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Evaluation of laser prostatectomy devices by thermal imaging.

David G Molenaar, Remco J van Vliet, Christiaan FP van Swol,
Tom A. Boon, and Rudolf M Verdaasdonk

LASER CENTER AZU

Medical Laser Center, Department of Urology,
University Hospital Utrecht, The Netherlands.

ABSTRACT.

The treatment of Benign Prostatic Hyperplasia (BPH) using Nd:YAG laser light has become an accepted alternative to TURP. However, there is no consensus to the dosimetry using the various laser devices.

In our study, we have evaluated the optical and thermal characteristics of 7 commercially available side firing laser probes. For the thermal analysis, an optical method was used based on 'Schlieren' techniques producing color images of the temperature distribution around the laser probe in water. Absolute temperatures were obtained after calibration measurements with thermocouples.

Laser probes using metal mirrors for beam deflection, heated up entirely. The local temperature rose up to 100 degrees centigrade, thus inducing vapor bubble formation that interfered with the emitted beam. Laser devices, using total internal reflection for deflection, showed far less heating primarily at the exit window, though Fresnel reflections and secondary beams indirectly heated up the (metal) housing of the tip. After clinical application, the absorption at the probe surface and hence temperature increased due to probe deterioration.

Color Schlieren imaging is a powerful method for the thermal evaluation of laser devices. The thermal behavior of laser probes can be used as a guidance for the method of application and as an indication of the lifetime of the probes.

1. Introduction.

Recently, many different laser devices to treat Benign Prostate Hyperplasia have become commercially available. The physical properties of the different devices are not fully understood. Knowledge of these characteristics that includes the optical and thermal properties is of interest for the determination of the suitable dosimetry. The thermal and optical properties of the devices are highly related since light absorption by the device will lead to temperature increase. The optical characteristics are published in a separated paper[1].

This paper is aimed at the thermal properties of the devices which are determined using an optical method that enables real time visualization of thermal gradients. Knowledge of the thermal and optical characteristics may lead to an optimal use of the different laser devices.

2. Materials and methods.

2.1 Methods of light deflection.

The devices consist of a silica fiber, provided with a fiber-tip. This fiber-tip is responsible for sidewards delivery of the laser light. The fiber-tips can be classified in two types: The fiber tips that use total internal reflection for sidewards delivery and the fiber tips which consist of a metal deflector. This paper discusses the UroLase (Bard), ProLase II (Cytocare), ADD (Laserscope), SideFire (Myriad Lase), Ultraline (Heraeus), Tulip (Intrasonix), and the Matteoli Bridge.

2.1.1 Deflection by a metal mirror.

The fiber tip consists of a metal reflecting mirror, which is either gold plated (UroLase, Matteoli Bridge) or made of a gold alloy (SideFire). Light emitted through a bare fiber is aimed at a reflective surface. At the deflection surface light will be lost due to absorption. Absorption causes two effects: The absorbed light energy is transformed to heat, leading to a temperature increase of the fiber tip, and a decrease of the light transmission of the device. The reflectance of the mirror is increased by using gold as deflecting material that has a relatively high reflection coefficient (0.991 for Nd:YAG light, 1064 nm)[2].

2.1.2 Deflection by total internal reflection.

Devices with angled fiber tips make use of reflection caused by a difference in refractive index between the angled tip and the surrounding medium. The end of the fiber is polished at such an angle that rays in the fiber are reflected at the angled surface, as their angle of incidence exceeds the critical angle. This critical angle depends on the difference between the refractive index of the fiber and the surrounding medium. These fiber tips can be divided into two sub-types, the metal and non-metal fiber tips.

The metal fiber tips are provided with a metal housing that prevents the secondary beams to reach the prostatic tissue hence the fiber tip is heated due to absorption of light energy. The ProLase II and the Angled Delivery Device (ADD) are devices of this type.

The non-metal fiber tips do not have a metal construction. Since the absence of metal parts the non-metal fiber tips, thermal effects will not occur in such an extent compared to the metal fiber-tips.

An example of this type of fiber tip is the UltraLine.

2.1.3 Physical characteristics of laser prostatectomy devices.

Since the devices are based on different deflection mechanisms, the physical properties of each device will differ. The properties that are of interest for the tissue effect are the power density on the prostatic tissue and the thermal effects. An optical technique that enables real-time visualization of thermal images is used.

2.2 The color Schlieren thermal imaging method.

2.2.1 Thermal imaging.

To approach the situation during clinical use the fibers are evaluated in a watery environment. For evaluation of the thermal behavior of the fiber tips in water several detection methods can be applied. The most common method of measuring heat is using thermocouples. This is a relatively uncomplicated way of measuring temperature within a wide range and with an acceptable resolution. Since the temperature information is delivered by an electrical signal, data conditioning by computing devices is easy. However, the information obtained by a thermocouple is one dimensional. To obtain real time temperature information of an area, an array of thermocouples can be used which is limited in spatial resolution and which interferes with the environment. For this reason other two dimensional measurement methods should be applied. A thermo camera produces 2-D temperature information but can not be applied for an aqueous environment.

A new technique for determination of thermal distributions in an aqueous environment called the **color Schlieren method**[3] is discussed. This technique allows visualization of temperature gradients in transparent media.

2.2.2 Fundamentals of the color Schlieren method.

The color Schlieren method is an optical technique to visualize density changes in media based on spatial filtering resulting in contrast enhancement[3]. This method is used in a broad range of applications such as fluid dynamics, ballistics, aerodynamics and ultrasonic wave analysis image processing. The application discussed in this paper is aimed at temperature distributions in water.

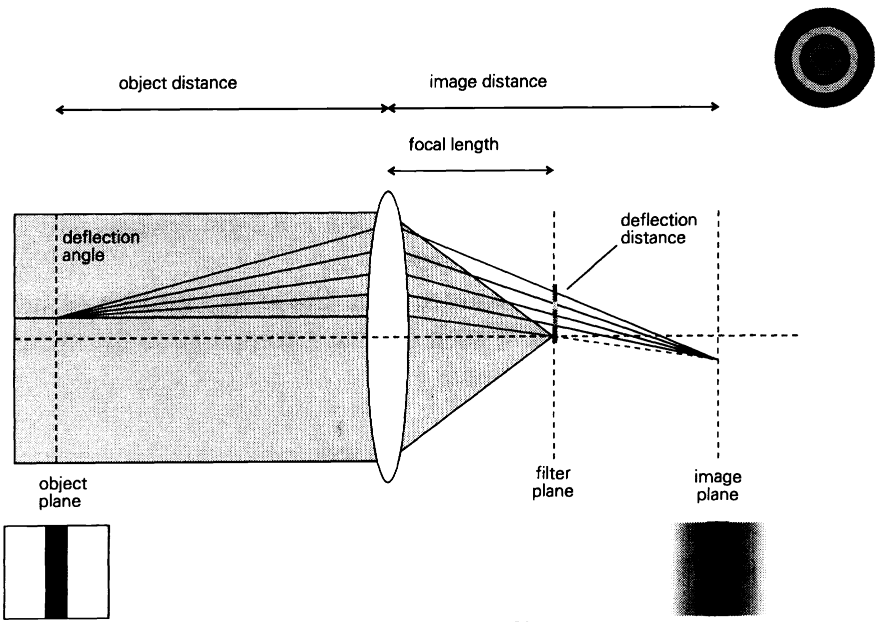


Figure 2-1: Setup of the Schlieren apparatus.

The setup for the color Schlieren apparatus is represented in Figure 2-1. A parallel light beam passes an object, submerged in water and positioned in the object plane of the lens. This object induces a disturbance in the light path of the beam around it, caused by thermal effects and light rays will be deflected.

In the focal plane of the lens a color filter is positioned. The color filter consists of colored rings shifting from black in the center to red for the most distant rings. The lens images the object in the image plane, however, the deflected rays cross the filter at different positions depending on the extent of deflection and will be color coded. The resulting image of the object consists of colors representing information of the deflection angle. The extent of deflection is related to the temperature hence the colors in the image can be related to the temperature of the object.

2.2.3 Calibration of the color Schlieren setup.

Up to now the Schlieren apparatus was used only for qualitative visualization of thermal gradients. In order to obtain quantitative temperature information the Schlieren apparatus was calibrated. This is possible when using well-defined symmetries[4]. A filter design using discrete colors separated by black rings facilitates distinction of the isotherms in the image. Calibration measurements pointed out that absolute temperatures can be extracted from the images with an accuracy of 10-20 % for well-defined conditions[5].

3. Results.

All fiber tips were positioned vertically in a water filled cuvet of approximately 30°C using 40 W laser power. They were positioned in such a manner that the fiber tip radiates its light to the right side as seen from the image. The images were recorded by a video camera. All evaluated devices were new, except for one UltraLine fiber which was used once clinically. Unfortunately, it is not possible to present colored images in this paper. The original color images give a much better representation of the thermal distributions.

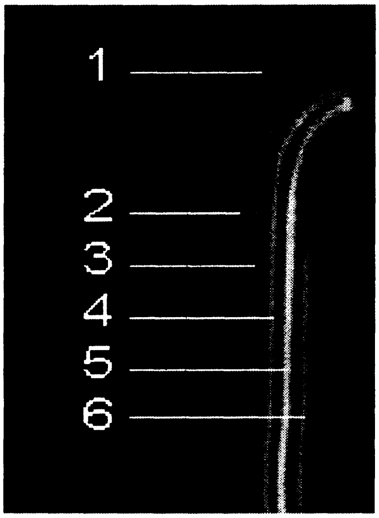
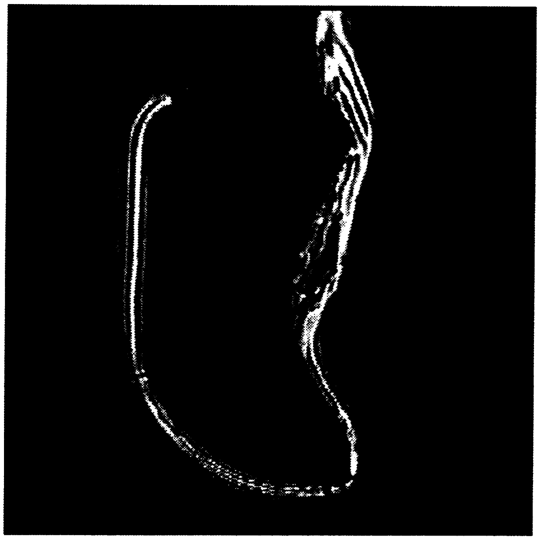


Figure 3-1: Line numbers for calibration table.

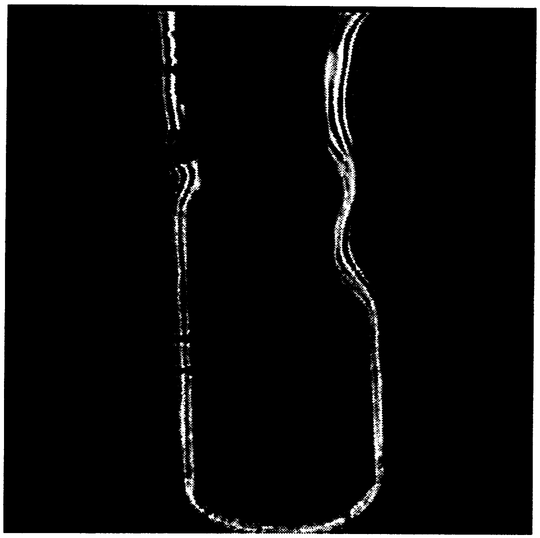
Table 1: Calibration table of the Schlieren images.

Isothermal line number	*Corresponding temperature rise (°C)*	*Original Schlieren image color*
1	1	dark blue
2	1-2	blue
3	2-4	light-blue
4	4-6	blue-green
5	6-7	light-green
6	7-9	green-yellow
7	9-12	yellow
8	12-15	yellow-orange
9	15-18	orange
10	18-24	red

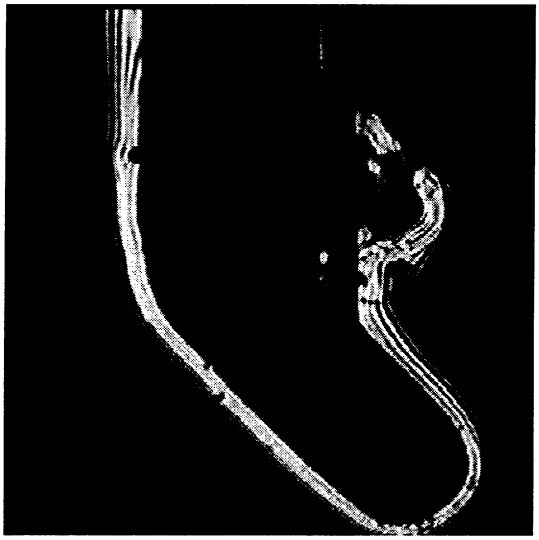
Figure 3-1 is a blow-up of a part of a Schlieren image showing a temperature gradient in detail with the corresponding isothermal lines. The line numbers with the corresponding temperature rise are presented in Table 1. This table is valid only for the used color Schlieren filter.



UroLase



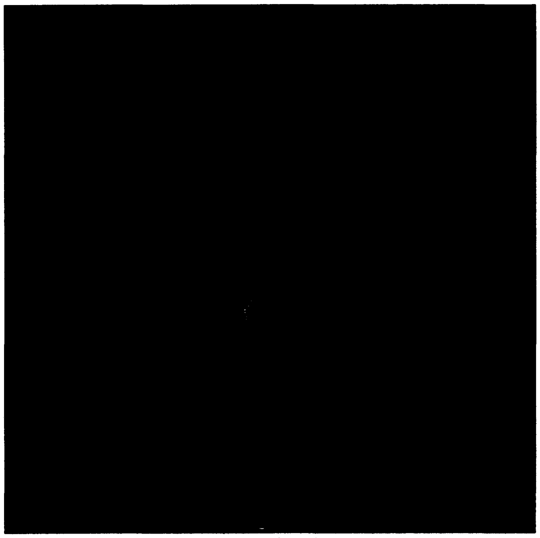
SideFire



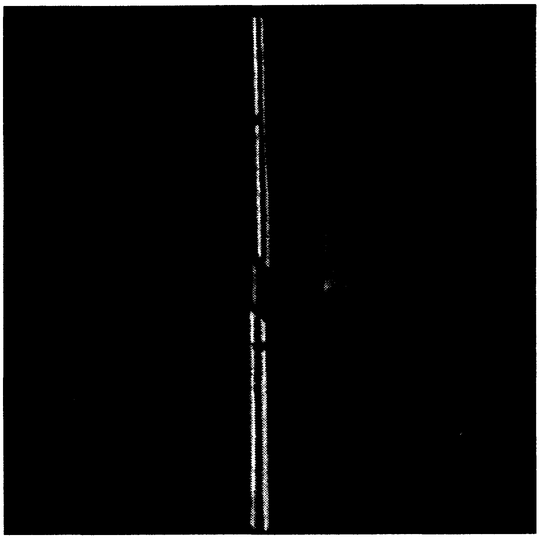
Matteoli Bridge

ADD

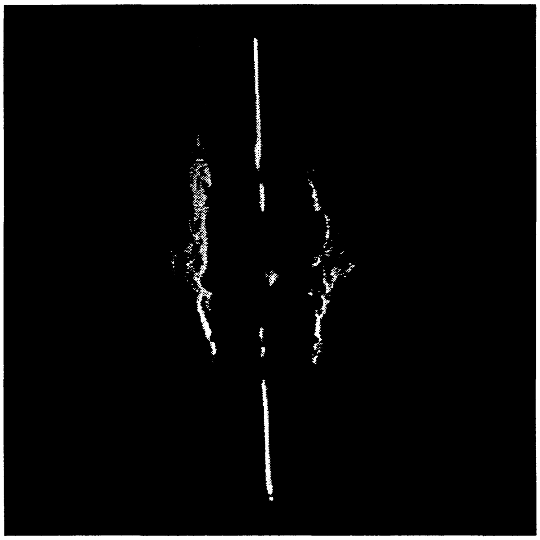
ProLase II



Tulip device



UltraLine (new)



UltraLine (used once)

Table 2: Results.

Device name	*Temperature rise at exit window (°C) ± 15%*	*Temperature rise at back side (°C) ± 15%*	*Absorption (%) ± 1.5%*[1]	*Type of fiber tip*
UroLase	70	10	51	metal mirror
SideFire	30	10	57	metal mirror
Matteoli Bridge	70	20	39	metal mirror
ADD	15	18	23	metal housing
ProLase II	30	5	32	metal housing
Tulip device	2	no temperature rise	-	-
UltraLine	3	no temperature rise	17	non-metal
UltraLine (used once)	70	70	50	non-metal

4. Discussion.

There is a substantial difference in the heating of fiber tips based on a metal reflector compared to the fiber tips based on internal reflection. In case of the metal reflectors, the absorption data (table 2) indicate that much energy is absorbed by the metal reflector and the housing. Taking the physical properties of the metal tip into account, this can easily result in temperature rises up to the boiling point of water. These boiling bubbles are observed near the exit window of the beam and will interfere with the beam characteristics thus influence the power density at the tissue.

Fiber tips based on total internal reflection show less thermal effects since a direct absorbing surface is absent. The maximum surface temperature rise of these fiber tips is approximately 5 to 10 °C at 40 W laser power. The thermal effects of these fibers are caused indirectly by secondary beams from transitions and internal reflections. Normally, these secondary beams 'escape' from the probe but when the fiber tip is provided with a metal housing, the secondary beams are captured. This results in a temperature rise of tens of degrees (table 2).

When a device is used clinically, the surface of the probe will deteriorate due to the exposure to very high local temperature when tissue particles get in contact with the probe. This process will increase the absorption for all devices. The Ultraline is presented here as an example because the difference between a new and a used probe is striking. The rate at which the devices deteriorate during clinical application needs to be investigated. We have started this study using a specially developed powermeter[6].

The heating of the probes does not have to be a disadvantage. It might even make the procedure more effective when using the probe in contact with tissue. Though, the surgeon should be aware of the extent of the thermal zone towards the proximal part of the fiber since this will be in contact with the sphincter area and might cause damage.

5. Conclusions.

The thermal behavior of the devices for BPH treatment are closely related to the design and the optical characteristics of the fiber tips. Fiber tips which have metal parts in their construction show more thermal effects than the non-metal fiber tips. During clinical application the thermal effects will increase due to probe deterioration.

Color Schlieren imaging is a powerful method for the thermal evaluation of laser devices. The thermal behavior of laser probes can be used as a guidance for the method of application and as an indication of the lifetime of the probes.

6. References.

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