Photopolymerization of Composite Resin Using the Argon Laser

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Abstract

Because of the dental profession's increased utilization of light-cured restorative materials, there has been a corresponding increase in research into the light sources used to initiate polymerization. The argon laser is one promising source, as the wavelength of light emitted by this laser is optimal for the initiation of polymerization of composite resins. The literature reflects a strong divergence of opinion about many aspects of the effectiveness of laser curing compared to conventional light curing. Research indicates that the argon laser offers a greater depth and degree of polymerization, less time required and an enhancement of the physical properties of composite resins polymerized. These advantages are offset by reports that the increased polymerization caused by the laser results in increased shrinkage, brittleness and marginal leakage. Dentists interested in the new technology need to monitor ongoing studies.

MeSH Key Words: *argon; composite resins; lasers*

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The first laser, a pulsed ruby laser, was developed by Theodore H. Maiman in 1960.[1] Since that time, dental interest in lasers has been high and research has been continuing into ways to improve dental treatment through laser application.[2] Since the early 1980s, one research focus has been the use of the argon laser for photopolymerization of composite resin restorative materials.[3] This interest has arisen because the wavelength (488 nm) of light emitted by the argon laser is optimal for the initiation of polymerization of composite resins.[4] Photo-activated composite resin polymerizes when the initiator (camphoroquinone) in the resin is activated by light.[5,6] Camphoroquinone activation is initiated by a hue of blue light that has a wavelength within the range of 400 to 500 nm, with broad peak activity in the 480-nm range.[3,7]

Conventional visible light curing (VLC) units consist of white light with unwanted wavelengths filtered out,[3] thereby producing a polychromatic spectrum of blue light. The resulting hue and brightness of the colour are of wide spectrum and low intensity, respectively. In research on composite-resin photopolymerization, VLC units can activate camphoroquinone, but optimum curing power is not achieved, and the units often fail to meet the challenges presented by more complex resin restorations.[8] Additionally, the hue and brightness parameters of conventional VLCs are not uniform over time. Bulbs, reflectors and light tips degrade, and filters become baked from heat generated by the units. As a result, the spectrum of light is slowly altered.[8,9] These changes may result in a lack of predictability and consistency in restoration quality.

Unlike VLC units, the argon laser does not employ the use of filters. Instead, it generates one wavelength of blue light (i.e., the light is monochromatic) having a band width of only 40 to 45 nm.[4,10] In addition, the brightness of the light can be set to the manufacturer's specifications for optimum efficiency, unique for each brand of composite resin. Some lasers can be calibrated before each cure, ensuring standard treatment for each patient. As with conventional VLC units, exposure time can be adjusted as necessary.

Laser photons travel "in phase" (i.e., are coherent), and are collimated such that they travel in the same direction.[1,10] Less power is put out by the argon laser units than the conventional VLCs, yet they can cure the resin more effectively because the wavelength of the light is specific to the job being performed. VLC units emit wide bandwidths of 120 nm, resulting in a broad spectrum of wavelengths that overlap and are said to be "out of phase," or incoherent.[10] Two photons of incoherent light that are 180 degrees out of phase can cancel each other, resulting in decreased curing power and less polymerization of the composite resin. VLC units also produce a divergent beam of light, resulting in a loss of 40% of energy 6 mm from the curing surface. In contrast, the argon laser emits a collimated (narrow, focused, nondivergent) beam focusing on a specific target, resulting in a more consistent power density over distance.[4,8,11,12]

Advantages

Because of the properties of the argon laser described above, the thoroughness and depth of composite resin polymerization are greater with this laser than they are when VLC sources are used. Less unpolymerized monomer is found in resins cured by argon laser compared to those cured with VLC units.[8,11] This thoroughness results in the enhancement of certain physical properties of the laser-cured composite resin, including compressive strength, diametral tensile strength, transverse flexural strength and flexural modulus.[4,8,11,13]

Wear resistance is equivalent when using either method of polymerization,[14] but argon laser polymerization has demonstrated the potential to improve shear bond strengths in both enamel and dentin.[15,16] Another study found no significant difference between bond strengths using argon laser and halogen lamp curing units.[17] However, a significant difference was reported in bond strengths according to distance between the resin surface and the light source. The authors found that the laser-cured bond strengths did not decrease with increasing distance, whereas there was a significant decrease in halogen-cured bond strengths at distances greater than 0.5 mm. Furthermore, in all the above studies, the laser required less time to achieve equivalent or greater polymerization of the restorative material.[4,8,11,13,15-17] One manufacturer claims that the argon laser needs only one-fourth of the exposure time: 10 seconds for 2 mm depth of cure compared to the 40 seconds recommended for VLC systems (Dentalaser Brochure 1998, Premier Laser Systems, Inc.).

Finally, from a practice marketing perspective, laser utilization may present an image to the public of an office dedicated to staying abreast of the latest technology. The perception of the lay public and patients' perception and acceptance of laser utilization in dentistry have been shown to be positive.[2,18,19]

Disadvantages

Although the size, weight and portability of newer argon laser curing units have improved greatly over the older ones, at approximately 20 pounds the unit is still fairly cumbersome and occupies considerably more space than a conventional VLC unit. The laser can generate a substantial amount of heat, the cooling fans tend to be noisy, and there is a 30-second time lag between turning the unit on and actual light emission.[20] These shortcomings can be overcome, in part, with units now available that can be centrally installed, with curing wands radiating into individual operatories.

Because the technology in the dental office is still new, cost of the argon laser curing unit is a deterrent to its acquisition. Depending on the manufacturer, portable argon curing lasers range from $12,000 to $20,000, and central installation may incur additional expenses. Added to the cost consideration is the fear of rapid obsolescence in an arena of rapid technological change.[21]

When laser light strikes a target, it may be absorbed, transmitted, scattered or reflected. When laser light is transmitted, tissue boundaries are crossed and tissues other than the target material are irradiated. Consequently, whenever a laser is used in the oral cavity, the dentist must determine the risk to surrounding tissues.[12] When using the argon laser to remove intracanal debris in extracted teeth, Moshonov and others found that in dry canals after a few seconds it was impossible to hold the teeth between fingers because the root surface became too hot.[22] Although power densities used by Moshonov were considerably higher than those used for photopolymerization, the finding nonetheless points to the need for consideration of periodontal and pulp tissues.

It has been demonstrated, *in vitro* using extracted human teeth and *in vivo* in dogs, that there is a temperature rise in the dentinal roof of the pulp chamber as well as within the pulp itself when an argon laser is used to cure composite resin in cavity preparations.[23,24] However, the peak temperature increases within the pulp chamber were believed to represent no significant pulpal risk when using the low limits of laser energy recommended to cure composite resin. There is little chance of leaving the laser on the tooth long enough to damage the pulp.[24] It has been shown, however, that extended curing times can have deleterious effects on the parakeratinized gingiva of dogs. When 10-, 20- and 30-second exposure times were tested, minimal effects were noted following the 10- and 20-second exposure times, whereas necrosis, disruption and vesiculation were noted five days after application of 30-second exposures.[25]

Short-wavelength light is more energetic than long-wavelength light.[10] The argon laser beam is in the short-wavelength blue light spectrum, which has the highest energy photons of any wavelength of visible light. Its energy level is only slightly less than that of ultraviolet light, which has a well-documented history of posing a biohazard. Consequently, extreme care must be exercised to avoid direct exposure of the patient's eyes, as exposure could result in immediate visual damage. Additionally, concern has been expressed that indirect exposure by reflection could also harm the operator's eyes over time.[26]

Although there are numerous reports of enhanced physical properties of laser-polymerized composite resins, there are conflicting reports about the marginal seal obtained with argon laser curing. Increased shrinkage and brittleness of some small-particle resins has been reported when they have been cured with a laser.[20] No significant change was shown in linear polymerization shrinkage in one *in vitro* study,[27] and another study showed that laser-cured pit and fissure sealants demonstrated a superior seal to those cured with visible light.[28] However, Class V composite restorations in extracted primary and permanent human teeth showed a higher degree of microleakage in the laser-cured group compared to the light-cured group. These differences were significant using a dye leakage measurement but not significant using an isotope leakage measurement.[29] Another study investigated the possibility of obturating root canals using argon laser-cured composite resin. SEM evaluation revealed resin penetration into tubules; however, the observation of tears and gaps between resin and canal walls led the authors to suggest that polymerization shrinkage affected dentin adhesion.[30] A possible explanation for these conflicting results is that a durable composite dentin bond can be formed only on flat surfaces or in very shallow cavities. In other situations, the polymerization contraction will disrupt the dentin bond.[29,31] One author suggests that this disruption could be attributed to the increased penetration and heat of the laser, which results in both a greater degree of polymerization and a higher degree of polymerization shrinkage compared to conventional light curing.[29]

Pulsed argon laser curing may be the solution for the shrinkage problem. Pulsing, or periodic interruption of the laser beam, can be precisely controlled in nanoseconds. The theory is that interruption of the beam allows the target material to cool between laser pulses, thus preventing overheating. Two studies have shown promising results in reduced polymerization shrinkage;[32,33] however both studies compared a nano-pulsed blue dye laser and a continuous wave argon laser. Since the dye laser is a completely different instrument from the argon laser, it is difficult to conclude whether their results were due to pulsing of the laser beam or use of a different laser.

Recent research on the influence of light intensity has suggested that the more rapid rate of cure obtained by high-intensity curing does not allow enough time for stress relaxation by flow of partially cured material.[34] *In vitro* results with conventional VLC units have shown that the use of high-intensity curing has a negative effect on the marginal integrity of the final restoration.[34-36] However, light-initiated prepolymerization at low intensity followed by a post-light-cure at full intensity (soft-start polymerization) significantly improved the marginal integrity of light-cured composite fillings.

If these results can be extrapolated to the argon laser, perhaps the greater depth of penetration and intensity of the laser beam result in a rapid polymerization with no chance for stress relaxation. Pulsing the beam may lessen this disadvantage by allowing the partly cured resin to flow and thereby reducing overall shrinkage. However, the intensity of the pulses remains the same. It may be beneficial to prepolymerize at a lesser intensity or with a conventional light source to reduce polymerization shrinkage. At the very least, this finding illustrates the reality of rapid changes in laser dentistry technology and the need for further research.

The reported enhancement of physical properties achieved by laser polymerization may become less significant with aging of the cured resin. When diametral tensile strength values for a hybrid resin were compared over time, argon laser activation resulted in higher early values than conventional visible light curing, but these differences essentially disappeared at 20 days.[37] Because the reaction of polymerization continues after initiation, the samples cured with the VLC units increased in strength over the 20-day period.

Clinical Significance

As dental technology continues to evolve, new methods of performing certain dental procedures will continue to replace those once thought as the pinnacle. The argon laser may be one such example. Its use in polymerizing composite resins clearly demonstrates an immediate higher degree of polymerization than is obtained with VLC units. This enhanced polymerization is reflected in the resultant improvement in physical properties and bond strengths.

Although the enhancement may be a temporary effect, it may nonetheless have important clinical implications in preventing early restoration failures. Not only is early maximal polymerization important to avoid retention failures, it is also important in reducing adverse pulpal responses to unpolymerized monomer. It must be noted, however, that reports of decreased pulpal sensitivity when curing composites with the argon laser are anecdotal only.

The reduction in polymerization times provided by the argon laser may prove beneficial in reducing chairside time and achieving patient satisfaction, especially with restless children. It could also be helpful in situations where maintenance of a dry field for any length of time is difficult. Also, in cases where it is impossible to place the light wand in close proximity to the restoration, the laser beam offers the advantage of no loss of power over distance, as is suffered by the VLC unit. The increased penetration depth of the argon laser may make it possible to cure thicker increments satisfactorily or to cure through thicker sections of tooth. It could also make it possible to control the direction of polymerization shrinkage by curing through the tooth. These advantages may make the argon laser an important tool when placing restorations that are complicated or in hard-to-reach areas. On the other hand, the narrow, focused beam of the laser may make angulation of the handpiece more critical in areas of compromised access.

The argon laser can be used to initiate polymerization in any of the currently used light-activated restorative materials. In addition to restorative composite resins, this growing family includes bases, liners, pit and fissure sealants and impression materials. Therefore, the argon laser may prove to be quite versatile clinically.

The question of marginal leakage is a serious one. If excessive polymerization shrinkage offsets the benefits realized by using the argon laser, then there is no overall gain. In fact, a negative effect may result. If polymerization shrinkage can be reduced only by using a lesser intensity over a longer exposure time, then no time benefits are realized. If polymerization shrinkage is reduced only by using a different laser, then there is a heavy financial penalty for trying to stay abreast of technology. To justify such an expensive piece of dental equipment, longitudinal studies must be closely followed. In the meantime, clinicians should keep up to date about this new technology and critically evaluate the current literature before making an irreversible decision.

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