Abstract. Diode lasers are now capable of delivering up to 60 W of power down thin optical fibres, and their medical applications have increased considerably over the past 5 years. Most of the recent experimental and clinical work has been performed using the 805 nm diode laser wavelength, which is more heavily absorbed and is less penetrating than the 1064 nm Nd-YAG wavelength in most tissues. In contact and non-contact mode, the overall tissue effects from the diode laser are similar to the Nd-YAG laser, but with interstitial therapy the 805 nm wavelength produces significantly greater necrosis than the 1064 nm wavelength. Experimental work has established the effectiveness of the diode laser and clinical work has confirmed its suitability for a wide variety of procedures. Diode lasers have the major advantages of being small, compact, portable, efficient, easy to use and virtually maintenance free; they are likely to replace more cumbersome lasers for many medical applications.

INTRODUCTION

Diode lasers were introduced in the 1980s with power outputs of around 100 mW, but they now have capabilities of several tens of watts of power and are widely used in industry (1). They are semiconductor devices which produce laser light from electrical currents passed through them, and have a high electrical-to-optical efficiency; this allows them to be made lightweight and compact and to operate from a standard AC electrical outlet with a relatively high power output.

The initial medical uses of diode lasers were restricted to ophthalmological applications because of low power output, the limiting factor being the coupling of the laser diode power output to appropriate optical fibres which allowed only a few watts of power to be transmitted. Over the last 10 years, the power output has increased and more widespread clinical applications have been found. Arrays of laser diodes can now produce powers of many kilowatts (1).

In the early 1990s, Diomed (Cambridge, UK) produced a 25 W fibre coupled diode laser with a continuous wave 805 nm wavelength light from a 0.4 mm core optical fibre. The system measures 38 cm × 41 cm × 15 cm and weighs only 11.4 kg; it can be run from a 110 V wall plug draining less than 1 A (1). Minimal heat is generated and this allows relatively quiet air-cooling. Reliability studies have shown a mean time to failure of 25,000 h at maximum output power. Diomed have recently introduced a 60 W diode laser with the same dimensions as the 25 W laser.

Laser diodes are small, compact, portable and relatively quiet, and clearly have many advantages over the conventional solid-state and gas lasers (such as Nd-YAG, KTP/YAG, Ho-YAG and Argon) which are bulky and difficult to transport and may have a warm-up time of several minutes and/or require water-cooling, as well as requiring regular maintenance. The main disadvantage of diode lasers has been that their power output has until recently been a maximum of 25 W compared with 100 W from a Nd-YAG laser.

There have been several experimental studies comparing the diode lasers with other lasers, mainly the 1064 nm Nd-YAG laser. Clinical work has also been undertaken at several centres showing the potential of diode lasers, although the clinical work has been on small numbers of patients and has been largely
carried out to show the feasibility of using the diode lasers for various clinical applications rather than as strict comparative studies between different lasers.

**LASER–TISSUE INTERACTION**

High power diode lasers are available over a wide range of wavelengths from 600 nm to 1020 nm. There are small differences in tissue properties across these wavelengths due to changing absorption properties of blood and the peak in the water absorption spectrum at 975 nm. However, there are large differences in the transmission performance of most commercial delivery fibres across this waveband. Laser optical fibres have been mainly developed for the Nd-YAG laser at 1064 nm, with an internal transmittance of 99%; the 805 nm wavelength has a marginally better internal transmittance, but at 980 nm the transmittance drops to about 70% (2).

The wavelength of a laser diode is determined by the active compound used. Most of the experimental and clinical work to date has been performed using an 805 nm GaAlAs laser (Diomed, Cambridge, UK). More recently, a 980 nm InGaAs laser (Cynosure Inc., Bedford, MA, USA) has been used. High power 'red diode lasers' (AlGaInP) are also available at wavelengths of 640 nm to 700 nm and can produce up to 8 W of power down quartz optical fibres (3). The 805 nm Diomed laser is now capable of delivering 60 W of power down a 0.6 mm core diameter optical fibre (2), and the 980 nm Cynosure laser delivers up to 50 W down a 1 mm fibre (4); the lasers weigh 29 lbs and 35 lbs, respectively. The absorption coefficient of the 980 nm wavelength in water is about 20 times that of the 805 nm and three times that of the 1064 nm wavelength (4); experimental work in chicken breast and bovine liver showed the ratio of the absorption coefficients of 980 nm vs 1064 nm was 1.05 (4).

Jacques et al (5) performed an in vitro study in dog liver and found the absorption coefficient of the 805 nm wavelength to be 3.5 times greater than that of the 1064 nm wavelength; the scattering coefficients were found to be similar, and the penetration of the 805 nm wavelength was found to be less than that of the 1064 nm by a factor of about 2.2 (mean penetration depths of 1.3 mm and 2.8 mm, respectively). The increased absorption of the 805 nm wavelength occurs principally in de-oxygenated blood, in which it is 15 times more strongly absorbed than that of the 1064 nm wavelength (6). There is greater tissue heating when more blood is present (5). Jacques et al (5) found that the 805 nm diode and 1064 nm Nd-YAG laser were very similar in their tissue effects, but suggested that the 805 nm laser may be better for contact probe cutting of tissue and achieving haemostasis during such cutting because it is more strongly absorbed. Because the Nd-YAG laser is more penetrating, it may be better for coagulation therapy that requires maximum depth of coagulation (5). For non-contact use, the 805 nm laser provides relatively poor surgical precision when cutting or vaporizing soft tissue, because of several mm of collateral thermal injury resulting from soft-tissue penetration and scattering. Non-contact diode laser therapy may be more appropriate for procedures which require photoagulation of tissue or debulking type vaporization. Precise vaporization in non-contact mode is often desirable in endoscopic therapy; 600 nm wavelength is more strongly absorbed by haemoglobin, and so high power red diodes may give improved surgical precision in non-contact mode compared with 805 nm devices, but will still offer less non-contact surgical precision than the carbon dioxide and the Argon lasers which are both strongly absorbed laser wavelengths (2).

**EXPERIMENTAL WORK**

There have been some experimental studies on contact and non-contact application of the diode laser, as well as interstitial therapy.

**Contact mode**

Contact mode allows good tactile feedback, produces a thin (0.3–0.5 mm) region of photoagulated tissue adjacent to the incision with a bare optical fibre or sapphire tip, and provides haemostasis. This is due to a hot tip process with a thin film of carbonized tissue on the surface of the contact tip; the surgical effect of contact mode laser therapy is that of a red hot tip, and the laser beam itself does not come into direct contact with the tissue. A cutting or vaporization action is achieved by this red hot cautery effect, and this allows very delicate tissue cutting and destruction with little lateral damage. When using a bare