Round Table: LEDs in clinics

- Marine Amouroux is a research fellow at Université de Lorraine. She mentioned the definitions of radiometric and photometric quantities (as well as units associated to such quantities) used to describe an optical radiation according to the norm PR NF ISO 80000-7. In terms of medical applications, Marine Amouroux proved the importance of characterizing the RCI quantity (Color Rendering Index) of light sources found in dermoscopes. Finally, she reminded the audience of the physical principles of light emission in several light sources such as the ones used in domestic lighting (filament lamp), LEDs (electroluminescence in Light Emitting Diodes) and LASER (stimulated emission).

- Georges Zissis is a Professor at Paul Sabatier University in Toulouse (Laplace Laboratory, UMR 5213 CNRS-Toulouse III). Georges Zissis explained the photobiological principles of LEDs light interaction with biological tissues (eyes especially) that cause epidemiologic hazard, especially if such LEDs (Light Emitting Diodes) become more and more common in our everyday life environment. The spectral ocular hazard function for retinal cells (measured through the apoptosis rate of retinal cells when irradiated with light in different spectral bandwidths) displays a maximum rate between 420 and 470 nm. LEDs emitting white light, like they are currently made, emit precisely their most intense irradiance in the 420-470 nm spectral bandwidth (maximum at 450 nm). Therefore, LEDs constitute a potential epidemiologic hazard which long term - impact cannot be known yet (age-related macular degeneration: AMD).

- Anne Le Pillouer-Prost is a dermatologist in Marseille (France) and the Vice-President of the European Society for Lasers Dermatology, proposed a review of the scientific literature dedicated to the use of LEDs in the dermatology field. If LEDs performance seems promising especially for several diseases (mucositis and radiodermatitis prevention, acne treatment, alopecia, pigmentary disorders, etc.) more clinical studies (randomized, double blind, placebo-controlled and with higher statistical significance) are required in order to precise indications and protocols.

- Gérard Toubel is a dermatologist in Rennes (France); he is the former President of the LASER Group of the French Society of Dermatology. Gérard Toubel proposed a critical analysis of information found in advertisement made by companies selling medical or home - devices based on LEDs. Scientific evidences given by such industrial groups are either weak or nonexistent, when they are not wrong: some light penetration depths announced in such advertisement do not match with the values found in the scientific literature. For other types of outliers: pictures before / after treatment with the medical device are taken in different light environments and at different distances; evidences are based on qualitative appreciation of one histological picture without any quantitative type of analysis. Security seems to be the only sales argument; clinical performance still needs to be proven.
Round Table: Optical fibers for medical applications

The first communication given by Geneviève Bourg-Heckly (Pierre et Marie Curie University), entitled « The optical fiber: back to basics », intended to provide the basic notions required to understand the principle of operation of an optical fiber with a focus on the relevant parameters for medical use. Made by drawing silica or plastic to a very thin diameter, optical fibers are key elements of medical lasers as they allow to guide the laser beam to the tissue target in a flexible way. The light transmission by an optical fiber makes use of the phenomenon of Total Internal Reflection (TIR) which allows to confine the light inside the fiber core and transmit it with minimal power losses. An optical fiber consists of a core surrounded by a cladding layer, the whole surrounded by a protection jacket. To obtain the TIR condition, the refractive index of the core must be slightly greater than that of the cladding. When light enters the fiber with an appropriate angle, it will experience multiple internal reflections, bouncing back and forth off the boundary between the core and cladding down to the end of the fiber. Optical fibers can be classified in two types: multimode and single-mode. In multimode fibers, light rays can propagate along the fiber at various angles, following different paths, while in single-mode fibers, due to the very small core diameter, light propagates along the fiber axis. For medical applications, the key parameter to be considered is attenuation which is strongly wavelength dependent and thus determines the spectral range of use. Because silica exhibits a very low attenuation on a broad spectral range, from UV to 1700 nm in the near Infrared, the most common fibers are made of pure or doped silica.

Beyond 1700 nm, the silica strong attenuation does not allow to use this material to transmit light. That is why Er:YAG (2936 nm) or CO2 (10600 nm) laser beams are delivered through articulated arms. In the second presentation, entitled «Infra-Red fibers: towards fibered Er:YAG and CO2», Marc Fauchecux (Laser & Medical Devices Consulting) presented the current developments aimed at overcoming this limit. This is a crucial issue, since without fiber the access to internal tissue for therapeutic or diagnostic purpose is impossible, resulting in a strong reduction of medical indications. A first solution consists in using hollow-core fibers which are now commercially available for Er:YAG and CO2. Much easier to handle than Er:YAG and CO2, they can be used in laparoscopy but not in endoscopy which requires small probe curvatures. Featuring limited curvature and high transmission losses, they are, furthermore, difficult to sterilize. The second solution is based on the development of solid core fibers but using other materials than silica such as chalcogenides which permit high transmissions in the infrared domain; the current spectral range spreads from 2000 to 9000 nm but should be soon extended to 10000 nm. These fibers show the same type of limitations than hollow core ones to which must be added toxicity issues for chalcogenides. Finally, Photonic Crystal Fibers, a new type of fibers under development, based on a different type of guiding than TIR, seem very promising. However their industrial cost is still unknown.

The manufacturing of optical fibered probes dedicated to medical applications raises some specific issues which was the topic of Martine Deboigne’s communication (SEDI-ATI Fibres Optiques) entitled « Available medical optical fibers ». A great variety of fibered probes are available, which can be classified according to the power and the wavelengths to be transmitted, the connectics and the assembly technologies. The emission at the fiber output can be axial, lateral or annular. Diffusing probes make it possible to deliver an uniform irradiance over a frontal or lateral profile. Finally, medical probes manufacturing must comply with all the regulations needed for clinical use. To illustrate her point Martine Deboigne gave several examples: Endovenous Laser Therapy (EVLT) probes, PDT (Photodynamic Therapy) probes, Laser Induced Interstitial Thermotherapy (LITT) probes …

To date nearly all the optical probes dedicated to medical applications are fibered probes; however a novel technology, also based on optical fibers, which allows the obtention of light emitting fabrics, is the
object of promising developments. **Serge Mordon (INSERM)** described the principle of operation of this technique and its application to Photodynamic Therapy (PDT) in the 4th communication entitled « Light emitting fabric for photodynamic therapy ». The development of flexible light sources brings numerous benefits: irradiance homogeneity, choice of wavelength, easy implementation ... In the medical field, two techniques are being developed: either embroidery-based or woven-based light emitting fabrics. In the latter solution, side-glowing emission is obtained by fiber microbending: if the bending angle of the fiber is greater than a critical angle, side-emission effect is created by leaking some light from the fiber's core to the cladding. To obtain a uniform light irradiance, a light source is connected to each fiber extremity. The weaving can be performed using an automatic weaving machine. Currently, an irradiance of 20 mW/cm² with an homogeneity of ± 15% is achieved. The main application under clinical evaluation is the PDT treatment of actinic keratoses of the scalp for which a specific helmet has been developed but many other applications can be considered.
Round Table: Laser bone ablation: when laser hits a bone snag

A review of the literature was presented by Serge MORDON (INSERM Onco Thai Lab., Lille, France). Bone cutting using mechanical instruments has a poor precision and is associated with thermal as well as mechanical collateral damage that delays healing. Since first attempts in 1973, three main laser sources have been used for bone ablation: excimer lasers, that create a desorption, thermal lasers (CO₂, Er:YAG, Er:Cr:YSGG) and ultrashort pulsed lasers (USPL), that form a plasma associated with a photodisruption of the bone.

Laser bone effects depend on two parameters: light penetration and increased temperature. The deepest penetration of light in the bone is observed with the 1064 nm Nd:YAG laser. Temperature increase is a major problem during bone cutting, as a consequence of collateral damage to the tissue, such as necrosis and delayed healing. During a bone cut using CO₂AET, temperature increase may reach 400°C (without cooling device); when used with such cooling (high pressure air / water stream), temperature reaches 120°C.

Er:YAG laser allows for a fine bone cut (500μm width), temperature increase is limited by the cooling system – that must also be used with CO₂ and Er:Cr:YSGG lasers. No relation between optical penetration and ablation efficiency has been demonstrated. USPL allow for bone ablation independently from temperature, because of a mechanical effect with a bone photodisruption caused by the plasma-generated shock wave at the focal point. Their use is associated with an improved healing, as compared with other lasers, but ablation rate is less. Worthwhile results have been obtained using femtosecond lasers and picosecond pulsed laser.

Lasers may also be used for bone repair, by precise osteotomy of small volume bone pieces that may serve as bone grafts, and for bone fixation by tenon-mortice laser-shaped bone specimens. A surgical prototype for robot-assisted cold laser osteotomy – named CARLO - has been designed in Switzerland and offers interesting perspectives for laser bone ablation.

Marc FAUCHEUX has presented new laser technology for bone ablation. Expected benefits of lasers over mechanical instruments are important – no contact technique, no pressure or vibrations, no bone dust production, possibility of coagulation, ablation pathway flexibility, accuracy of cutting, handiness, possibility of robot control – although drawbacks are observed: mechanical and thermal collateral damage, low cutting speed, reduced ablation depth and absence of light penetration depth control. Biological effects of light on the bone are related to several light absorption bands, due to bone tissue biological components – hydroxyapatite, the major component, proteins, water -.

Thermal lasers (Er:YAG, Er:Cr:YSGG, CO₂, FEL) provide a precise, thin bone cutting, associated with low rate of thermal collateral damage (using short pulses) and no microfissures in the bone. However, they also have drawbacks: variable ablation rate, according to laser source – low rate for excimer lasers, better for Er:YAG and short pulses CO₂-, some thermal collateral damage, moderate handiness, complexity and cost, significantly higher than those of mechanical instruments.

Advantages of femtosecond lasers are absence of thermal effects and a fine and sharp cut. A commercially available fiber laser, with a 1030 nm wavelength, 750 fs pulses at a 1Hz to 1KHz repetition rate, with a 500μJ maximal energy per pulse, is capable for perfectly round shape bone perforations, with smooth and sharp edges, without any thermal damage zone. Finally, ablation depth control systems are under development: associating a spectrometer with the laser source allows for a real-time monitoring of ablation depth. Reproducible 1500 μm deep bone incisions have been described, using a microsecond pulsed laser, with a thermal damage zone of 5 to 10 μm.
When coupled with such ablation depth control systems, femtosecond pulsed lasers combine aforementioned advantages, while allowing a precise and real-time controlled bone cutting. However, they remain complex and still have a high cost when compared to mechanical instruments. Large scale industrial production is still pending. A medical prototype has been developed by the company Fraunhofer ILT (Institute for Laser Technology): a picosecond laser (25W, 20 kHz, 25 ps pulses) with a hand-held piece that contains a 3D microscanner measuring in real time the ablation depth. This laser is capable of bone cut of 10 mm maximal depth, 0.5 mm large, at a 12.5 mm/minute speed.

In ENT surgery, lasers have been used for a long time, for the treatment of various diseases involving the larynx, pharynx, trachea, ear, nose or mouth – benign or malignant tumors, angiomas ...). Several lasers sources are used (KTP, Nd :YAG, CO\textsuperscript{2}, dye lasers, diode lasers, diode lasers ...), although none for bone ablation, mostly because of the risk of bone thermal necrosis and its consequences, and the risk of collateral vascular and nervous structures lesions due to heat transmission. Guillaume BOLOT has reviewed reported experiences as well as potential applications of lasers for bone ablation in ENT surgery.

In otology, otospongiosis represents a good indication for CO\textsuperscript{2} laser. Strong absorption of light by the perilymph gives an advantage of laser over the bone drill, with a reduced risk of nerve damage, especially for audition. Laser stapedectomy and platectomy are now validated procedures.

In laryngology, the use of a CO\textsuperscript{2} laser in larynx endoscopy allows for a blood-free dissection and vaporization of benign or malignant lesions of vocal cords, benign laryngeal tumors such as chondromas, or malignant tumors (curative treatment of dysplasias and grade I and II endolaryngeal tumors, palliative treatment of other malignant tumors with respiratory pathway reopening).

Tracheal stenoses are treated either surgically, or with the use of diode laser in endoscopy, or with endotraqueal placement of an enlarging prosthesis.

For nasal and sinuses diseases, a CO or diode laser may treat a pure mucosal choanal perforation, while an associated osseous perforation usually requires the use of a micro-drill. Obstructive rhinopathies, specific as well as non-specific, are significantly improved with KTP or diode laser turbino-plasty, that performs a blood-free mucosa retraction of the turbinates bones with no risk of bone necrosis, with excellent long-term results. In sinuses diseases, the use of a laser is associated with an important risk of deep thermal lesions, mostly a thermal bone necrosis, and also irreversible lesions of nervous and vascular underlying structures, such as optic nerve, olfactory nerve, internal carotid artery. Endoscopic meatal disconfinement or ethmoidectomy may be helped with a laser, but requires an appropriate visual control of the exposed target.

The current use of lasers in Neurosurgery is limited to some applications where they tend to be advantageous over conventional instruments, while some previously abandoned applications such as interstitial therapies (interstitial thermo-therapy and photodynamic therapy) are currently revisited. Despite numerous experimental works reported on laser cranial and spinal osteotomy, no surgical application is currently validated, because of a lack of efficacy when compared to conventional instruments, of a risk of collateral thermal damage to the surrounding structures highly sensitive to heat, of unfavorable ergonomics and high costs.

Bertrand DEVAUX presented the current status of bone ablation in neurosurgery and suggested new perspectives on the use of laser sources for neurosurgical practice.

The bone flap cutting off with a laser doesn’t appear advantageous when compared to regular craniotomy instruments, for several reasons: the skull bone may be very thick, exceeding the laser-induced ablation depth, the cutting speed with a laser is significantly slower than with a craniotome (less than 20 mm per minute, while a large craniotomy is usually performed in less than 5 mm), the light penetration in the skull is not controlled, with the risk of thermal lesions of the underlying dura and brain.
Similarly, *spinal osteotomies*, for spinal cord tumor exposure, or for lumbar or cervical disc herniation, would not gain from the use of a laser, for the same reasons. However, several cerebral and spinal lesions might benefit from the use of a laser for their treatment. Thermal, excimer, or ultrashort pulse lasers (USPL) may replace regular neurosurgical instruments, or may be used in association with them. Skull base *ossifying meningiomas* (mostly developed from the orbit wall and sphenoid wings) are usually incompletely resected by piecemeal reduction and drilling. A thermal pulsed laser or USPL could reduce the resection time, decrease the blood loss and limit the risk of mechanical lesions to surrounding nervous structures (optic nerve, oculomotor nerves). Similarly, the resection of *suprasellar craniopharyngiomas*, benign tumors of difficult surgical access, is often complex due to the narrow surgical route, to the frequently adherent calcifications, and to the risk of lesions to the surrounding functional structures. An ablative laser could improve the resection of these tumors, through their cavitation and photoablation.

Percutaneous treatment of cranial or spinal osteoid osteomas, benign tumors frequently painful, could be performed using local, MRI-guided, interstitial thermotherapy. Such a technique of osseous cranial and spinal tumors ablation under MRI control has been reported in 2011. Thermal ablation was performed via a dedicated high technology system, which includes a 980 nm diode laser, an optic fiber with a diffusing tip and a cooling applicator. Real-time thermal and ablated volume control during the application of laser light was performed in the MRI unit. Early clinical applications were described, with promising results.