Optical fiber curing of a dental composite: a holographic, thermographic, and Raman study

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The main limitation of dental resin-based composites (RBC):

- Shrinkage during polymer chain formation
- Generating polymerization shrinkage stress (PSS) inside a confined environment such as a tooth cavity (Fig. 1)

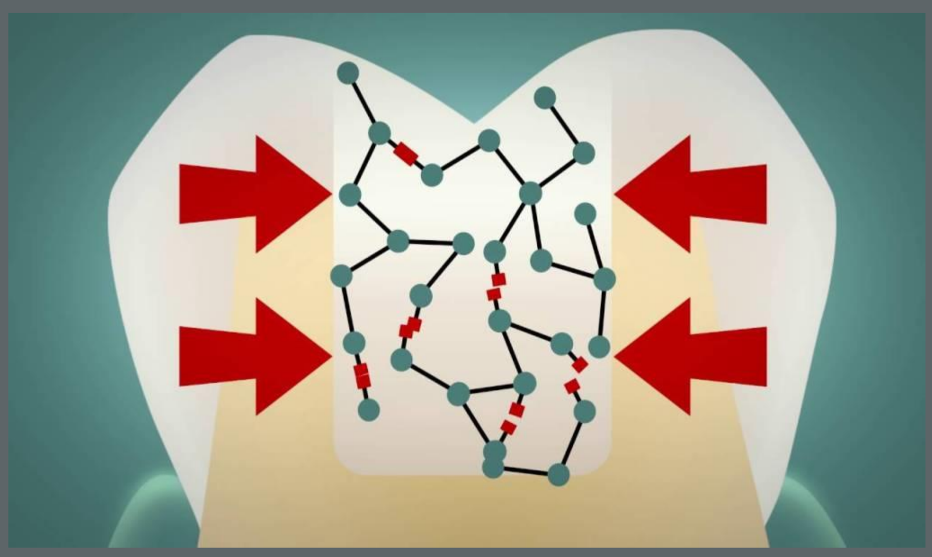

Fig. 1 Polymerization shrinkage stress

Study goal:

- To introduce a novel photo-activation protocol using optical fibers (Fig. 2) inserted into the RBC (Fig. 3), for reducing PSS and guiding light directly into deeper layers of the restoration

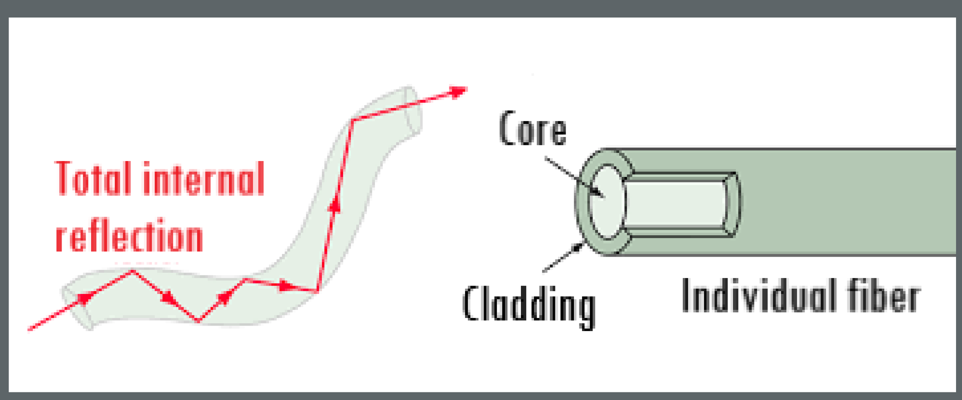

Fig. 2 Optical fiber

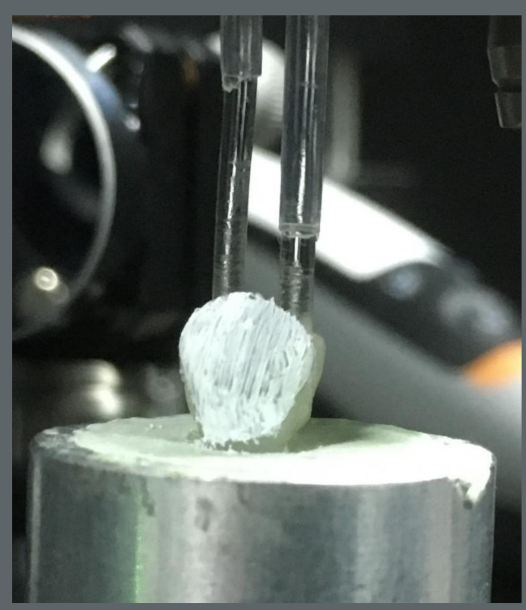

Fig. 3 Optical fibers inserted into the tooth cavity model filled with the RBC

- The proposed two-step experimental photo-activation:
  - 1st step: two optical fibers (φ 1.5 mm) connected with a commercial dental LED unit, were inserted into the filling to cure the RBC from within
  - 2nd step: fibers were extracted, remaining voids filled with the RBC and final conventional curing was performed
- Control group: conventional photo-activation on a separate group of samples (n=15 models per curing protocol)

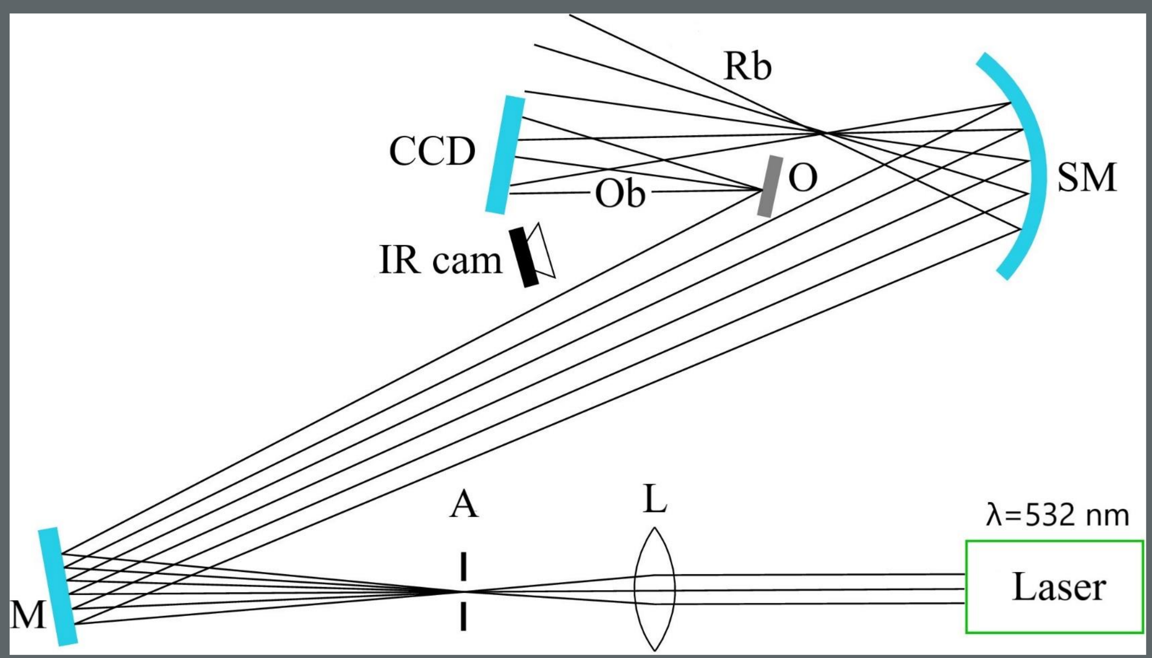

Fig. 4 L-lens, A-aperture, M-mirror, SM-spherical mirror, O-object, Ob-object beam, Rb-reference beam, CCD-charge-coupled device, IR cam-infrared camera

- Tooth model deformation as a secondary manifestation of PSS was measured in real-time using digital holographic interferometry
- Simultaneous monitoring of RBC temperature change was conducted with an infrared thermal camera
- As a separate experiment - degree of monomer-to-polymer conversion (DC) was measured immediately after curing and after 24h of dark storage, using Raman spectroscopy

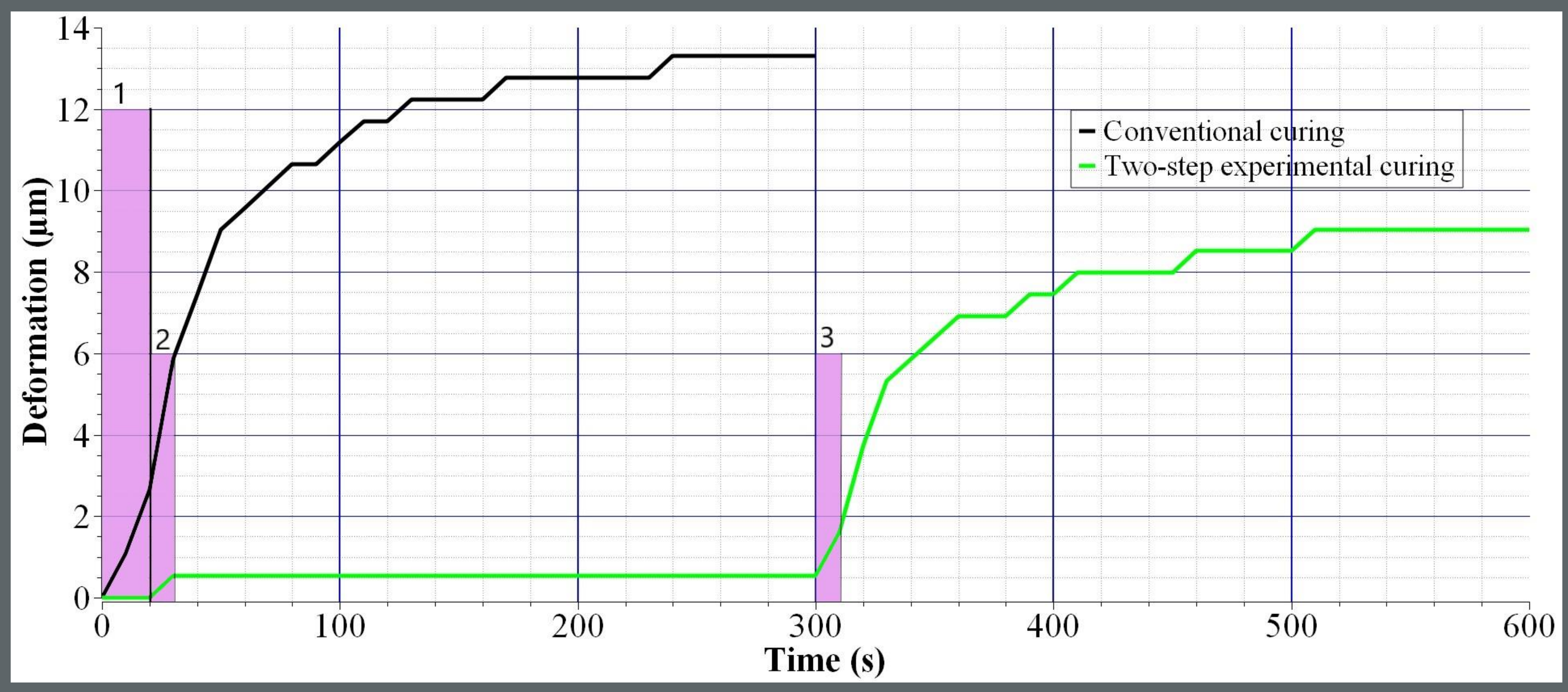

Fig. 5 Real-time tooth model deformation. 1 = 20 s conventional LED irradiation; 2 = 10 s 1st step LED irradiation via optical fibers, 3 = 10 s 2nd step conventional LED irradiation

Experimental vs. conventional photo-activation:

- 34 % reduction of tooth model deformation (Fig. 5)
- 39 % lower RBC temperature change, leading to lower thermal shrinkage during the cooling process (Fig. 6)
- The time to reach the maximum exothermal temperature was prolonged, allowing polymer chains to re-arrange and accommodate the volume reduction by viscous flow

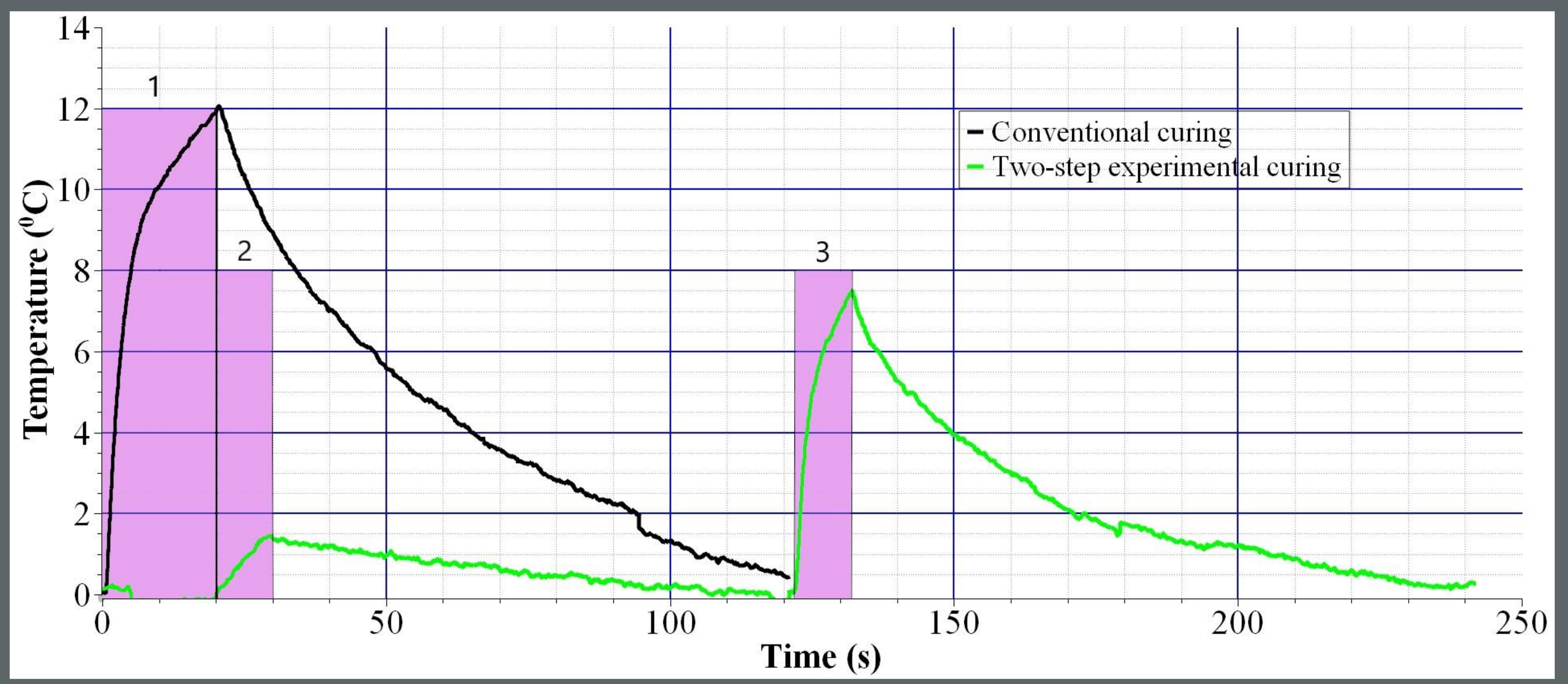

Fig. 6 Real-time RBC temperature change. 1 = 20 s conventional LED irradiation; 2 = 10 s 1st step LED irradiation via optical fibers, 3 = 10 s 2nd step conventional LED irradiation

- Significantly lower immediate DC contributed to the reduction of model deformation (Table 1)
- After 24h, the DC increased in both groups of samples, but remained significantly lower for the ones cured using the experimental protocol

Photo-activation protocol	Radiant exposure (J/cm²)	Tooth model deformation (μm)	Temperature change (°C)	Time to reach the maximum temperature (s)	Immediate DC (%)	24 h post-cure DC (%)
Conventional	20	13.4	10.7	7.5	41.4	46.3
Experimental (1st + 2nd step)	14.5	8.8	6.5	8.2	33.5	38.1

Table 1. Photo-activation parameters and results

- The protocol can be easily implemented into dental clinical practice by coupling the fibers with standardized commercial light guides
- Measuring the irradiance of the selected light source is necessary to adequately determine the exposure time
- Insufficient radiant exposure (i.e. lower than suggested by the manufacturer) compromises the DC and therefore material biocompatibility and mechanics