Novel laser tissue-soldering technique for dural reconstruction

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Object. The goal of this study was to use a modified version of the CO₂ laser–soldering system to develop a simple and reliable technique for the repair of dural defects after excision of brain tumors.

Methods. The authors used a CO₂ fiber optic laser system that they had developed for heating, monitoring, and controlling tissue temperature in situ and in real time, thereby reducing damage to the brain parenchyma. They adapted the system for dural closure by using free fascial grafts in a porcine model. Measures for estimation of reconstruction quality included visual assessment under magnification and direct measurements of adhesive strength and cerebrospinal fluid leak (CSF) pressure.

Reliable soldering was achieved in 54 of 57 experiments, providing a 95% success rate. The average peak adhesive strength was 82 ± 3 mN/cm². The measured leak pressure of the fascia–dura mater bond was 66 ± 5 mm Hg. Conventional suturing performed using Prolene stitches resulted in immediate CSF leakage from areas between the stitches and from the area of the needle hole itself.

Conclusions. Fascia–dura mater soldering using the CO₂ laser is feasible and may support CSF pressure up to six times higher than normal intracranial pressure. Findings of this study may provide a basis for the development of new tools for dural reconstruction.

Key Words • cerebrospinal fluid leak • skull base • dura mater • fascia • laser soldering • welding

Extrication of large intracranial tumors frequently requires excision of the dura mater overlaying the tumor. In such cases, primary closure of the dura is inadequate, and dural reconstruction requires placement of a fascial patch over the excised area to form a watertight seal. In skull base procedures, the aim of reconstruction is to provide a barrier between the contaminated nasosinusoidal space and the sterile subdural compartment, thus preventing any CSF leak or airflow into the intracranial space. To avoid these complications, the dura must be closed quickly with a type of closure that supports instant CSF pressure and withstands considerable shearing forces during the postoperative period.

Conventional repair of large dural defects includes fascial grafts, which are sutured to the edges of the intact dura mater. Suture repair is not completely watertight, however, and CSF leakage through gaps between the sutures and through holes created by the needle is not uncommon. Moreover, the reconstructed dura is at increased risk for tears and breaks during the immediate postoperative period (especially in elderly persons or following radiotherapy).

Laser tissue soldering is a relatively new technique for the binding of biological tissues by means of a laser beam.¹ It has been used for the repair of bladder and ureter defects⁵ and for placement of nerve grafts.⁶ In two earlier studies a conventional laser approach was used for primary dural closure,²,⁶ but dural soldering alone offered no advantage over conventional methods.

Our objective was to use a novel laser soldering system to develop a simple and reliable technique for the repair and reconstruction of dural defects following neurological surgeries.

Materials and Methods

The Applied Physics group at Tel Aviv University has developed a fiberoptic CO₂ laser system for temperature-controlled soldering of tissues (Fig. 1). The basic idea is to apply a biological solder (albumin) on the approximated edges of a cut, to use a CO₂ laser to heat a spot on the albumin (and on the underlying tissue) to a temperature of approximately 70°C for 10 to 12 seconds, and to move the laser beam from spot to spot along the cut. The CO₂ laser was chosen because its radiation is highly absorbed and it does not penetrate deeper into tissue.

The laser soldering system has been fully described in our previous publications.⁴ In brief, the system is based on a CO₂ laser emitting at a λ of 10.6 μm, an infrared detector, two infrared fibers, and...
A personal computer. Fibers with a diameter of 0.7 mm and a length of approximately 2 m were prepared in our laboratory from polycrystalline silver halides, AgCl x Br 1 /H 2 O (0 < x < 1). These materials appear highly transparent under infrared lighting; they are flexible, nontoxic, and biocompatible, and highly suitable for laser soldering. The two fibers were placed in a holder 10 cm long and 1 cm wide, so that the distal ends of the fibers were placed a few millimeters from the surface of the dura mater. The delivery system is the size of a pen and is easy to handle in areas of difficult access such as the skull base. The proximal end of one fiber (“power fiber”) was attached to a CO 2 laser, and the laser radiation was focused into the proximal end of this fiber. The laser beam emitted from the distal end heated a spot on the surface of the dura. The heated spot emitted infrared radiation whose intensity was determined by the temperature. The emitted radiation was collected by the distal end of the second infrared fiber (“sensor fiber”), transmitted to the proximal end of this fiber, and then focused onto an infrared detector. The computer was used to measure the voltage signal from the detector and to determine the temperature of the heated spot. A computer program was used for feedback control, so that if the temperature was too low the laser power was increased and vice versa.

In this work we used a sealed-off CO 2 laser (Sharplan, Lumenis, Yokneam, Israel), which operates in a direct current mode with an average continuous wave power level of 0.7 W. The output beam was modulated by an external chopper, which generated pulses at a rate of 8 Hz. The duty cycle of the chopper was controlled by the computer, which made it possible to control the power of the laser, which was focused into the “power” fiber. Typically when the laser’s power was turned on, the pulse duration varied between 15 and 35 msec. The mean power measured at the distal end of the “power” fiber was 0.7 W. The average power density on the irradiated surface was roughly 3 W/cm 2.

In this study an aqueous 47% solution of bovine serum albumin (Sigma Chemical Co., St. Louis, MO) served as a solder and was spread on the edges of a cut or hole. This solder was heated by the laser soldering system, and heat propagation into the tissue was responsible for heating the underlying layers. Fifty-seven experiments on specimens from 15 adult pigs were performed. The dura and fascia were quickly immersed in cold ACSF containing (in millimolar concentrations) 124 NaCl, 3 KCl, 2 MgSO 4 , 1.25 NaHPO 4 , 2 CaCl 2 , 26 NaHCO 3 , and 10 dextrose, and saturated with 95% O 2 /5% CO 2 at a pH of 7.4. The biceps muscle fascia was exposed and the fascial layer was undermined and elevated from the underlying muscles. Each dural section and fascia was transected using a scalpel into two strips measuring approximately the same size (2 × 4 cm each). The

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![Graph showing a typical result of temperature variations during the soldering procedure.](image)

**Fig. 3.** Graph showing a typical result of temperature variations during the soldering procedure. The tracing illustrates the real-time temperature control obtained during laser heating. The thick black lines represent active laser soldering. Using this system avoids damage to the brain parenchyma.

Wet strips were approximated by delicate forceps during the procedure. The fiber holder was held 3 to 4 mm above the tissue. Fusion of the tissue was begun by spot-welding for approximately 12 to 15 seconds at the middle of the target area to provide the initial binding. One drop of “solder” (albumin) was then applied over the incision by using a 25-gauge needle. With the solder covering the repair site, soldering was completed by moving the fibers across the weld line at a rate of approximately 1 mm for 10 seconds. The procedure was completed when the two fused tissues were visually deemed to be sealed and watertight. The weld line was approximately 2 cm long and the soldering procedure was completed within approximately 200 sec.

**Force Measurement Apparatus.** We measured the mechanical force required to detach the fused tissues. The temperature-controlled laser soldering procedure was used to bond the fascia to the dura mater as mentioned earlier. The soldered tissue was mounted onto two grips used to hold the two edges of the specimen. The grips were connected to a vertical apparatus, which we designed and constructed to measure the force of the dura–fascia weld. The two grips were connected to a mechanical system that gradually increased the distance between the grips (model 4502; Instron, Ltd., Buckinghamshire, UK). There was a gradual rise in tensile strength when the two edges of the preparation were retracted and the force during loading was digitally recorded (Fig. 1). During retraction there was a gradual increase in the tension of the specimen. At a certain tension the weld broke apart, and an immediate decrease in tension was monitored. The maximal force (tensile break) is represented by the peak of the curve displayed in Fig. 1. The difference between the maximal force and the baseline was used to calculate the PAF acting between the two tissues. The magnitude of the bonding forces between the two tissues was measured at room temperature.

**Measurement of Leak Pressure.** Another set of welded tissue was used to estimate the leak pressure. Measurements of leak pressure were obtained using a pneumatic system connected to a bag of ACSF. The temperature-controlled laser soldering procedure was used to bond the fascia to the dura mater. A cylindrical metal container, shaped like a drinking glass, was specially designed and constructed by us and used to measure the burst pressure. The dura was attached to the rim of the container by using a plastic ring or fast glue (Fig. 2). The container was filled with ACSF and connected to a pneumatic system that gradually increased the water pressure in the container (Parker Hannifin Corp., General Valve Operations, Fairfield, NJ). At a certain stage, water began to leak through the dura–fascia interface. We define the pressure at which the leak occurred as the burst pressure of the laser-soldered fascia. Pressure changes were expressed in millimeters of Hg (1 mm Hg = 1.4 cm H₂O = 0.13 kPa).

**Conventional Suturing.** The dura mater and fascia were prepared in the manner described earlier. The two strips of dura and fascia were bound together using 6-0 Prolene sutures. These sutures were evenly spaced 3 mm apart and 3 mm from the cut edge of the dura on either side and tied using five simple knots.

All protocols were approved by the institutional Helsinki committee for experimentation on animals.

**Results**

Experiments were performed on 57 specimens from 15 adult pigs by using a CO₂ temperature-controlled laser system alone (Materials and Methods). Reliable soldering was obtained in 54 of 57 experiments, providing a 95% success rate. Figure 3 illustrates the real-time temperature control obtained during the soldering experiment. An example of one experiment of dura–fascia soldering is shown in Fig. 4. The average PAF was 82 ± 3 mN/cm². The mean PAF for the fascia–dura interface that had been bound by conventional suturing was greater than 10 N/cm² (the exact force could not be measured because the tissue, not the stitches, disintegrated under a high-loading force).

Additional experiments were performed to estimate the leak pressure. The measured mean leak pressure for fascia–dura bonding was 66 ± 5 mm Hg. We performed another five experiments by using conventional suturing of the fascia and dura with 6-0 continuous Prolene stitches; there was an immediate CSF leak from the areas between the stitches and from the suture line in all of them.

**Discussion**

An en bloc tumor resection may create extensive dural and skull base defects, producing a free conduit between ex-
tracranial and intracranial spaces. Following tumor extirpa-
tion, cranial base defects require reconstruction to pro-
duce a barrier between these two compartments. Re-
constructive failure carries potential life-threatening compli-
cations (for example, CSF leakage, pneumocephalus, and meningitis), which may also delay recovery time and the ini-
tiation of adjuvant therapy.

We have previously demonstrated the advantage of us-
ing a double-layer fascial sheath as the procedure of choice for anterior skull base reconstruction. The thinness and
low mass of the fascia lata enable the surgeon to cover large
dural defects with a single fascial sheath. Our histological
analysis of previously harvested human fascial flaps
showed evidence of the integration of vascularized fibrous
tissue into the fascial graft; the fascial flap was uniformly
coated by fibrous tissue, and invasion of blood vessels was
attained without the presence of an overlying vascularized
flap. Using an animal model, Tachibana, et al., also dem-
onstrated a tight connection between a fascial graft and a
dura within 1 week after surgery. Thus, the rapid heal-
ing process of a fascia reconstruction can provide a robust
physiological barrier between the nasopharynx and the in-
tracranial space within days following surgery.

The last decade has witnessed a transition for laser tissue
welding systems from the laboratory to accepted clinical
practice. Recent publications from the Tel Aviv University
Applied Physics Group have demonstrated the efficacy of
using a temperature-controlled CO2 laser soldering tech-
nique for bladder and ureter repair, cornea and skin closure,
and other purposes. In the current work, our aim was
to develop an animal model for dura–fascia repair by using
a novel laser apparatus that enables the control of surface
temperature, thereby affording protection to the brain pa-
renchyma during dural soldering. We investigated this tis-
ue-closure technique for immediate sealing of the dura
mater. Our working hypothesis was that dura–fascia laser
soldering should provide five primary physiological and
technical benefits: 1) a high-quality seal to provide a water-
tight and airtight barrier; 2) the capability of withstand-
ing considerable shearing forces and the ability to support a
CSF pressure greater than 20 mm Hg during the postopera-
tive period; 3) a biophysical strength and elastic properties
of the soldered tissue that is close to those of intact tissue
within seconds after fusion; 4) the avoidance of artificial
material, which should reduce incidences of dehiscence and
infection; and 5) the application of a laser technique that is
simple and will reduce the time required for the procedure.
It should also make dural closure possible in situations in
which space constraints make traditional suture closure dif-
ficult, as in anterior skull base procedures.

In two previous studies investigators examined the use of
laser technology for dural reconstruction. Hadley and asso-
ciates used a canine model to investigate the utility of the
CO2 laser and fascial patches for dural reconstruction; CSF
leaked through all their laser closures immediately after
welding. Those authors obtained similar results for prima-
ry closure when using sutures. Nevertheless, autopsies per-
formed 2 weeks postoperatively demonstrated an 86% re-
iliability for each technique. The authors found that fibrin
glue was superior to both the laser and sutures, and that it
supported more than 40 mm Hg of CSF pressure imme-
diately following reconstruction. In another work, Foyt, et
al., studied primary dural closure by applying convention-
al and laser techniques; as we did, they found that dura
welding was superior to conventional suturing, providing a
mean leak pressure of 26 mm Hg as opposed to 9.4 mm Hg.
The measurements they obtained using solder-reinforced
sutures yielded a mean leak pressure of 64 mm Hg, a figure
lower than what we found in our experiments on the use of
a laser alone.

We have used our welding system for heating spots on
tissues to approximately 70°C with an accuracy of several
degrees. The laser beam was moved along the reconstruc-
ted dura during welding. A concern is raised as to whether
heating the dural surface can inflict damage on the under-
lying brain parenchyma. The reason we chose the CO2 la-
sor is because its radiation is highly absorbed by water, soft
tissues, and albumin. The laser energy heats only the top
(roughly 20 μm) of the albumin layer, and the underlying
dura–fascia layers are heated by conduction. Heat, there-
fore, does not penetrate deep into the dura. This procedure
greatly reduces the risk of thermal damage to underlying
tissues.

Preliminary results from our laboratory performed on
five pigs in vivo showed no injury to brain tissue (for ex-
ample, no coagulative necrosis, presence of inflammation, or
thermal damage). Additional in vivo studies are needed to
investigate the reaction of brain tissue and the dura mater to
laser soldering.

We have demonstrated the utility of a laser soldering
 technique involving fascial patches for dural reconstruction.
The mean CSF leak pressure of 66 mm Hg (> six times
higer than normal intracranial pressure), which we doc-
umented using the laser soldering technique, indicates that
this technique may be appropriate for dural sealing immedi-
ately following a surgical procedure, sparing the use of ny-
lon sutures or biological glue. This method has only been
used on animals, and further development and evaluation is
mandatory before this system can be applied to skull base
surgeries.

Conclusions

We have demonstrated good results for a laser soldering
technique in dural repair and reconstruction. Laser solder-
ing appears to be superior to conventional suturing because
it can provide a tight seal and can bear a very high level of
intracranial pressure immediately after surgery. We hope
that the current study will help set the ground for implemen-
tation of laser soldering techniques in humans during neuro-
logical surgeries. The method may also be applied for the
repair of a CSF leak and for tumor excision in the anterior
skull base by using endoscopic techniques. Implementation
of laser soldering in neurological and skull base oncological
surgeries may allow access to anatomical areas previously
considered inoperable, shorten the duration of the surgery,
allow better dural reconstruction shortly after the procedure,
and afford lower morbidity and mortality rates. Dural re-
construction with the aid of laser technology may obviate
the use of continuous spinal CSF drainage, which is re-
quired with conventional techniques, and may shorten the
patient’s hospital stay.

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References

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