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Chapter IX

EFFECT OF CO₂ MILLIWATT LASER ON TENSILE STRENGTH OF MICROSURGICAL SUTURES*

T. Menovsky, J.F. Beek, & M.J.C. van Gemert

As previously outlined in this thesis, microsurgical laser tissue fusion is currently the subject of intensive investigations in various fields of surgery. Despite recent improvement, LANR still needs additional stay sutures to provide the acute tensile strength and to facilitate manipulation of the nerve ends. Most commonly, 10-0 monofilament nylon sutures are used for supporting the laser welds in microsurgical laser repair of tissues (Neblett, 1986; Abramson, 1991; Rosemberg, 1988A; Poppas, 1992).

Due to the shallow tissue penetration at 10,600 nm, the CO₂ laser is currently one of the most frequently lasers used for microsurgical tissue fusion. As the CO₂ laser energy is mostly absorbed at the tissue surface, it also may affect the suture material with regard to its tensile strength when occasionally irradiated. Alternation of the tensile strength of the sutures could be disastrous for the dehiscence rate of the welded tissues.

Because no data are available on the effect of CO₂ laser irradiation on microsurgical suture material, this study was designed to investigate the tensile strength of 10-0 nylon thread irradiated by a CO₂ laser at different power densities and exposure times. As a possible alternative to nylon thread, we also investigated the tensile strength of 25 μm stainless steel thread, both laser irradiated and nonirradiated.

Materials and methods

Two different surgical suture materials were used in this study, i.e. 10-0 monofilament nylon thread (Dermalon, Davis-Geck, Hampshire, United Kingdom), and 25-μm soft stainless steel thread (Trakus GmB, Bergneustadt, Germany). The suture material (± 5 cm each) was stretched on a piece of cork and single pulse laser irradiation of the thread was performed at 12 different laser settings (power densities of 62, 124, and 186 W/cm²; pulse duration of 0.5 s, 1.0 s, 2.0 s, and 3.0 s). During irradiation, the thread was positioned in the centre of the laser beam. Six irradiations were performed for each group of laser settings. Normal nonirradiated thread (n=6) served as a control. The CO₂ milliwatt laser used for the experiments is described in chapter IV. Powers of 50, 100, and 150 mW were employed.

The tensile strength of the threads was measured directly after the irradiation using a tensometer (TM type W, manufactured by Monsanto, United

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Kingdom), coupled to a motor pulley and a x-y plotter. The threads were strained at a rate of 3.18 mm/min, until breakage occurred. The force (in Newton, N) to do so was recorded as the tensile strength. The data were statistically analysed using a Student t-test.

**Results**

The tensile strength of the nonirradiated nylon group was 0.35 ± 0.02 N. Irradiation at power densities of 186 W/cm² resulted in disruption of the nylon thread, regardless of the pulse duration. Thus no tensile strength could be recorded for these groups. Also, at power densities of 124 W/cm², disruption of the nylon thread occurred with pulse duration of 2.0 s and 3.0 s. Irradiation at 124 W/cm² for 0.5 s and 1.0 s resulted in a decrease of the tensile strength with a factor of 3 to 4. At power densities of 62 W/cm², the tensile strength of the nylon thread was not altered at 0.5 s and gradually decreased with irradiations at 1.0 s, 2.0 s, and 3.0 s pulse duration. These values were significantly lower than the control group (p<0.01). The relation of the relative strength loss at different power densities and pulse durations is shown in figure 9.1. Figure 9.2 shows the relative strength loss at identical total doses of energy at different pulse durations.

The tensile strength of nonirradiated stainless steel thread was 0.55 ± 0.03 N (mean ± SD), which was statistically different from the 10-0 nylon control group (p<0.01). Laser irradiation of the steel thread did not alter its tensile strength, not even at power densities of 186 W/cm² for 3.0 s pulse duration. Table 9.1 gives an overview of the tensile strength data for the 10-0 nylon thread.

**Discussion**

When dealing with nerve repair, the nerve ends will, after transection, retract due to the elasticity of the nerve. Therefore, end-to-end nerve repair is always under some degree of tension, which will vary with the degree of elasticity of the nerve and with the position of the surrounding joints. In CO₂ LASR, one or two stay sutures are usually placed in the epineurium (for easy handling and approximation) and subsequent laser irradiation follows of the nerve (BEGGS, 1986; BENKE, 1989; HUANG, 1992). Still, the dehiscence rate varied from 40% to 87% (FISCHER, 1989; HUANG, 1992; KORFF, 1992). However, in experiments performed in the same nerve model (rat sciatic nerve), nerve repair with one or two sutures without laser irradiation resulted in a dehiscence rate of 0% (CRUZ, 1986; ARCHIBALD, 1987).

In our pilot experiments, we have performed LASR of the rat sciatic nerve using the CW Ho:YAG laser (λ = 2,094 nm) (MENOVSKY, 1995a & 1995b). LASR was accomplished by placing two epineurial sutures and then welding the nerve around its circumference with repeated single spots (0.5 s) at 350 mW. Irradiation of the sutures was inevitable, as we were using a 600 μm fibre tip.
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Fig. 9.1. Relative loss of tensile strength of nylon suture thread as a function of power density at different pulse durations. An asterix (*) signifies that the thread disrupted during irradiation.

Fig. 9.2. Relative loss of tensile strength of nylon suture thread at identical total energy doses at different pulse durations. An asterix (*) signifies that the thread disrupted during irradiation.
Table 9.1. The effect of CO$_2$ laser energy doses on the tensile strength in Newton (mean ± SD) of 10-0 nylon suture thread

<table>
<thead>
<tr>
<th>Power density (W/cm$^2$)</th>
<th>Pulse duration (s)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>62</td>
<td>0.34 ± 0.03</td>
</tr>
<tr>
<td>124</td>
<td>0.08 ± 0.05$^{a}$</td>
</tr>
<tr>
<td>186</td>
<td>b</td>
</tr>
</tbody>
</table>

$^{a}$one suture disrupted during laser irradiation
$^{b}$all sutures disrupted during laser irradiation

in a noncontact mode. Although all nerves seemed to be fused at the moment of initial surgery, ten of the 18 nerves (56%) were separated over an observation period of up to three weeks. In the control group (two epineurial sutures alone), no dehiscence was found. This experimental finding and the data in the literature led us to the hypothesis that either i) the tensile strength of the sutures was impaired by laser irradiation, or ii) the biomechanical properties of laser irradiated tissue was altered, or iii) a combination of these factors resulted in the high dehiscence rate.

There are only two studies that report on the effect of laser irradiation on the tensile strength of sutures. In the first study a diode laser ($\lambda = 808$ nm) was used in combination with the chromophore indocyanine green (ASHTON, 1992). The size of the sutures investigated varied from 3-0 to 6-0 which is too large for microsurgical tissue welding. Logically, these sutures are of little use for microsurgical repair of tissues. In the second study, the laser utilised was a KTP laser (532 nm) and the sutures investigated were 4-0 PGA (POPPAS, 1993 & 1995). We have selected the CO$_2$ laser and 10-0 nylon thread (which has a diameter of 25 $\mu$m) for this study, as these are most commonly used for microsurgical laser repair of arteries, veins, and nerves. The laser settings investigated (power densities of 62, 124, and 186 W/cm$^2$, pulse duration of 0.5 s, 1.0 s, 2.0 s, and 3.0 s) represent the parameters generally used for tissue welding. Moreover, the selected laser settings have been shown to produce strong welds in our previous study of nerve welding (Chapter IV). Irradiation with the CO$_2$ laser at 186 W/cm$^2$ resulted in suture disruption regardless of the pulse duration. Disruption of the sutures also occurred at 124 W/cm$^2$ for 2.0 s and 3.0 s. At power densities of 124 W/cm$^2$ for less than 2.0 s pulse duration and at 62 W/cm$^2$ for 1.0 s, 2.0 s, and 3.0 s pulse duration, the mean tensile strength was significantly less than that of the control group ($p<0.01$).

Although it is obvious that disruption of the suture thread occurs at high CO$_2$ laser powers, it is surprising that it also occurs at very low powers, as the effects on tissue by irradiation with low power CO$_2$ laser are only microscopically visible. These results suggest that irradiation of the nylon sutures with a low power CO$_2$ laser impairs the tensile strength of the repair, which may result in early wound dehiscence. It is likely that other surgical threads
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9.3. Scanning electron micrograph of normal 10-0 monofilament nylon suture thread (original magnification x 190).

9.4. Scanning electron micrograph of 10-0 monofilament nylon thread following CO₂ radiation at 124 W/cm² for 0.5 s (original magnification x 190). Note the narrowing and nearly disruption of the thread.
such as PGA or polypropylene also will be influenced by laser irradiation, as well as surgical threads larger than 10-0.

The suture material used in this study was dry. During surgery, the thread will become wet after contact with tissue, and it is likely that the damage threshold for laser irradiation will be altered. However, our pilot experiments showed that there was almost no difference in tensile strength of dry and wet nylon thread after laser irradiation. Moreover, tissue welding with the CO2 laser is successful only when performed in a dry operative field. As the CO2 laser is used clinically for welding of the vas deference (ROEMERBERG, 1988A & 1988B) and vessels (OKADA, 1987 & 1989) and in general for many other surgical procedures, meticulous care should be taken to avoid irradiation of the surgical thread. The appearance of normal and irradiated 10-0 nylon thread (124 W/cm², 0.5 s) is shown in figures 9.3 and 9.4 respectively.

As an alternative to nylon sutures, we have used 25 μm soft stainless steel thread which has the same diameter as 10-0 nylon. The use of stainless steel as suture material is known since the begin of this century. However, the practical use of stainless steel wire is limited to orthopaedic procedures for fixation of bones. The use of stainless steel thread for microsurgical repair of nerves or vessels has never gained favour because of the kinking of the wire, its difficult manipulation, and knotting (GRANBERRY, 1963; EDSHAGE, 1968). The mean tensile strength of the steel thread was 0.55 ± 0.03 N, which is statistically different from 10-0 nylon thread (p< 0.01). Irradiation of the steel thread with the CO2 laser did not affect the tensile strength, regardless of the power density or pulse duration that were used. This means that the steel thread, from the point of safety, can be used in combination with laser welding, without impairing the tensile strength of the repair site.

In conclusion, this study showed that i) irradiation of 10-0 nylon thread with a low power CO2 laser results in disruption of the thread or reduction of the tensile strength, ii) stainless steel thread has a greater tensile strength than 10-0 nylon thread, and iii) irradiation of stainless steel thread with a CO2 laser does not alter its tensile strength. In clinical laser procedures, meticulous care should be taken not to irradiate the nylon surgical thread.