A Comparative Study of Coagulation Effects on the Cortex of the Rat using Nd-YAG (1.32 µm), Nd-YAG (1.06 µm) and CO₂ Lasers

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Résumé. Les auteurs présentent une étude comparative de la coagulation du parenchyme cérébral au moyen de différents lasers. Les études expérimentales ont été effectuées sur le cortex du rat. Elles ont consisté à comparer les effets thermiques et histologiques de 3 longueurs d’onde: Nd-YAG (1.32 µm), Nd-YAG (1.06 µm) et CO₂ (10.6 µm). La température corticale de surface induite par le tir laser a été mesurée au moyen d’une caméra infrarouge. Les courbes du profil thermique de chaque tir et de son évolution au cours du temps ont ainsi été obtenues. Les résultats montrent qu’il existe une excellente corrélation entre les données thermiques et les données histologiques recueillies pour chaque tir. Il apparaît ainsi que pour des augmentations de température équivalentes, les lésions corticales 8 jours après le tir sont similaires pour les lasers Nd-YAG (1.32 µm) et CO₂, mais significativement différentes pour le laser Nd-YAG (1.06 µm).

Par exemple, le profondeur de nécrose varie entre 200 et 250 µm pour le laser CO₂ utilisé avec une puissance de 3 à 10 W, un temps d’exposition de 0.05 s et une fluence de 5 J/cm². La profondeur de nécrose varie entre 210 µm et 260 µm lorsqu’on utilise le laser Nd-YAG (1.32 µm) avec une puissance de 5 à 14 W, un temps d’exposition de 0.4 s et une fluence de 50 à 170 J/cm². Avec le laser Nd-YAG (1.06 µm), la profondeur de nécrose est beaucoup plus importante. Elle varie entre 490 µm et 550 µm pour une puissance comprise entre 12 et 19 W, un temps d’exposition de 0.4 s et une fluence de 150 à 250 J/cm².

Ces résultats expérimentaux montrent que la longueur d’onde 1.32 µm est bien adaptée à la neurochirurgie puisqu’elle est bien absorbée par le parenchyme cérébral et qu’elle est transmissible par une fibre optique.

Abstract. This paper represents a comparative study on brain tissue of three lasers: Nd-YAG (1.32 µm); Nd-YAG (1.06 µm); and CO₂ laser. The experimental studies were performed on rats. They consisted of a comparison between the thermal effects and the consequent histological lesions produced. The surface temperature of the cortex induced by each laser shot was measured with an infrared camera. The results show that there exists an excellent correlation between surface temperature and the histology of the lesions produced. It appears that for equivalent surface temperatures the cortical lesions 8 days after irradiation were similar for Nd-YAG (1.32 µm) and for CO₂ lasers but significantly different for the Nd-YAG (1.06 µm) laser. For example the depth of coagulation necrosis varied between 20 to 250 µm with the CO₂ laser using the power of 3 to 10 W at an exposure of 0.05 s with a fluence of 5 J/cm² and varied from 210 to 260 µm using the Nd-YAG (1.32 µm) with the power of 5 to 14 W with an exposure of 0.4 s with a fluence of 50–170 J/cm². With the Nd-YAG (1.06 µm) the depth of coagulation necrosis varied from 490 µm to 550 µm using a power of 12 to 19 W with an exposure of 0.4 s with a fluence of 150–250 J/cm². It would appear that the Nd-YAG laser at a wavelength of 1.32 µm should be valuable in neurosurgery as this wavelength is highly absorbed by brain parenchyma and is transmissible with a fibre optic delivery system.

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INTRODUCTION

For many years a number of papers have demonstrated the value of the CO₂ laser in neurosurgery. However, its surgical applications have been restricted by the fact that coherent light at a wavelength of 10.6 μm cannot be transmitted by a fibre optic delivery system. The Nd-YAG laser at a wavelength of 1.06 μm does not have this drawback. However, its low absorption and high scattering lead to a very deep effect in tissues. For neurosurgery there is a need for a wavelength which can be transmitted by a fibre and is highly absorbed by brain parenchyma. Lasers which have offered this promise are Holmium (2.1 μm) (6), the carbon monoxide laser (5 μm) (1) or the Nd-YAG (1.32 μm) (5).

However, the first two systems are still under evaluation and only the Nd-YAG at 1.32 μm is commercially available at present. It has been shown clearly that the absorption coefficient of water and saline is approximately ten times greater at 1.32 μm than it is at 1.06 μm, but a theoretical interaction model is not adequate to obtain data for the optimal laser parameters to be used in neurosurgery. An experimental investigation was set up to quantify the different reactions on brain parenchyma at 1.32 μm and compare these effects against those obtained with the Nd-YAG laser at 1.06 μm and the CO₂ laser. These studies were carried out on the brains of rats.

MATERIALS AND METHODS

The three lasers were a CO₂ laser CM500 (Cilas, France), Nd-YAG laser 1.06 μm Medilas (MBB, Germany) and Nd-YAG laser 1.32 μm (MBB, Germany). The Nd-YAG laser beams were transmitted via a 600 μm quartz fibre and refocused with a handpiece to give a 2 mm diameter spot with a uniform energy distribution.

The CO₂ laser beam was transmitted via an articulated arm with 125 mm focusing an objective lens. The output power was measured with a Calorimeter (OPHIR, Israel). An infrared thermographic video camera AGA 720 (Agema, Sweden) was used to record the surface temperature of the tissue during and after laser irradiation (8). The signal was digitalized by a microcomputer system and the main specifications of this system were: temperature resolution, 1°C; spatial resolution, 0.25 mm per pixel; viewing dimensions, 20 × 16 mm; digitization, 1 point per line, 65 lines per frame, which define the profile and 25 frames per second.

Thermal data were visualized as a temperature profile, giving the spatial distribution of the thermal energy at a given time (Fig. 1) and temperature evolution at a given position in the frame during 12 s (Fig. 2). The experiments were carried out on the brains of 45 living Whistar male rats providing an excellent model for cerebral parenchyma. General anaesthesia was produced with ether inhalation followed by an intra-peritoneal injection of chloral.

A craniotomy was performed under optical magnification (Microscope: ZEISS OPMI 1). Through a 2 cm skin incision a 15 mm × 6 mm craniotomy was produced with an electric drill. Two laser shots were performed on each hemisphere with a total of 4 shots per rat. (A stereotaxic frame was used to completely immobilize the head of the rat during the experiments.)

Histological examination of the lesions was performed after 24 h, 8 days and 3 months. Three groups were defined depending on the survival time: 24 h (N = 20), 8 days (N = 20) and 3 months (N = 5). Tissue samples were fixed in buffered neutral formalin for 48 h and 4 μm slides were stained with Hemalun-Fluoxine and Trichrome Masson and 10 μm slides with Waelke and Kluner Barrera. The histological assessment of the brain included the measurement of the depth of necrosis and a qualitative assessment of the structure of the necrotic area.

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**Fig. 1.** Temperature profile at a given position. The arrow is at the thermal maximum point which was chosen for recording the temperature evolution.