JOURNAL OF MATERIALS SCIENCE: MATERIALS IN MEDICINE **11** (2000) 361–364

Correlation between light intensity and exposure time on the hardness of composite resin

L. CORRER SOBRINHO, M. F. DE GOES, S. CONSANI, M. A. C. SINHORETI,
Department of Biomaterials, Piracicaba Dental School (UNICAMP), Avenida Limeira, 901, Piracicaba-SP, Post code 13414-900, Brazil

J. C. KNOWLES*
Department of Biomaterials, Eastman Dental Institute, 256 Gray's Inn Road, London, WC1X 8LD, UK
E-mail: j.knowles@eastman.ucl.ac.uk

This study evaluated the correlation between light intensity emitted by the curing units and exposure time on the of degree polymerization of dental composites by measured Knoop hardness. Specimens with 5 mm diameter and 2 mm height were prepared in a copper mold, covered with a mylar strip and polymerized for 30 sec by curing units with 50, 130, 180, 220, 280 and 520 mW/cm^2, respectively. The output for all units was measured using a Curing Radiometer (Demetron). Other specimens were polymerized for 45, 60, 75, 90, 105, 120, 135, 150, 165 and 180 sec utilizing units of 130, 220 and 280 mW/cm^2. Knoop hardness values of the top and bottom surfaces were measured after 24 h. The results indicate that the curing units with higher light intensity presented improved values of Knoop hardness on the top and bottom regions. As expected, the top surface always presented improved Knoop hardness values in relation to the bottom, after exposure for 30 sec. The values obtained on the surface were statistically superior compared to the values on the bottom ($p < 0.05$) for the intensity of 130, 220 and 280 mW/cm^2 after 30, 45 and 60 sec of exposure.

1. Introduction

The use of light to polymerize composite resins has increased in the last few years. The polymerization requires sufficient intensity of light and suitable wavelength to activate a light-sensitive material, containing a camphorquinone to react with a reducing agent [1]. This combination will result in the formation of free radicals, which can then migrate and initiate the polymerization of the resin [2]. The wavelength of light that causes the camphorquinine excitation is within the blue region of the visible spectrum, between 450 and 500 nm [3]. The intensity of this radiation is very important to produce a sufficient number of free radicals to cure the restorative composite material.

An adequate light with proper wavelength range must reach all areas of a light-activated restoration to ensure suitable polymerization and long-term clinical sucess. The cure depth is affected by many factors, including curing light, intensity, exposure time, distance from the curing tip and attenuation of the light by the composite resin [3, 4].

The polymerization depth is directly related to the thickness of the material and influenced by light intensity. Therefore, the top surface gives higher hardness values compared to the bottom surface, and the hardness may be improved by increasing exposure time [5–7].

In the last few years, the widespread use of light-sources has given rise to manufacturers producing several varieties of light-source. Nevertheless, these light-source units do not show any information about the quantity of energy emitted by them. However, many factors can affect the intensity of light-curing units, such as line voltage [8], condition of the bulb and filters [9], resin adherent to the curing tip end, and fracture of optic fiber bundles inside the curing unit [10]. Thus, the manufacturers have recently produced a large number of radiometers.

The radiometer is useful for measuring the light intensity of the curing unit in the amount of energy on a given surface area (mW/cm^2), in a limited wavelength range (400 to 520 nm). This is a way that clinicians can rely on to verify periodically the intensity of dental curing lights [11–13].

The purpose of this paper was to study the correlation between the light intensity emitted by curing units monitored by a radiometer and the exposure time on the polymerization degree of dental composite by Knoop hardness.

---

*Author to whom all correspondence should be addressed.

0957–4530 © *2000 Kluwer Academic Publishers*

2. Materials and methods

The specimens were made in a circular cavity with 5 mm diameter and 2 mm height, inside a sectional copper mold (10 mm diameter and 10 mm height) which permitted the removal of the specimens. The cavity was filled with composite resin (Herculit XRV-A3, Kerr Manufacturing Company, MI), covered with a mylar strip, and polymerized for 30 s. Three curing units (Heliomat-Vivadent Co., Rio de Janeiro) with intensity of 50, 220 and 280 mW/cm^2; two curing units (Fibralux-Dabi-Atlante Co., Ribeirão Preto) with intensity of 130 and 180 mW/cm^2; and one curing unit (Visilux 2 Dental Products/3M St Paul, MN) with light intensity of 520 mW/cm^2 were used. The light output for all units was measured by Curing Radiometer Model 100 (Demetron Research Corporation, Danbury, CT). Eighteen specimens were made for the control group. They were divided into three groups of three specimens for each light intensity used.

Three specimens were made using light emission at 45, 60, 75, 90, 105, 120, 135, 150, 165 and 180 sec utilizing Fibralux with 130 mW/cm^2 and Heliomat with 220 and 280 mW/cm^2 curing units. These 90 specimens were considered experimental groups.

After the polymerization procedure, the specimens were removed from the copper mold and stored at 37 ± °C and 95 ± 5% relative humidity for 24 h. After storage, the specimens were put in a vertical position and embedded in polyester resin (Resapol T208). (Norton S.A., Brazil) and submitted to metallographic polishing (Metalserv-Rotary Pregrinder, UK) with chromiun oxide (0.03 μm) and alumina (0.05 μm) aqueous solution.

Microhardness indentations were made across a section of the composite resin using a Durimet (Leitz Wetzlar, Germany), with a 50 g load by 30 sec. Five measurements were made on both top and bottom of each specimen. The mean measurements for each surface were converted to Knoop hardness number (KHN), and submitted to Tukey's statistical analysis.

3. Results

The mean values of Knoop hardness for the composite resin exposed for 30 sec are shown in Table I. The greater hardness values in the top region were obtained with 280 and 520 mW/cm^2 light intensities, as expected, with no statistical difference between them. In the bottom region, the greater values were obtained with 520 mW/cm^2. The top surface always presented statistically superior hardness values in relation to the bottom ($p < 0.05$) with all (50, 130, 180, 220, 280 and 520 mW/cm^2) light intensities after an exposure time of 30 sec.

Figs 1–3 show the mean values of hardness for light intensities of 130, 220 and 280 mW/cm^2. Top and bottom surface hardness improved with increasing exposure time. Knoop hardness values obtained in the surface region were statistically superior when compared to the values obtained on the bottom region ($p < 0.05$) for 130, 220 and 280 mW/cm^2 light intensities after 30, 45 and 60 sec of exposure. The other exposure times (75 to 180 sec) gave no statistical difference between the top and bottom regions.

4. Discussion

Visible light with proper wavelength and sufficient intensity is essential for adequate polymerization of light-activated composite resins [4]. The radiometer used in this study showed that decreasing the light intensity decreased the top and bottom hardness. Thus, the radiometer manufacturers state that there is a direct relationship between emitted intensity and depth of cure. Instructions for the Curing Radiometer model 100, indicate that an intensity of 300 mW/cm^2 or more should provide a 3 mm cure depth. However, the data from this study contradict that statement. We verified that the increments should not be greater than 2 mm and other authors show 1 mm thickness is ideal for improving the composite resin hardness [14].

Duration and exposure intensity of visible light are important factors in composite resin polymerization. Composite resin requires sufficient intensity of the light and suitable wavelength for the camphorquinone activation responsible for initiating polymerization [15]. Continuing exposure sustains the camphorquinone activation near the surface. The curing units with intense light showed superior Knoop hardness values on the top and bottom regions.

In our study, the Knoop hardness values obtained on the top surface were statistically superior in relation to the values obtained on the bottom for 130, 220 and 280 mW/cm^2 light intensities after 30, 45 and 60 sec of exposure, but they were similar after 60 sec. Similar results were obtained in previous studies [16, 17].

In addition, prolonged irradiation time is effective in increasing the hardness, especially at the deeper levels of the specimens [5, 17–20].

Inadequate polymerization indicates a reduction in the physical properties of composite resin. Changes in strength, water sorption, stiffness, toughness and color

TABLE I The mean values (KHN) obtained on the top and bottom surfaces of the composite resin specimens, exposed for 30 sec and cured with 50 to 520 mW/cm^2 light intensity

Light intensity (mW/cm^2)	Top	SD	Bottom	SD
50	56.02 a, A	0.92	36.40 b, A	1.34
130	65.22 a, B	1.04	56.81 b, B	1.08
180	69.98 a, B	1.63	59.47 b, B	1.58
220	76.60 a, C	1.17	67.42 b, C	1.10
280	80.86 a, CD	2.02	72.85 b, C	1.63
520	84.80 a, D	1.98	80.64 b, D	1.41

Means followed by the same small letter in the line and capital letter in column indicate no statistical difference at the 95% confidence level (Tukey's test, $p < 0.05$).

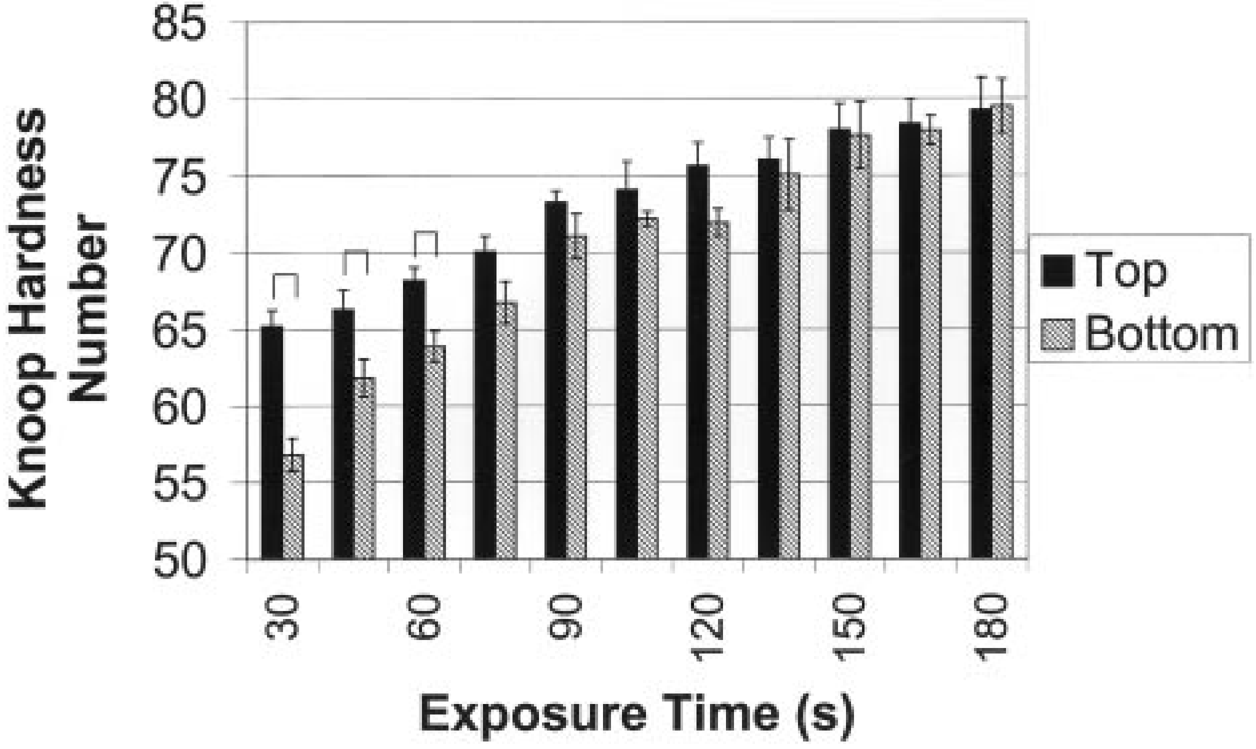

Figure 1 Mean values (KHN) of the top and bottom surfaces, exposed for 30 until 180 sec and cured with 130 mW/cm^2 light intensities.

stability are significant problems when approximation of the curing tip end in class II restorations is impossible [21].

The curing times recommended by manufacturers should be extended to cure the composite regardless of the restoration depth [4, 20]. On the other hand, some investigators had concluded [4, 12] that the radiometers are not fully reliable. Instead they can become very useful for monitoring the output from a curing unit periodically by clinicians to maximize the cure of composite resin [2, 11–13]. In addition, according to our study, the clinician should utilize curing units with light intensity greater than 280 mW/cm^2 and 75 sec of exposure.

5. Conclusions

The results of this paper show that: (1) Curing units with higher light intensity improved the Knoop hardness

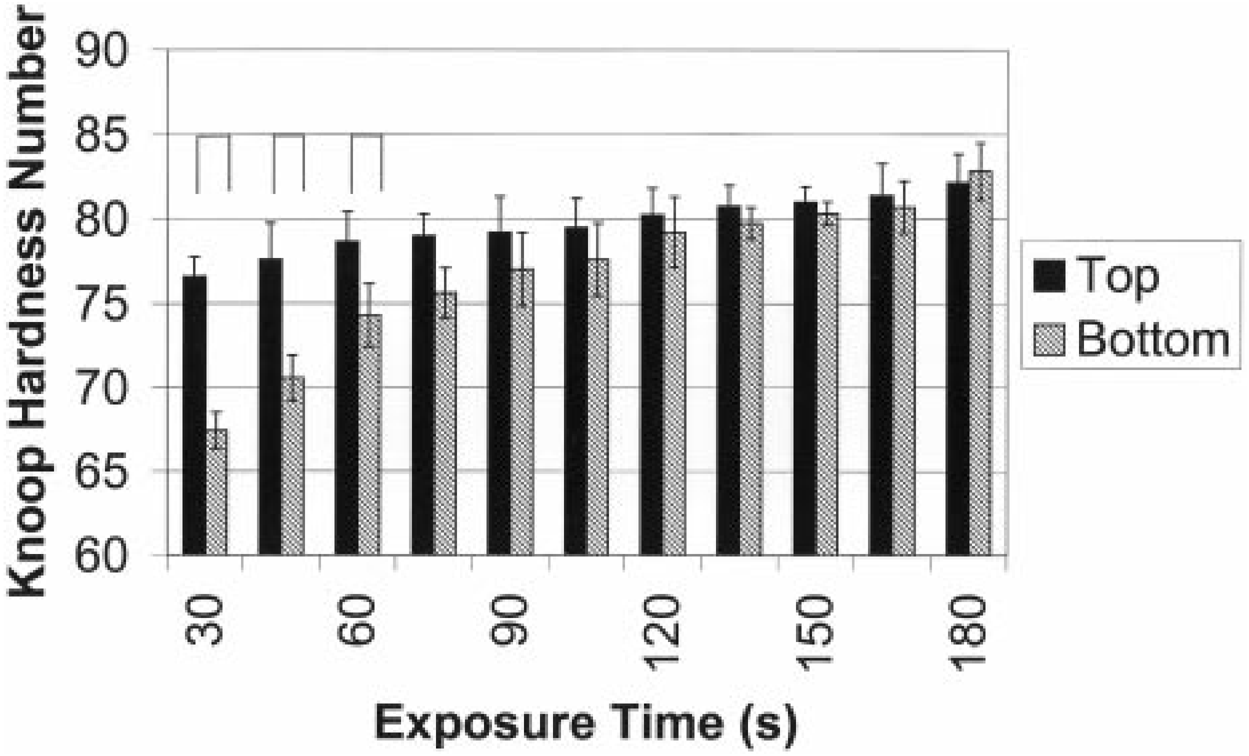

Figure 2 Mean values (KHN) of the top and bottom surfaces, exposed for 30 until 180 sec and cured with 220 mW/cm^2 light intensities.

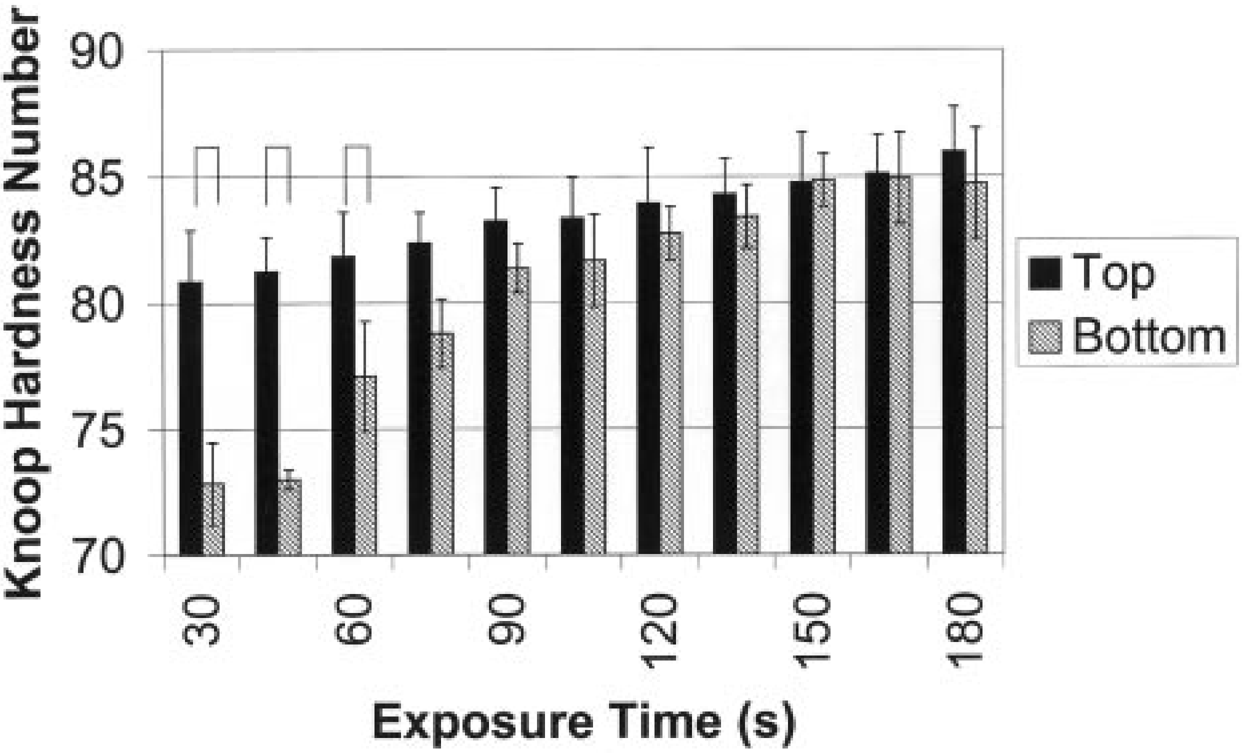

Figure 3 Mean values (KHN) of the top and bottom surfaces, exposed for 30 until 180 sec and cured with 280 mW/cm^2 light intensities.

values on the top and bottom regions. The top surface always presented statistically superior Knoop hardness values in relation to the bottom at 50, 130, 180, 220, 280 and 520 mW/cm^2 intensities and after 30 sec exposure ($p < 0.05$). (2) The same results were obtained with 130, 220 and 280 mW/cm^2 after 30, 45 and 60 sec exposure. The exposure times of 75, 90, 105, 120, 135, 150, 165 and 180 sec did not present a statistical difference between the two regions.

References

1. W. D. COOK, *J. Dent. Res.* **59** (1980) 800.
2. F. A. RUEGGEBERG, *Quintessence Int.* **24** (1993) 391.
3. American Dental Association, *J.A.D.A.* **110** (1985) 100.
4. J. A. PIRES, E. CVITKO, G. E. DENEHY and E. J. SWIFT JR, *Quintessence Int.* **24** (1993) 517.
5. H. BAHARAV, D. ABRAHAN, H.S. CARDASH and M. HELFT, *J. Oral Rehabilit.* **15** (1988) 167.
6. W. D. COOK, *Biomaterials* **7** (1986) 449.
7. C. DE LANGE, J. R. BAUSCH and C. L. DAVIDSON, *J. Oral Rehabilit.* **7** (1980) 369.
8. P. L. FAN, W. T. WOZNIAK, W. D. REYES and J. W. STANFORD, *J.A.D.A.* **115** (1987) 442.
9. D. C. WATTS, O. AMER and E. C. COMBE, *Brit. Dent. J.* **156** (1984) 209.
10. B. F. POLLACK and A. L. LEWIS, *General Dent.* **29** (1981) 488.
11. C. S. FOWLER, M. L. SWARTZ and B. K. MOORE, *Operat. Dent.* **19** (1994) 47.
12. E. K. HANSEN and E. ASMUSSEN, *Scand. J. Dent. Res.* **101** (1993) 115.
13. S. Y. LEE, C. H. CHIU, A. BOGHOSIAN and E. H. GREENER, *J. Dent.* **21** (1993) 373.
14. F. A. RUEGGEBERG, W. F. CAUGHMAN and J. W. CURTIS JR, *Operat. Dent.* **19** (1994) 26.
15. R. J. BLANKENAU, W. P. KELSEY, W. T. CAVEL and P. BLANKENAU, *J.A.D.A.* **106** (1983) 471.
16. J. C. NEO, G. E. DENEHY and D. B. BOYER, *J.A.D.A.* **113** (1986) 100.
17. S. MASUTANI, S. ARAI, S. ANDO, K. NAKAGAWA and H. J. ONOSE, *Dent. Res.* **66** (1987) 126.
18. R. L. LEUNG, P. L. FAN and N. M. JOHNSTON, *J. Dent. Res.* **61** (1982) 248.
19. *Idem.*, *J. Dental. Res.* **62** (1983) 363.
20. H. MATSUMOTO, J. E. GRES, V. A. MARKER, T. OKABE, J. L. FERRACANE and HARVEY, *J. Prosth. Dent.* **55** (1986) 574.
21. M. L. SWARTZ, R. W. PHILLIPS and B. RHODES, *J.A.D.A.* **106** (1983) 634.

Received 6 October 1998
and accepted 30 April 1999