Laser in Neurosurgery, Angioplasty & Cardiology

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What is neurosurgery?

Neurosurgery deals with diseases of the central nervous system (CNS), i.e. the brain and the spine.
Neurosurgery of brain

- Surgery of brain tumor

- Difficulties
  ➔ Extremely localized operations are necessary due to the complicated structure and fragility of the brain.
  ➔ The tumor itself is often not easily accessible, and very important vital centers are situated beside it.

- life-threatening
  ➔ this is because space inside skull is very limited.
  ➔ growth of new tissue increases the pressure inside the brain which leads to mechanical damage of other neurons.
Structure of human brain

- Major part of the brain - cerebrum, diencephalon, cerebellum, and brainstem.
- Part of diencephalon hypothalamus, hypophysis, thalamus, and epiphysis.
- Part of brainstem - mesencephalon, pons, and medulla oblongata.

Fig. 4.50. Scheme of a human brain
In general, brain tissue can be divided into gray matter and white matter.
History of laser application in neurosurgery

- **[1960s~1970s]**
  - The application of lasers in neurosurgery has been extremely slow. Ruby laser was not of great help in neurosurgery.
  - Initial experiments with the CO₂ laser were performed at too high energy levels.

- **[1970s~1980s]**
  - Reawakened interest in neurosurgical lasers, especially moderate CO₂ lasers and Nd:YAG lasers.
  - The principal advantages of lasers in neurosurgery are evident:
    - It can cut, vaporize and coagulate tissue without mechanical contact.
    - Simultaneous coagulation of blood vessels eliminates dangerous hemorrhages which are extremely life-threatening when occurring inside the brain.
    - The area of operation is sterilized as lasing takes place, thereby reducing the probability of potential infections.
History of laser application in neurosurgery

- **1980s ~ 1990s**
  - Developed neurosurgery using CO\(_2\) laser
  - CO\(_2\) laser is able to perform precise cutting. However, it is not appropriate for the coagulation of all blood vessels because some blood vessels diameters are very smaller than CO\(_2\) laser wavelength such as arteries and veins with diameters > 0.5mm
  - Nd:YAG lasers are effective in coagulating blood vessels ➔ Combined CO\(_2\) and Nd:YAG lasers, it is very effective for ablation and coagulation.

- **Lasers**
  - **CO\(_2\) laser wavelength**: 10.6um
  - **Nd:YAG laser wavelength**: 1064nm
The main problem with CW lasers is that they do not remove brain tumors but only coagulate them.

- It could lead to the occurrence of severe edema
- Healthy tissue might damaged due to heat diffusion

- [1990s~]
  - Having studied pulse lasers for neurosurgery: Er:YAG and Nd:YLF lasers.
  - In free-running and Q-switched Er:YAG case, they limited thermal alteration of adjacent tissue but mechanical damage was very pronounced.
  - Since the Er:YAG laser emits at a wavelength of 2.94um, its radiation is strongly absorbed in water. soft brain tissue(having high water content) is suddenly vaporized which leads to vacuoles inside the tissue with diameters ranging up to a few millimeters.
History of laser application in neurosurgery

Fig. 4.51(a) Brain tissue after exposure to an Er:YAG laser (pulse duration: 90µs, pulse energy: 60mJ). Mechanical damage is evident.

Fig. 4.51 (b) Voluminous ablation of brain tissue achieved with the same laser.

⇒ It is not very helpful that even large volumes of brain tissue can be ablated with Er:YAG lasers.
History of laser application in neurosurgery

Fig. 4.52. Ablation curve of white and gray brain matter obtained with a Nd:YLF laser (pulse duration: 30 ps, focal spot size: 30 μm). Data according to Fischer et al. (1994)
History of laser application in neuro surgery

Figs. 4.53(a) Brain tissue after exposure to a picosecond Nd:YLF laser (pulse duration: 30 ps, pulse energy: 0.5mJ)

Figs. 4.53(b) Histologic section of brain tissue after exposure to the same laser (bar: 50um).

→ There is no evidence of either thermal or mechanical damage to adjacent tissue.
Stereotactic neurosurgery

- This is very precise technique in order to plan a suitable penetration channel before surgery.
- It requires a so-called stereotactic head ring made of steel or carbon fibers which is tightly fastened to the patient’s skull by several screws.

→ By this procedure, the risk of hitting a vital center within the brain can be significantly reduced, and the success of a treatment becomes more predictable.
Stereotactic neurosurgery

Fig. 4.54. Concept of stereotactic laser neurosurgery

Fig. 4.55. Schematic drawing of laser probe
Spinal Surgery

- The CO2 laser has proven to be useful in treating tumors of the spinal cord.
- Such tumors can be coagulated without severe complications.
- Spinal surgery is also performed with spinal cord navigation system, endoscopic spinal core.
- However, spinal laser surgery is still in its infancy.
What is angioplasty?

- Angioplasty is concerned with the treatment of blood vessels which are narrowed by atherosclerosis.
- The obstructions stem from the formation of an anorganic plaque inside the vessels which reduces or even completely suppresses the blood flow.

*Atherosclerosis: a degenerative disease of the arteries characterized by patchy thickening of the inner lining of the arterial walls.*
Stenosis

- The degree of obstructions is so-called stenosis.

\[ \text{stenosis}\% = 100 \times \frac{\text{intimal area}}{\text{intimal area} + \text{lumen area}} \]

- The promotion factors of plaques are not completely understood.
- The formation of a plaque might be favored at sites of a local vessel injury where cells capable of repairing the vessel wall tend to gather.
- If some of the secreted products of these cells are not carried away, a plaque is formed.
- After the cells have died, primarily anorganic concrements with a high content of calcium are left behind.

* Intimal area: the interior wall of the vessel
* Lumen area: the space available for blood flow
PTCA

- Percutaneous transluminal coronary angioplasty (PTCA)
  - In 1970s, it is applied the dilatation catheter in coronary arteries
  - This technique is PTCA
  - PTCA increases the size of the vessel lumen by catheter and balloon which evoked cracking, splitting and disruption of the atherosclerotic plaque
  - However, PTCA might cause plaque hemorrhage, bursting of the vessel wall by inflation of a balloon
  - The treatment need to perform under X-ray control
  - To reduce the incidence of thrombosis, aspirin and heparin are usually administered.
PTCA-restenosis

- Arterial dissection and intracoronary thrombosis are most severe.
- Recurrence of the original stenosis may take place even months after the treatment—called by restenosis.
- It reported on the occurrence of restenoses in 30% of patients treated with PTCA.
- Restenoses are believed to be initiated by accidental injury of the vessel wall, resulting in the subsequent release of thrombogenic, vasoactive, and mitogenic factors.
- Endothelial damage leads to the activation of macrophages and smooth muscle cells.
- Thereby, growth factors are released which in turn may promote their own synthesis.
- A self-perpetuating process is initiated which is associated with a thickening of the intima, i.e. the interior part of the vessel wall.
- Finally, the vessel is obstructed again.
bypass surgery, atherectomy, HFRCA

- Among these (bypass surgery, atherectomy, and high-frequency rotational coronary angioplasty) only bypass surgery is performed during complete anesthetization.
- Bypass surgery is a very complicated type of surgery, since the chest must be opened and the heart beat is interrupted.
- Atherectomy is a more rigorous version of PTCA, where the plaque is additionally planed away by means of mechanical abrasion.
- In HFRCA, a miniaturized mechanical drill called a rotablator is used for vessel recanalization.
Angioplasty using lasers

- First experiments regarding laser angioplasty were performed (1980s)
- Laser light could ablate atherosclerotic plaque, it was quite uncertain whether such a treatment could be transferred to in vivo surgery.
- Laser light was applied to the plaque by means of optical fibers.
- Only thermally acting lasers—i.e. argon ion, CO2, and Nd:YAG lasers—were investigated at that time which induced severe thermal injuries such as extensive coagulation, necrosis of vascular tissue, and perforation of the vessel wall.

→ In 1986, Hussein developed a novel tip design, the so-called hot tip
Angioplasty using lasers

Hot tip

- It is converted all laser energy to heat by means of absorption ➔ Instead of using a tightly focused laser beam, plaques are removed by homogeneously distributed heat

Usually, CW argon ion lasers and Nd:YAG lasers are applied, although any kind of laser radiation could be used which is absorbed by the metal cap.

- Advantage: Diminish the incidence of thermal perforations

- Disadvantage: Induce unpredictable vasospasm ➔ they can induce severe secondary obstructions

Fig. 4.57. Scheme of a laser-driven hot tip for vessel recanalization
Angioplasty using Excimer lasers

- In 1985, it demonstrated that pulsed XeCl excimer lasers
- Pulsed excimer XeCl lasers are capable of performing efficient plaque ablations with only minimal thermal injury of adjacent tissue
- Unfortunately, though, an unpredictable type of complication occurred as discussed below which soon slowed down initial enthusiasm.

Fig. 4.58. Scheme of laser angioplasty for vessel recanalization
Angioplasty using Excimer lasers

Fig. 4.59 (a) Histologic section of atherosclerotic plaque inside a blood vessel (bar: 150 μm). The vessel wall is located at the bottom of the picture.

(b) Ablation of atherosclerotic plaque with a XeCl excimer laser (pulse duration: 60 ns, repetition rate: 20 Hz, bar: 150 μm, plaque: left, ablation: right).
Angioplasty using Excimer lasers

- Today, it is well accepted that restenoses are extremely pronounced following excimer laser angioplasty.
- Their occurrence can be attributed to an enhanced proliferation of smooth muscle cells.
- Most of these cells undergo DNA synthesis during two weeks after laser treatment, resulting in intimal thickening within the first four weeks.
- Obviously, the mechanism of photoablation is more stimulating than only mechanical cracking or abrasion.
- Thus, even though photoablation is a rather gentle technique for removing plaques, its long-term effects forbid its use for the purpose of vessel recanalization.

→ Therefore, excimer laser angioplasty is generally being rejected today, and it is rather doubtful whether it will ever gain clinical relevance.
Angioplasty using TMLR

- More promising are CO2 laser systems which can be used to create additional channels for the blood supply of the heart.
- These channels originate from the epicardium, i.e. the periphery of the heart, and remain open after laser treatment.
- Called transmyocardial laser revascularization (TMLR)

TMLR

- have confirmed the effect of revascularization.
- judge treatment effects by measuring the local contractility of the heart muscle.
- TMLR show improved contractility both in the short- and long-term. they observed diminished areas of necrosis.
Thank you