A New Q-switched Nd:YAG Laser: Design Review and Clinical Applications

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Overview

For the last ten years, the Q-switched Nd:YAG laser (QSYL) has been the most widely used device for the removal of professional and amateur tattoos and pigmented lesions. The QSYL, Q-switched ruby laser (Palomar RD-1200), and Q-switched alexandrite laser—all of which are used for similar applications—produce high-peak-power pulses in the very short nanosecond range. Most Q-switched Nd:YAG lasers have pulse durations of approximately 3 to 10 nanoseconds (ns) and peak powers of 10 to 150 megawatts (MW).

These short-pulse, high-peak-power lasers have been very successful in the treatment of targets that have short Thermal Relaxation Times (TRT), such as tattoo granules and melanosomes. However, older QSYL's have suffered from unreliable energy-delivery systems and a limited ability to treat some relatively complex targets. The Q-YAG 5™ (Palomar Medical), the newest of the QSYL's, overcomes these problems by utilizing a direct-delivery handpiece, wavelength mixing mechanism, and other design features.

Laser/Tissue Interaction

The addition of an electro-optical device known as a Q-switch to the laser cavity allows the production of pulses in the nanosecond range. Typically, the Q-switched alexandrite produces 60 to 75 ns pulses; the Q-switched ruby, 25 to 30 ns pulses; and the Q-switched Nd:YAG, 5 to 10 ns pulses. The current energy output of these systems varies from 0.3 to 2.0 J per pulse.

A useful figure of laser comparison, known as peak power, is calculated by dividing the pulse energy in joules (J) by the pulse duration in seconds. For example, the Medlite IV™ (Continuum Inc.), an older Q-switched Nd:YAG with a one joule, 7 nanosecond pulse, has 140 megawatts of peak power. The Q-YAG 5, with its shorter 3 ns pulsewidth, has roughly the same peak power. These peak power levels are several orders of magnitude greater than those of most of the non-Q-switched pulsed lasers on the market today. In comparison, the LightSheer™ (Coherent, Inc.) hair removal laser has a peak power of 1,600 watts. This makes the Q-YAG 5 90,000 times more powerful than the LightSheer.

Previous research has indicated that lasers producing shorter pulses and higher peak power at a given fluence and spot size have a more profound effect on tattoo granules of multiple colors as well as pigmented lesions. This may be due to the fact that melanosomes have a TRT of less than 100 ns. (Large melanin-containing structures may have longer TRT's, and individual melanin granules have appreciably shorter TRT's.) The power density (peak power in watts/spot size in cm^2) would have to be sufficient to heat up the target to the point of thermal damage before the target "thermally relaxed"—i.e., released its heat. Of course, the control of the power density at the surface of the skin is critical, wherein too high a power density will ablate the epidermis.

An example of this effect was seen in the early versions of the Medlite lasers, which were designed with a Guassian beam. The power density at the center of this beam was high enough to cause skin ablation, produce bleeding, and cause tissue splatter, which was evident in most treatments. Initially, many physicians thought that the tissue splatter was a desirable effect, but in actuality much of the energy in the pulse was wasted in plasma formation and did not penetrate into the dermis at all.

Another model for the destruction of tattoo inks has been developed that provides some insight into a possible mechanism of QSYL tissue interaction. Since little heat transfer throughout a target chromophore can occur in the nanosecond domain, the process that destroys or fractures the entire ink granule itself may be photo-mechanical or photo-disruptive in nature.

Laser Design Features

High-peak-power pulses cannot be delivered through an optical fiber, and so thus far, the transmission of Q-switched laser energy has been via a 7-mirror articulated arm. This relatively unchanged older design is plagued by numerous disadvantages. The very nature of the arm's restricted movement around the patient and its obligatory twisting and bending (intentional or unintentional) makes the arm susceptible to misalignment and breakage. Arm and mirror misalignment decreases beam homogeneity, which leads to mirror degradation and consequent burning of mirrors, handpieces and other critical components.

Because arm moveorientations can make the center of the laser impact move within the orientation of the handpiece, exact treatment spots require a degree of estimation and practice. Beam steering and launch optics within the laser housing will also need proper alignment and adjustment before the output beam can propagate down the arm. Moving the laser from one location to another can cause misalignment of the optics and hasten their eventual failure, as well as compromise the clinical treatment results.

The new Q-YAG 5 laser has been designed and developed with the express intent to eliminate the articulated arm and launch optics entirely by building the laser directly into the handpiece. This self-contained, compact single unit incorporates both the fundamental laser cavity and frequency-doubling crystal into a convenient user-friendly delivery system.

The incorporation of the entire laser into the handpiece eliminates approximately 20 optics used in Medlite systems. Consequently, the repeatability of the day-to-day performance of the Q-YAG 5 is unsurpassed. The laser handpiece can be used either in a freehand fashion or left attached to the balancing/support arm. A quick disconnect is used to release or reattach the handpiece to the balancing/support arm at the discretion of the user.

The proximity of the actual laser head to the treatment site translates into delivering a superior quality beam profile and minimal loss of power in the optics. The handpiece is connected to a small power supply by an umbilical, making the laser easily separable into two units for easy transport or movement within or to different treatment sites.

Since spot size can be easily dialed into the handpiece and there is no need to change handpieces, users can even change spot sizes in the middle of a treatment in order to produce a desired tissue effect on a particular site. The simple movement of a thumb wheel changes the spot size immediately and the new spot size appears on the screen readout of the laser. An optical lens window protects the unit from contamination during treatment and can be easily cleaned or replaced, if necessary, by the user.

The Q-YAG 5 laser also presents a number of new advances in functionality. Because the frequency-doubling crystal is an integral part of the laser head and is a KTP (not KDP, as used in the Medlite series lasers), there is no thermal sensitivity for angle-tuning in order to maintain peak 532 nm output. It is now unnecessary to twist a delicate knob on the back of the laser in order to "peak up" the doubling crystal. The percentage of 1064 nm versus 532 nm within each pulse can also be adjusted (the clinical advantages of this will be discussed later).

In a typical QSYL, the frequency-doubling efficiency is approximately 50% of the fundamental 1064 nm wavelength. In the Q-YAG 5 laser, the user can maximize the 532 nm output and still deliver the residual 1064 nm light simultaneously. The percentage blending of the output can be adjusted to suit varying desired tissue effects.

Lastly, the direct-delivery design of the laser system can illuminate the treatment site with an "aiming spot" that is visible each time the laser pulses regardless of whether or not the q-switch is firing. In a ddition, because the illuminated beam spot is a direct output of the laser head, the spot is an accurate depiction of the expected laser impact site.

Clinical Applications

The QSYL has been a leading technology in the removal of tattoos and pigmented lesions for many years. The Q-YAG 5 continues the QSYL's leadership in these areas with an improved beam profile, shorter pulsewidth, and high peak power. Improvements in tattoo removal result from the Q-YAG 5's ability to treat a wider variety of inks more efficiently. The goal of removing all types and colors of tattoo inks with a single laser system has thus far been unrealized, but the Q-YAG 5 has shown promise in this regard with its next-generation technology.

The mixed wavelength (1064-532) capability of the Q-YAG 5 permits unique treatment protocols not possible with older systems. While most cases of Nevus of Ota (dermal melanocytosis) have been treated with the 1064 nm wavelength, a significant number of patients have experienced a better result with the addition of the 532 nm wavelength. It is possible that upper dermal and epidermal pigmentation in this type of lesion is better targeted by the 532 nm light, and overall treatment may be more successful when the pulses arrive simultaneously.

New treatment protocols are now being adopted to treat with this combined wavelength technique. Ultraviolet light-induced cosmetic freckling and lentigines have already shown a very dramatic response. Other possible applications for the combined wavelength are the treatment of junctional nevi, Becker's nevi, nevus spilus, etc. Chloasma/melasma, post-inflammatory hyperpigmentation and stasis dermatitis-induced changes may also respond to this new, mixed wavelength.

The QSYL has shown some promise in skin rejuvenation/skin toning treatments of photo-aged skin. This work has been done primarily with the 1064 nm wavelength. Patient satisfaction has been high for this quick, easy, painless, no-down-time procedure. The mixed wavelength may make this technique more effective by both stimulating collagen remodeling (1064) and reducing vascularity and pigmentation (blended 1064-532). Lastly, improvements in both the severity and scarring of acne vulgaris have been reported (mechanism unclear at this time). The mixed wavelength may also offer some advantages in terms of the erythema seen in this condition.

Continued research in all of the above areas is planned. Without doubt, the Q-YAG 5 promises to be a significant improvement over previous QSYL's in terms of both clinical results and reliability.

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