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Curing Times of P40 Exposed to Different Light Sources

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Abstract: Glass casting chambers were filled with P40 resin and placed under different light sources to record curing rates and temperatures reached during the process. Results were used to assess the effects of different light sources and the method of application of that light on the curing of P40 resin. It was found that curing of P40 resin was achieved by exposure of the resin to sunlight, artificial UV-A light and mercury lighting. Fluorescent lighting had no effect on P40 resin. Curing rate was increased as was maximum temperature reached during the process when light sources were allowed unregulated interaction with the resin.

Key words: **plastination; P40; light; ultraviolet; UVA; sunlight; mercury; curing**

Introduction

P40 polyester plastination was designed to produce permanent preservation of tissue slices within a rigid, durable sheet of cured resin (von Hagens, 1994). These polyester plastinated specimens are for educational and research purposes (Barnett, 1997; Weiglein and Feigl, 1998; Henry and Weiglein, 1999; Sora et al., 1999; Latorre et al., 2002). Although designed for plastination of brain slices (Henry and Latorre, 2007), P40 plastination may also be used for plastination of other tissues (Latorre et al., 2004) as well as body slices (Latorre et al., 2007). P40 plastination relies on ultraviolet radiation to cure the resin. This study will examine the effects of different sources and delivery of UV light on the curing times and temperatures during curing of P40 resin.

Materials and methods

Glass casting chambers were constructed as described by Henry and Latorre (2007). P40 resin, without catalyst, was poured into the chambers and the chambers were left open on one end. These chambers filled with P40 resin were exposed to different light sources until cured. All chambers were monitored for temperature changes and curing time during the experiment. Curing was monitored by inserting a wire through the open side of the chamber and into the resin. The three delivery methods of the light sources used for exposures included the following: uncontrolled, direct exposure; uncontrolled, indirect exposure; exposure under controlled conditions. Light source/light exposure combinations tested in this experiment included direct sunlight, indirect sunlight, controlled exposure to direct sunlight, controlled exposure to artificial UV-A light, fluorescent light, mercury light, controlled exposure to mercury light and exposure to combined fluorescent and mercury lighting. Temperatures during experiments were recorded and regulated when required using an Omega CN4400 thermo-regulator. Curing of the P40 resin was monitored by probing the chamber contents with a wire and by external visual observations.

Experiment 1: Chambers exposed to direct sunlight were placed outdoors in sunlight on a non-cloudy day in June in Tennessee (30 ^{o}C) and left to cure. The temperature of the surface of the glass chamber and the progress of curing were monitored every 10 minutes.

Experiment 2: Chambers exposed to indirect sunlight were placed outdoors in the shade on a non-cloudy day in June in Tennessee (30 ^{o}C) and left to cure. The temperature of the surface of the glass chamber and the progress of curing were monitored every 10 minutes.

Experiment 3: Chambers under controlled exposure to direct sunlight were placed in the sun on a non-cloudy day in June in Tennessee (30 ^{o}C). The temperature of the surface of the glass chamber and the progress of curing were monitored every 10 minutes. When the surface temperature of the casting chamber reached or exceeded 30^{o}C, the chamber was moved into the shade and cooled with a fan to 25^{o}C at which point it was returned to the direct sun.

Experiment 4: Chambers with controlled exposure to artificial UV light were placed 28.0cm from four 40 watt UV-A light bulbs (two above and two below) and cooled with a fan during the entire experiment (Fig. 1). The temperature of the surface of the glass chamber and the progress of curing were monitored every 10 minutes. When the surface temperature of the casting chamber reached at least 30^{o}C, the light source was turned off until the temperature of the chamber reached 25^{o}C. At that point, the bulbs were turned on once again.

Experiment 5: Chambers exposed to fluorescent lighting were placed on a table top and exposed to fluorescent lighting in a room with no windows. The fluorescent bulbs were located 150.5cm from the casting chamber. The temperature of the surface of the glass chamber and the progress of curing were monitored every 10 minutes.

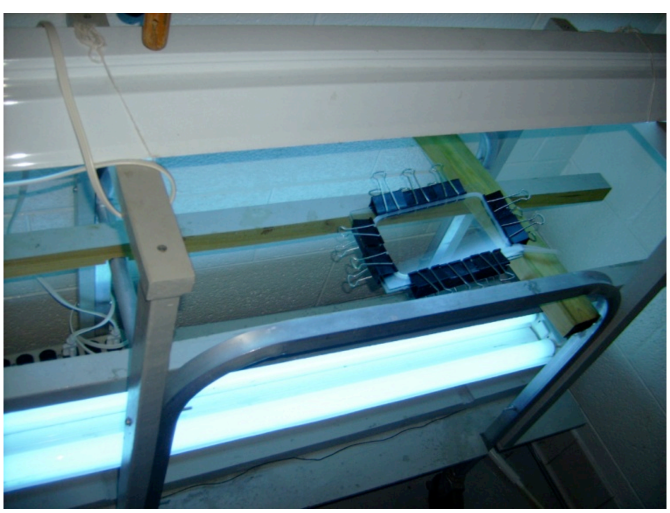

Figure 1. Typical UV-A light source used to cure P40 resin.

Experiment 6: Chambers exposed to direct mercury light were placed within a cardboard shield 58.4cm beneath the mercury bulb. The shield was used to keep out fluorescent light which was also present within the room. The temperature of the surface of the glass chamber and the progress of curing were monitored every 10 minutes.

Experiment 7: Chambers exposed to direct mercury light were placed within a cardboard shield 58.4cm beneath the mercury bulb (Fig. 2) and cooled with a fan during the entire experiment. The shield was used to keep out fluorescent light which was also present within the room. The temperature of the surface of the glass chamber and the progress of curing were monitored every 10 minutes. When the surface temperature of the casting chamber reached at least 30^{o}C, the light source was turned off until the temperature of the chamber reached 25^{o}C. At this point, the mercury light was turned on once again.

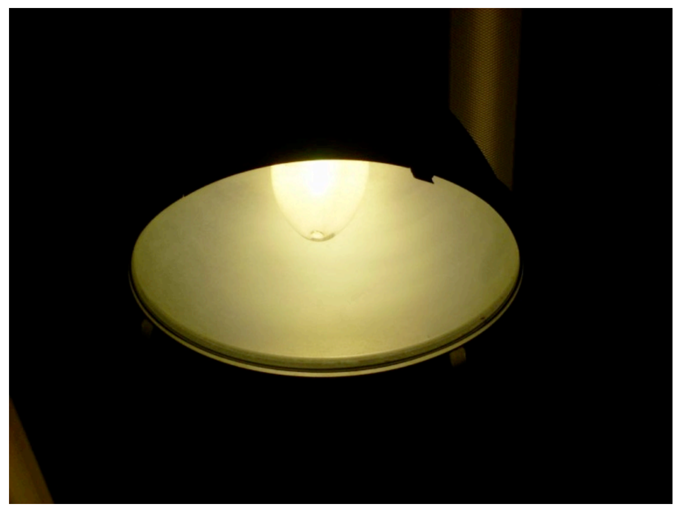

Figure 2. Mercury light source used to cure P40 resin.

Experiment 8: Chambers exposed to combined fluorescent and mercury lighting were placed on a table top 233.7cm beneath the mercury bulb while also exposed to light from fluorescent bulbs within the room. The temperature of the surface of the glass chamber and the progress of curing were monitored every 10 minutes. The chamber was 302.3cm from the fluorescent lights.

It should be noted that curing of all chambers was considered complete when all but the top 5mm of P40 resin was hard enough to resist the insertion of a metal wire. The P40 resin at the air-interface of an open chamber will not cure due to the resin being in contact with air.

Results

Experiment 1: The P40 resin in chambers exposed to direct sunlight with no temperature regulation formed a solid gel by 20 minutes of exposure and cured completely within 40 minutes. The maximum temperature recorded during the curing process was 68°C and resulted in breakage of the glass used to form the casting chamber.

Experiment 2: The P40 resin in chambers exposed to indirect sunlight with no temperature regulation formed a solid gel by 40 minutes of exposure and cured completely within 80 minutes. The maximum temperature recorded during the curing process was 44°C.

Experiment 3: The P40 resin in chambers exposed to direct sunlight under controlled conditions formed a solid gel by 30 minutes of exposure and cured completely within 40 minutes. The maximum temperature recorded during the curing process was 40°C.

Experiment 4: The P40 resin in chambers exposed to artificial UV light under controlled conditions formed a solid gel by 30 minutes of exposure and cured completely within 40 minutes. The maximum temperature recorded during the curing process was 36°C.

Experiment 5: The P40 resin in chambers exposed to fluorescent lighting never exhibited any signs of curing or the onset of curing by 40 hours into the experiment. The resin remained liquid in form and no increase in surface temperature of the glass chamber was detected at any time. These chambers were exposed to fluorescent lighting for eight to nine hours per day for an additional month post experimentation and curing of the P40 resin was never initiated and the resin remained in liquid form.

Experiment 6: The P40 resin in chambers exposed to mercury lighting with no temperature regulation at close proximity formed a solid gel by 70 minutes of exposure and cured completely within 90 minutes. The maximum temperature recorded during the curing process was 34°C.

Experiment 7: The P40 resin in chambers exposed to mercury lighting under controlled conditions in close proximity to the light source formed a solid gel by 70 minutes of exposure and cured completely within 90 minutes. The maximum temperature recorded during the curing process was 60°C.

Experiment 8: The P40 resin in chambers exposed to fluorescent lighting and mercury lighting, at the increased distance, formed a solid gel by 80 minutes of exposure and cured completely within 180 minutes. The maximum temperature recorded during the curing process was 24°C.

A summary of findings is listed in tables 1 and 2.

Light source	Cure times
Direct sunlight	30 minutes
Indirect sunlight	80 minutes
Controlled exposure to direct sunlight	40 minutes
Artificial UV-A light	40 minutes
Fluorescent lighting	did not cure
Mercury lights	90 minutes
Controlled exposure to mercury lights	130 minutes
Mercury and fluorescent lighting combined	180 minutes

Table 1. Curing times of P40 resin when exposed to different light sources.

Light source	Maximum temperature
Direct sunlight	68 °C
Indirect sunlight	44 °C
Controlled exposure to direct sunlight	40 °C
Artificial UV-A light	36 °C
Fluorescent lighting	N/A
Mercury lights	60 °C
Controlled exposure to mercury lights	34 °C
Mercury and fluorescent lighting combined	24 °C

Table 2. Maximum temperatures reached during curing when P40 resin is exposed to different light sources.

Discussion

As expected, ultraviolet light sources provided the fastest cure rates of P40 resin as they are the suggested method of initiating the curing process. Cure rates were similar for both natural sunlight and artificial ultraviolet light sources when the P40 resin was placed directly within the light source. Curing P40 outdoors in the shade doubled the time for curing when the times were compared to direct exposure to UV sources regardless of temperature regulation. P40 resin was not exposed to the artificial source of ultraviolet light in the absence of temperature regulation as it would result in the breaking of the glass of the chamber. It was discovered that placing the curing chambers in direct sunlight without temperature control would result in the breaking of the glass of those chambers as well.

Direct exposure to mercury lighting produced a curing time of P40 resin similar to that of outdoor shade. Temperature control during curing of P40 with mercury lighting increased cure time by approximately 45% when compared to direct mercury lighting. When the distance from the mercury bulb was increased, the curing time was markedly increased.

Fluorescent lighting was found to have no effect on the curing of P40 resin. As no increase in temperature of the glass chamber was observed, no exothermic reaction as occurs in curing of P40 resin was present. The P40 resin used in this stage of the experiment was derived from the same stock used to fill all other casting chambers and should have cured if fluorescent lighting had an effect on P40 resin. After it was determined that fluorescent lighting would not cure the resin as it is not ultraviolet in nature, we set those casting chambers in the sun. The P40 resin in those chambers that did not respond to fluorescent lighting did cure in sunlight. This trial with fluorescent lighting was included within the experiment as it would be a common source of light within a laboratory setting.

It has been suggested that P40 slices be cured a minimum of 1 hour (Henry and Latorre, 2007). While there was some relatively small variation in cure times, each of the ultraviolet light source trials (artificial or natural) reached the peak of the exothermic process within 70 minutes (range was 30 to 70 minutes). This variation can likely be explained by dissimilarities in sample positioning, time of day, atmospheric conditions and efforts to control excessive temperatures. The P40 resin was often cured to the point of resisting the insertion of metal wire prior to peak of the exothermic reaction. These trials confirm that approximately 1 hour of curing should be appropriate for ultraviolet light exposure to cure P40 resin.

The sample exposed to the combined mercury and fluorescent light sources (normal laboratory lighting in the institution hosting the experimentation) cured in approximately three hours. The increased curing time was due to the increased distance of the glass chamber from the source of light. Given the results of the fluorescent lighting trial, it is unlikely that the fluorescent source contributed any to the progress of the reaction. In order to expose P40 to mercury light only, the cardboard isolation shroud not only placed the glass chamber in close proximity to the source of light but also increased the temperature in and around the glass chamber due to the shroud holding in any heat produced by the mercury bulb or the exothermic curing reaction. Thus, the maximum reported temperature for the unregulated exposure to mercury lighting is most likely artificially increased. It would be unnecessary for one to use such a shroud to cure P40 as mercury lighting will cure at a great distance. It would not be proper to use artificial UV light to cure P40 at a distance as the exposure of the light to one’s eyes is detrimental. For the combined mercury and fluorescent lighting trial, the glass chamber was simply placed on a work table in the middle of the lab in order to approximate normal conditions likely to be encountered during assembly, sample positioning, etc. Although the mercury light source should be producing the same amount of ultraviolet radiation in both trials, the waves will be spread over a larger surface area at the increased distance. As a result, the concentration of ultraviolet waves per unit area in the combined trial would be less. The inverse square law can be used to determine the influence of distance on ultraviolet ray exposure.

$$\mathit{Intensity} = \text{original intensity} \times \frac{\text{New distance}^2}{\text{Old Distance}^2}$$

Mercury lights will also lose intensity as they age so if one were to use such a source, cure rates should be expected to increase as the mercury bulb ages.

While it is unlikely that anyone would use one of these alternative light sources to cure P40 samples, knowledge of their respective cure rates, and that of ultraviolet sources, is of practical value. Given the absence of an effect of fluorescent lighting on P40 resin, it is reasonable to avoid rushing during sample preparation. Experimenters should be mindful of any mercury lighting which may be present within a laboratory or of any sunlight entering a window whether it be a direct ray or merely ambient lighting. Additionally, the knowledge of expected cure time is useful when planning monitoring frequency. One may also wish to use mercury lights for curing of P40 resin should an artificial UV light apparatus be cost prohibitive or not allowed due to safety concerns.

The times recorded for the solid gel formation within the resin should be heeded as once this gel has formed, any tissue samples that may have slipped within the resin (i.e. to the edge of the chamber or into a second tissue sample within the chamber) may not be repositioned.

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