The concept of high concentration hydrogen peroxide used in-office to produce an almost immediate bleaching result dates back to the early 1900s.\(^1\) To accelerate the bleaching process, the bleaching agent can be additionally heat activated. This idea of power bleaching dates back to 1918, when Abbot reported the use of high-intensity light to increase the temperature of hydrogen peroxide.\(^2\) The use of direct heating has gradually decreased in recent years. It has been replaced by other energy sources, such as plasma-arc devices, halogen lamps, light emitting diodes, and other light sources.

Lamps emitting long wavelengths, i.e., visual spectrum or the larger invisible infrared (IR) spectrum, have lower-energy photons with a high thermal character, and these may induce unfavorable thermal effects. Shorter wavelengths, such as the argon laser (\(\lambda = 488\) nm) or KTP laser (\(\lambda = 532\) nm; Kalium-Titanyl-Phosphat [German], or Potassium-Titanyl-Phosphate [English]) have higher energy photons with less direct thermal characteristics.\(^3\)

Data on mechanisms of action and efficacy of laser, and light- and heat-activated dental bleaching are still limited.\(^4\) However, it is common to all described light-activated bleaching procedures that light is used in addition to the application of a bleaching agent (such as a bleaching gel) rather than on its own. It is the effect the light or heat has on the chemical bleaching product

**Abstract:** Different external bleaching procedures utilizing highly concentrated hydrogen peroxide formulations can be used for tooth bleaching and tooth whitening. Whitening is the removal of superficial discoloration of the teeth, whereas bleaching constitutes the removal of stains on and in tooth substance by means of oxygen radicals. Light can be used to enhance or accelerate the bleaching process. In most cases, the effect of light is limited to heating of the bleaching formulation and this process differs from “true photobleaching”. Photobleaching or photodynamic bleaching is a process where light from a laser or non-coherent light source is used to drive molecular changes in light-sensitive compounds, and where the discoloration or bleaching of the teeth is caused as a result of the generation of reactive oxygen species. Secondly, it is also possible to photobleach colored organic compounds and especially those that are inherently resistant to the action of the oxygen free radicals. At present, true photobleaching can only be performed with the KTP laser (532 nm) in conjunction with a red colored highly concentrated hydrogen peroxide gel. Furthermore, it has also been demonstrated that the use of the KTP laser with the Smart Bleach system is safe: no intrapulpal temperature elevations beyond 5.5°C have been registered, and there is no risk of enamel microhardness decrease. KTP laser bleaching can be considered a noninvasive esthetic procedure, and hence is the least invasive procedure of what is called today minimally invasive dentistry.

**Keywords:** laser bleaching, laser tooth whitening, KTP laser, photobleaching, power bleaching, tetracyclines.

(gel) rather than on the tooth substance itself and the chromophores it contains that may lead to an increased bleaching effect.

As mechanisms of action, thermocatalysis (acceleration of the release of hydroxyl radicals from peroxide by a temperature rise) and photolysis (release of hydroxyl radicals from hydrogen peroxide through direct excitation by light) are described. In order to increase light absorption, some bleaching products are mixed with specific colorants, eg, an orange-red color increases the absorption of blue light. The addition of small silica particles in the nanometer or lower micrometer scale gives these products a bluish appearance and increases the absorption of red and infrared light. The energy required for photolysis can only be provided by high frequency light ($\lambda = 248$ nm or lower UV C), which makes its use in the mouth impossible. Hence, the light source becomes an important factor for not only the safety of light-activated bleaching procedures but also for its efficacy.

**LIGHT SOURCES**

Different light sources are now on the market. Incandescent lamps such as quartz-tungsten-halogen (QTH), plasma arc, laser sources of different wavelengths, and light-emitting diodes (LED) have been proposed for light activation. The result is a large spectrum of wavelengths ranging from 380 nm up to 780 nm (between visible and infrared light). Despite the use of filters, a fraction of IR irradiation does not appear to be suppressed in QTH and plasma arc lamps, and hence is emitted during light exposure. The latter may result in a pulpal temperature rise.5

**LASERS AND ACTIVATION OF THE BLEACHING GEL**

Lasers differ from the previously listed systems because they emit one specific wavelength. Moreover, laser light is collimated and coherent. The effect of a laser beam depends on the interaction with the target tissue, as laser light can be reflected by, transmitted through, scattered in and absorbed by the target tissue, material or substance. As absorption is needed for the activation of the bleaching gel, the absorption spectra (ie, the fraction of incident electromagnetic radiation absorbed by the material over a range of frequencies) of the bleaching gel components become important. This also means that it is essential to be aware of the absorption properties of dental tissues and hence the risks associated with laser and light-activated bleaching. Wavelengths with a high absorption coefficient in water and in tooth substance (mineral) will be absorbed at the tooth surface (ie, wavelengths around 3000 nm and 10,000 nm for hydroxyapatite, and starting around 3000 nm for water), where wavelengths in the red and near-infrared range can penetrate biological tissues more easily. Light in the latter spectral range will penetrate deeper into dental tissues, making thermal damage to the pulp more likely.

As a matter of fact, the essential elements of laser light that determine its reaction with matter are the wavelength of the radiant energy (nm) emitted by the laser, the power density of the beam (The measurement of photonic energy relative to time and area of irradiance – W/cm$^2$), and the temporal characteristics of the beam energy, such as continuous vs pulsed delivery, pulse rate (Hz), and pulse duration. It is more practical to talk about the amount of energy per pulse in Joules (J) (1 J = 1 W x 1 s), rather than the average output power in Watts. A similar concept to power density is energy density, where energy density (J/cm$^2$) (= fluence) is the amount of energy per unit area. In addition to these factors, which are somewhat inherent to the particular type of laser, there are other variables that relate to differences in the method of energy transfer attributable to instrumentation or delivery systems, such as contact vs non-contact delivery mode, and focused vs unfocused beam.

Besides wavelength, the mechanism of action of the laser depends on the power of the radiation and the pump mode. The pulse mode (continuous wave of pulsed wave) is important for efficacy and safety. At low irradiances and/or energies, laser–tissue interactions are either purely optical or a combination of optical and photochemical or photobiostimulative. When laser power or pulse energy is increased, photothermal interactions become dominant. Pulsed lasers can create very high power densities within a very short time (at present, less than milliseconds).

Thus, before choosing a wavelength for bleaching, it is of the utmost importance to be aware that laser light absorption (wavelength and target substance dependent) is needed for the conversion of the light into heat. It is also the absorption of the respective photons that influences the temperature rise within the bleaching product, the dental hard tissues, or pulp tissues.
LASER BLEACHING

Laser tooth bleaching officially started in 1996, with the FDA approval of the argon laser (480 nm) and the CO2 laser (10.6 μm) for tooth whitening. However, care has to be taken with the CO2 laser: the characteristic of this wavelength is thermal, and it is well absorbed in water and hydroxyapatite, which are the primary components of enamel; the thermal effect from the CO2 laser is favorable for its reaction, but the potentially adverse pulpal responses are a valid concern due to secondary conductive thermal effects. At present, this wavelength is not advised for tooth bleaching.

The objective of laser bleaching is to achieve the ultimate power bleaching while avoiding any adverse effects. The argon laser emits fairly short wavelengths (488 nm) with higher-energy photons; conversely, plasma-arc lamps, halogen lamps, and other heat lamps emit short wavelengths as well as longer invisible infrared wavelengths (750 nm to 1 mm) with lower-energy photons and predictable high thermal character. This high thermal energy can create unfavorable pulpal responses.

Irradiation with the argon laser excites the already unstable and reactive hydrogen peroxide molecule; the energy then is absorbed into all intra- and intermolecular bonds and reaches eigenstate vibrations. The hydrogen peroxide molecule falls apart into different, extremely reactive ionic fragments that swiftly combine with the chromophilic structure of the organic molecules, altering them and producing simpler chemical chains. The result is a visibly whitened tooth surface.

Argon and diode lasers are now commonly used for in-office bleaching treatments. The difficulty with diode lasers is the broad range of wavelengths covered under this name, which makes comparison between different diode wavelengths difficult. Furthermore, output, irradiation time, and the bleaching agent itself are determining parameters and are confusing for the interpretation of the effects of diode laser bleaching. In this respect, higher temperature elevation in the pulp after irradiation with diode lasers than with other lasers or lamps has been reported, whereas the increase of the intrapulpal temperature after argon laser irradiation was limited and in the range of other lamps.

KTP LASER BLEACHING AND THE FEASIBILITY FOR PHOTOBLEACHING

Additional benefits of the use of KTP and argon laser is their feasibility for photobleaching. Photobleaching was described by Bridges et al in 1969. In an investigation of tetracycline staining of rat incisors utilizing 5 tetracycline analogues, they observed that after removal from the animals and upon exposure to daylight, the stained incisors discolored further and at the same time gradually lost their fluorescence under an UV light source. Once the teeth had reached the maximum level of discoloration, they then began to bleach. This loss of discoloration was seen to progress more slowly than the original discoloration. This finding led them to cut in half two human teeth stained by an unstated type of tetracycline and to expose one half of each tooth to an UV light source (360-nm wavelength) for a prolonged, but undisclosed amount of time. They reported that the process of further discoloration and subsequent bleaching was accelerated compared with the rat incisors exposed to daylight. The other halves of the teeth, which were kept in the dark, retained their yellow discoloration and their ability to fluoresce. They suggested that a modification of that method might in the future be used as a treatment for tetracycline-stained teeth. Extracted tetracycline-stained rat, dog and primary human teeth have been observed to darken when exposed to sunlight. Further exposure produces a subsequent lightening of the tetracycline stain.

Tetracycline incorporated into hydroxyapatite, when oxidized by light (photo-oxidation), produces the red quinone product and hydroxyapatite. The addition of diluted hydrogen peroxide to the KTP laser also induces a photochemical reaction in the bleaching gel, providing a higher intrinsic overall radical yield than thermal activation. The rate at which radicals are generated is higher than with thermal activation. Furthermore, heating is minimized, implying the use of higher energies, so that the overall radical yield per unit time can be further increased.

In addition to the feasibility of photo-oxidation, the KTP laser also induces a photochemical reaction in the bleaching gel, providing a higher intrinsic overall radical yield than thermal activation. The rate at which radicals are generated is higher than with thermal activation. Furthermore, heating is minimized, implying the use of higher energies, so that the overall radical yield per unit time can be further increased.

At present, one laser company has marketed a bleaching gel for the KTP laser: Smartbleach (SBI; Herzele, Belgium). The hydrogen-peroxide-based bleaching gel is mixed with a photosensitizer, rhodamine B dye, resulting in an aqueous gel at high pH (pH 9.5). The activation of the alkaline gel results in the release of hydroxyl and other oxygen free radicals, which can break down various pigmented organic mol-
molecules. Under these conditions (intense light and alkaline pH), hydroxyl radicals are produced by decomposition of the hydrogen peroxide. These radicals are more reactive than superoxide and other oxygen reactive species. Thus, the activation of the red bleaching gel with the KTP laser under alkaline conditions results in a photocatalytic effect (a limited portion of photothermal activation of the gel and a more expressed portion of photochemical activation). Besides the photocatalytic effect, there is also the feasibility of photobleaching thanks to the specific wavelength. It is clear that the KTP laser is capable of photo-oxidizing the chelate formed between tetracyclines and hydroxyapatite or calcium orthophosphate, which does not re-
spond to the free radicals produced by chemical bleaching agents. Most grey discolorations form the same chelate as tetracyclines with hydroxyapatite or calcium orthophosphate. These complexes are also photo-oxidizable by the 532 nm of a KTP laser (Figs 1 and 2). The combination of all these characteristics enables a more profound bleaching of teeth as compared to other bleaching systems. In this respect, research by Walsh and Liu has shown that the whitening effect of photochemical KTP laser bleaching is greater than that of diode laser photothermal bleaching. The efficacy of KTP laser bleaching for the bleaching of heavily tetracycline-discolored teeth has been demonstrated by Vanderstricht and De Moor. When comparing the long-term effect (3 years and more) of KTP-laser bleaching, in-office power bleaching, and in-office bleaching with a highly concentrated hydrogen peroxide gel followed by home bleaching with trays, De Moor and Vanderstricht demonstrated a more enduring bleaching effect (especially for tetracycline cases) for KTP laser bleaching than for other types of in-office bleaching (highly concentrated hydrogen peroxide bleaching gels applied during several sessions and power bleaching with lamps).

**KTP LASER BLEACHING, A SAFE PROCEDURE**

As already mentioned, higher temperature elevation in the pulp after irradiation with diode lasers than with other lasers or lamps has been reported, whereas the increase of the intrapulpal temperature after argon
laser irradiation was limited and in the range of other lamps.\textsuperscript{5,13,14} A comparison between temperature elevation in the pulp chamber after irradiation with a diode laser and the KTP laser on tooth surfaces without bleaching gel also demonstrated that the highest temperature elevations were seen when a diode laser was used.\textsuperscript{23} For all these systems greater pulpal and surface thermal changes occurred when the appropriate gel was omitted. It is obvious that the absorbing properties of the bleaching gel will also play an important role in influencing both surface and intrapulpal thermal effects.\textsuperscript{3,23}

Moreover, different gel compositions may result in different thermal changes with the same laser.\textsuperscript{26} Nevertheless, when comparing different systems (KTP, LED, diode lasers), only diode lasers remained critical during bleaching treatment even when a layer of bleaching gel was applied on the tooth surface. The temperature rise measured after KTP laser irradiation remained under the critical level of 5.5°C.\textsuperscript{8,26}

The pH of bleaching agents determines the rate of reaction of the bleaching process. The more free radicals are produced, the higher the pH.\textsuperscript{27} Optimal ionization occurs when hydrogen peroxide is buffered in a range of pH 9.5 to 10.8.\textsuperscript{6} Under alkaline conditions, the perhydroxyl ion is produced from hydrogen peroxide.\textsuperscript{28} Unfortunately, most commercially available bleaching products are acidic, as this results in a longer shelf-life.\textsuperscript{22} In other words, most products are optimized for shelf-life rather than for bleaching purposes.\textsuperscript{27} The acidic pH may cause structural changes to dentin and enamel.\textsuperscript{29-31} Furthermore, it has also been demonstrated that concentrated 30% solutions of hydrogen peroxide can reduce the microhardness of enamel and dentin. This reduction can be noted with exposure times as short as 5 min for dentin and 15 min for enamel.\textsuperscript{32} Surface alteration and change in microhardness were also seen when carbamide peroxide 10% was used.\textsuperscript{33,34} As far as the Smart Bleach system is concerned (KTP-laser and Smart Bleach Gel), no adverse effects on the surface morphology have been observed.\textsuperscript{26,35}

**KTP LASER BLEACHING, AN EXAMPLE OF NON-INVASIVE ESTHETIC DENTISTRY**

Patients may present years after a traumatic accident with a single, discolored and intact tooth, which affects the esthetics of the dentition. This discoloration can be
the result of obliteration of the pulpal space; the pulpal cavity, in these cases, is filled with dark tertiary dentin, resulting in a tooth with a less translucent appearance. The tooth has gradually decreased in translucency and has become yellow of yellow-brown in color but is still vital.²⁶

The most common approach for the whitening or bleaching of this type of teeth is the “walking bleach technique”, as external bleaching with conventional bleaching techniques (ie, non-laser bleaching) appears to fail. In this procedure, the bleaching mixture is left in the bur-cut pulp cavity for a few days, and the access cavity is sealed with provisional cement – an obviously endodontic approach. Although discoloration as a result of calcific metamorphosis or obliteration is always mentioned in publications and chapters in text books dealing with the causes of intrinsic staining, such texts neglect to recommended a method for decoloration of this particular type of discoloration. Here and there the term “power whitening” appears; the procedure itself, however, is seldom described for the bleaching of this particular type of teeth or is confined to just one case without follow-up.

In Vanderstricht and De Moor,³⁷ the working mechanism as well as the clinical procedure of KTP laser bleaching was explained. It was demonstrated that the system used (a KTP laser in association with a red-colored, highly concentrated hydrogen peroxide gel [Smart Bleach gel (SBI)]) is currently the only system providing laser bleaching (discoloration of stains on and in tooth substance) with photothermal, photochemical and photocatalytic activation of the bleaching gel. Moreover, this system offered the advantage of performing true photobleaching, meaning that the problem of persisting intense discoloration resistant to the action of the oxygen free radicals such as with tetracyclines and deep greyish discoloration could be solved. Both authors also demonstrated that bleaching of obliterated teeth was possible without the need of intracoronal bleaching. During their follow-up of bleached obliterated incisors, they were able to demonstrate a stable decoloration of at least three years, especially for teeth with a yellow to yellow-brown color. In this way, a non-invasive esthetic solution was provided for this particular type of discoloration. In fact, KTP laser bleaching is the least invasive procedure of minimally invasive dentistry. A representative clinical case is shown in Figs 3 to 8.

REFERENCES


