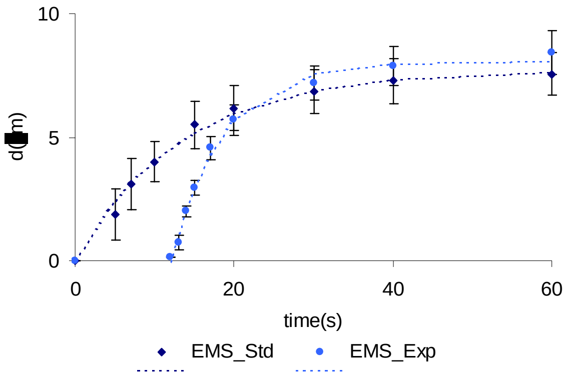

Fig. 2: Mean displacements (µm) of the teeth during the setting reaction obtained with the halogen Swiss Master Light.

A two-factor analysis of variance showed that only the type of light source had a statistical significant effect upon the displacement of the teeth during the polymerization reaction ($p<0.0001$). For both light sources, the use of a continuous or time dependent irradiance output did not significantly affect the displacement ($p=0.5625$)

Table 1. Mean $VH_{0.5}$ hardness and standard deviation at different locations in the restoration for the different illumination conditions .

	Freelight2		EMS	
Position	STD	EXP	STD	EXP
bottom	56±32	49±16	69±18	54±24
bottom	62±28	51±28	60±26	74±32
middle	98±10	90±17	87±12	96±20
middle	101±8	100±9	97±4	98±11
middle	99±5	98±5	96±7	99±15
middle	95±5	88±18	79±28	100±13
top	111±8	110±7	96±4	102±9
top	106±8	109±6	100±4	108±4

A multifactor analysis of variance showed that there was no significant effect from neither the type of source ($p=0.8895$) nor the illumination conditions used ($p=0.7414$) on the hardness of the material. However, significant differences were found ($p<0.0001$) between the hardness values measured at the top, the middle and the bottom of the cavities.

DISCUSSION & CONCLUSIONS: The curing contraction of the resin composite material will cause deformation of the surrounding tooth structure only through a bonded interface. The bond strength between the resin composite and dentin was determined in a pilot experiment in order to ensure that a good adhesion was obtained.

Tooth deformation will be also influenced by the the extent of the polymerization reaction. In the present study, the polymerization extent was assessed indirectly by measuring the Vickers hardness of the set resin composite. The hardness values indicated that comparable polymerization degrees were obtained with both light sources for both irradiaton modes. However, the hardness significantly decreased from the top to the bottom of the restoration. This result could be explained by the thickness of the composite layer which was slightly greater than ususally recommended.

For both light sources, the final teeth displacements were not influenced by the illumination mode. With the EXP mode of the Swiss Master Light an initial displacement delay was observed, which could be related to a shift of the gel point of the polymerization reaction. A significant lower displacement was obtained with the Freelight 2. As this effect can not be related to a lower extent of the setting reaction, it is probably due to a slower reaction rate induced by a lower irradiance output, which allowed greater flow of the resin composite.

In conclusion, the exponential curing modes tested in this study did not offer any advantage over conventional curing modes in term of tooth deformation. Therefore our working hypothesis has to be rejected.

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