

Development of an MR compatible, side-firing, internally CO₂ cooled, laser probe and associated control system for laser interstitial thermal therapy. Torchia M^{*}, Tyc R[†], McTaggart K[†], Taylor B[†], Qureshi S[†]

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Background: Thermal (both heat and cryogenic) therapies for the treatment and destruction of cancerous solid tumors have a long history of success. Most of these therapies employ a probe or fiber configured to emit somewhat uniformly from the source, thereby creating a spherical or ellipsoidal thermal “front.” This makes control of the deposition of heat (or cold) difficult to control precisely to the contours of the tumor. The development of this probe is a means of addressing that issue.

Purpose: The purpose of this development program was to design, build, and test a disposable, MRI compatible probe as a basis for stereotactically-guided focused laser interstitial thermal therapy using realtime MR thermometry as a feedback mechanism.

Methods: The probe body (2.54 mm diameter x 300 mm in length) was produced out of titanium tubing (A40 or CP GR2). An optically clear, close ended, 17.5mm long cylindrical sapphire capsule (2.45mm diameter) was bonded to the chamfered end of the tube where the laser energy exits. There are three main internal components in the probe:

1. Optical fibre - 600 um (silica core), 630 um (silica clad) , 750um Tefzel buffered (modified ETFE- ethylene-tetrafluoroethylene) fiber compatible with 810 and 1064 nm wavelengths. The distal end of the fiber is chaffered to 37 degrees resulting in the exit of the laser energy at approximately 74° to the axis of the probe. A standard SMA 905 is bonded to the proximal end of the fiber for connection to the laser system. The fiber is positioned within and approximately 10 mm from the closed end of the sapphire capsule and bonded in place.
2. CO₂ injector tube - a 0.25 mm ID PEEK tube. The distal end of the tube is nozzleed to 0.10 mm id using a short length of PTFE tube. The exit is positioned approximately 10 mm from the end of the sapphire capsule. The proximal end of the injector tube is adapted to a larger bore nylon tube fitted with a quick disconnect high pressure gas connector.
3. A micro-thermocouple (36g, T-type) is located at the distal end of the probe 1.2 mm from the end of the sapphire capsule.

The three components (fiber, injector tube, and thermocouple) exit the proximal titanium body of the probe through a specialized fitting that permits extracorporeal venting of the CO₂ cooling system gas. A long umbilical provides a connection to the probe for laser, electrical (thermocouple), and CO₂ between the control system located in the MRI equipment room and the MR imaging suite. In addition to the probe, the other subsystems include the cooling system, the laser, and the control software. The cooling system provides high pressure CO₂ gas to the probe injector tube (≤ 850 psi). The CO₂ exits injector tube nozzle and expands into the internal volume of the sapphire capsule. The Joule-Thompson (JT) effect results in cooling of the probe tip. The exhaust CO₂ gas then travels back up through the remaining internal volume of the probe shaft, exiting the back of the probe. Two laser wavelengths (both CW laser types) have been used with the system in testing, 810 nm diode laser and a 1064 nm Nd:YAG .

Results: The probe was demonstrated to be MRI safe and compatible and permitted real time imaging for both anatomical and thermometry based imaging. MRI imaging slices are oriented in planes transverse to the sapphire tip which results in images with minimal susceptibility artifact. The JT cooling system is highly effective. Internal temperatures of the probe at the sapphire capsule can be controlled to within 2-3C in the range of 10C to -50C. This efficient cooling allows for much higher laser energies to be used in comparison to traditional LITT diffusion tip fibers. Laser energies in the range of 50-75 watts (in pulse mode) are easily achieved with out tissue charring. Although the probe is designed to be a single use only device, it appeared to be highly robust in laboratory testing. Initial *ex vivo* tissue tests in brain demonstrate equivalent thermal dose (T_{43}) to a diameter of approximately 2 cm. The side fire probe provides the significant advantage of increased control over sector heat distribution within a treatment volume.

Conclusions:

The ability to more precisely control the deposition of heat within the margin of a solid tumor (or defined treatment boundary) is enhanced with this novel laser probe.