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Use of the 2 μm cw laser as addition and/or alternative for the Nd:YAG in Urology

Tjeerd de Boorder, Rudolf Verdaasdonk, *Tycho Lock, Matthijs Grimbergen, John Klaessens
Dept. of Clinical Physics, *Dept. of Urology, University Medical Center Utrecht, The Netherlands

ABSTRACT

Recently, 2 μm cw laser systems have been introduced for surgery. The 2 μm wavelength is predominantly absorbed by water and enables effective cutting and ablation of tissue similar to the cw CO_2 laser. In contrast to the CO_2 laser, the 2 μm wavelength is delivered through fiber optics and available for endoscopic procedures.

After many years of experience with the 1.06 μm Nd:YAG laser, we started to use the 2 μm cw laser as alternative for various urological treatments. The treatments strategies and optimal settings were examined in the lab comparing the two 1.06 and 2 μm wavelengths performing thermal measurements. Consequently, the laser was applied for various urological cases.

Penile tumors were resected with haemostatic effects and good aesthetic healing comparable with the Nd:YAG laser. Although the Nd:YAG has initially a deeper penetration, the blackening of the fiber during tissue cutting, provides a more superficial effect like the 2 μm laser.

Bladder (pre)malignancies were ablated after biopsy. Only with higher stage tumors, coagulation depth of the Nd:YAG might be preferable for adequate treatment.

Strictures in the urethra were incised and stents were effectively desobstructed: one patient with a stent implanted after a pelvic trauma, and one patient with catheterizable apedico stoma stenoses. The thermal damage during incision to deeper layers is minimal so recurrence due to scarring is not expected. Also hair grow in patients who underwent urethroplasty was effectively treated and scrotal atheromata cysts were effectively resected without recurrence. Laparoscopic nefrectomies are being considered using the 2 μm cw laser.

The 2 μm cw laser has shown to be a versatile instrument for effective treatment of various urological indications. More patients and long term results are needed to prove the clinical significance compared to other treatment modalities

Keywords: Urology, cw 2 μm laser, thulium laser, tumor surgery, Nd:YAG laser, fiber delivery, endoscopy

1. INTRODUCTION

Various laser systems are being used in urology, either as an alternative for other medical devices or as a unique tool (1). The Nd:YAG laser was one of the first laser introduced and appreciated for its effective haemostasis. The Nd:YAG wavelength (1064 nm) has a deep penetration in tissue and although blood is the dominant chromophore the absorption is low compared to other lasers in the visual and near IR e.g. the KTP and Diode laser. The Nd:YAG laser can effectively be used to create deep coagulation in tissue like prostate (BPH treatment) or bladder tumours (2). For heating large tissue volumes in a water environment, typically high power settings are being used (20 to 60 W) delivered through a fiber at a short distance from the tissue surface. When tissue needs to be cut or ablated, the Nd:YAG laser seems initially not effective. Only after the tissue is coagulated and further on dehydrated, the temperature at the tissue surface rise above 100 C. Above 200 C the tissue will turn black which instantly increases the absorption of the Nd:YAG light and tissue is ablated effectively. This moment of carbonization is usually uncontrolled and preceded by other effects like explosive vaporization underneath the surface ('popcorn' effect). When the fiber tip is used in contact with tissue, the carbonization phase can be initiated faster. Carbonized tissue particles will adhere to the tip and laser light is absorbed on the tip surface creating a hot knife for tissue cutting (fig. 1). For better control, the tip can be pre-carbonized before starting the surgery by dipping the tip in blood or carbon particles while exposing the laser. This way a 'dirty'or 'black' tip can be formed which can effectively be used to cut or ablate tissue even in an water environment and tissue with a low blood content (3).

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Figure 1: fiber tip with carbonized tissue adhered making it a 'hot' laser scalpel for bloodless tissue cutting

The CO_2 laser is a widely used in medicine especially in Dermatology and in ENT for effective and superficial tissue ablation. In the field of Urology, the CO_2 laser is not commonly used since its 10.6 μm wavelength is highly absorbed in water and can not be delivered through silica fibers which makes it impractical for endoscopic procedures.
However, the precise and superficial tissue ablation and cutting that can be achieved with the CO_2 laser can be of interest for various treatments in urology e.g. ablation of external condylomata accuminata and performing a circumcision.

The KTP laser has been introduced a few years ago especially for BPH treatment. The green light (532 nm) is well absorbed by the blood in the prostatic tissue. At high power irradiation (60 to 80 W) the tissue is instantly heated to above 100 C. The tissue is vaporized effectively with a adequate coagulation zone to prevent large bleedings.

The pulsed Holmium laser is also being used for BPH treatment. The 2.1 μm wavelength of well absorbed by tissue water. Typically, during the 300 μs pulse of the laser, water is instantly turned to an exploding vapour bubble that expanse and ruptures the surrounding tissue up to several mm. The residual heat after the pulse creates a zone of coagulation. Although proven effective for BPH treatment, the Holmium laser is best appreciated for its effectiveness in lithotripsy.

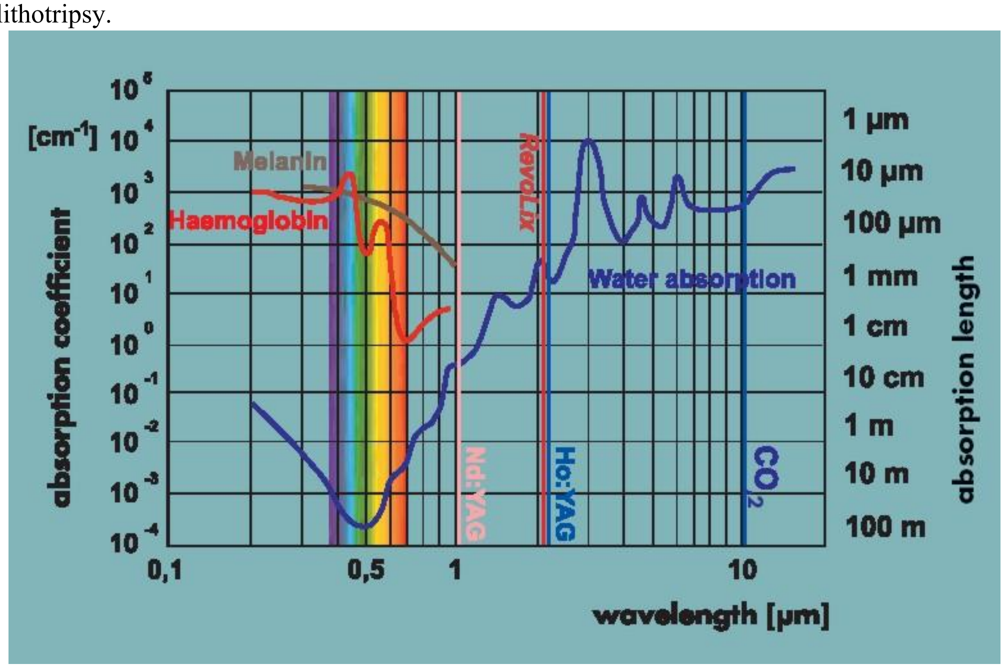

Figure 2: Absorption characteristics of chromophores commonly present in tissue for various laser wavelengths

In this paper, we like to introduce a new continuous wave 2 µm laser based on Thulium. Like the Holmium laser the 2 µm wavelength is well absorbed by water. However, the light is generated as a continuous wave instead of pulsed in the microsecond regime. Tissue water is effectively turned to vapour without the explosive effect that is observed with the Holmium laser. The tissue effect of the cw 2 µm laser can be compared with the cw CO_2 laser. It effectively cuts and ablates tissue with a superficial coagulation zone. The advantage over the CO_2 laser is that it can be delivered through small silica fibers and can effectively be applied during endoscopic procedures.
We studied the tissue interaction of the cw 2 µm laser in vitro in comparison to the commonly used lasers. In addition, case studies will be presented using the cw 2 µm laser for various clinical applications in urology based on the experience of our in vitro research.

Figure 3:
cw 2 µm laser system (Revolix junior 15 W, LISA laser, Germany)

2. METHODS

Laser systems
The following laser systems are used for the in vitro experiments and for the clinical treatments.

Thulium laser: The 2 µm cw laser system (Revolix junior, LISA laser, Germany) is based on diode pumped solid state technology. The power can be set between 1-15 Watt at a chopped mode from 50 msec to cw. Chopped pulses can be repeated for 0.5 10 Hz. For delivery low OH reusable silica fibers are available with diameters of 285 to 550 µm.

Holmium laser: This Versapulse laser system from Lumenis (formerly Coherent Medical) is actually a combination of a 2.1 µm pulsed holmium and a 80 W cw 1064 nm Nd:YAG laser. The pulses have energies from 0.2 to 2 J at up to 40 Hz.

CO_2 laser: This 10.6 µm Ultrapulse 5000C from Lumenis (formerly Coherent Medical) can be used in either cw mode (0.05 W to 80 W) or pulsed mode (1 to 500 mJ, rep rate 1 to 1000 Hz). The energy is delivered through an articulated arm with either a focussing hand piece or microscope manipulator at the end.

Temperature imaging technique
This image technique enables real-time visualization of dynamic temperature gradients within a transparent tissue model. This image technique is especially used for qualitative studies because it is complex to obtain quantitative data by relating the colours in the image to temperatures. The colour Schlieren setup was successfully used for various studies to obtain a better understanding of interaction of various lasers, rf, and ultrasound devices used in medicine. (1)

Tissue model
As a tissue model a polyacrylamide gel is used similar to the electrophoresis gels used for DNA research. To mimic the absorption characteristics of the Nd:YAG laser in tissue an absorbing dye was added to the gel (5mg/ml copper sulphate). For the Thulium laser the water in the gel itself is the dominant absorber for the 2.0 micron light.

Description of experiments
In the in vitro model we simulated various clinical conditions.
Interaction at an air-tissue boundary
A fiber was positioned at a fixed position several mm above the gel to visualize the coagulation effect of the various lasers. The power setting for both the Thulium and Nd:YAG laser was 10W for several seconds. For the CO_2 laser the beam was aimed at the surface out of focus (3 mm spot) with power settings of 10 W
To simulate tissue ablation and cutting, the fiber was positioned in contact with the tissue surface. The thermal effects were visualized using the same power settings. The beam of the CO2 laser was turned into focus on the surface.
Interaction at a water-tissue boundary:
To simulate cutting under water, the gel model was submerged under water and a 400 µm laser fiber was scanned along the surface with a speed of 5mm/s. Both the Nd:YAG and the Thulium laser were set on 20W. In case of the Nd:YAG laser, the experiment was also performed using a pre-carbonized "black tip fiber" on 20W

3. RESULTS

Comparison of working mechanism of Nd:Yag, Thulium and CO_2: Static conditions in air.
In fig 4 a coagulation mode is simulated with the Nd:YAG laser in the tissue model at 10W. The temperature gradient is shown after 20 seconds. In fig. 5 a cutting mode is simulated with the Nd:YAG laser in the tissue model at 10W. The temperature gradient is shown after 20 seconds. It is clearly visible that in contact mode, the tissue is ablated and a crater is formed in contract with the coagulating mode shown in fig 4.

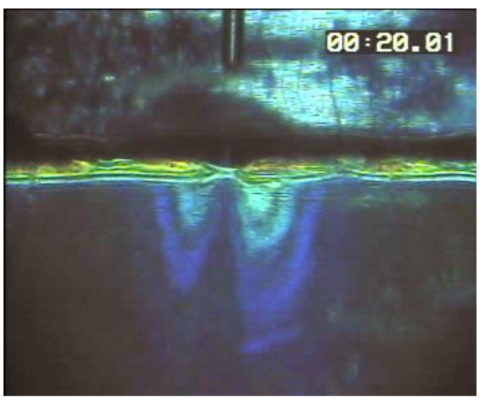

Figure 4. Fiber tip in non contact mode with Nd:YAG laser at 10W

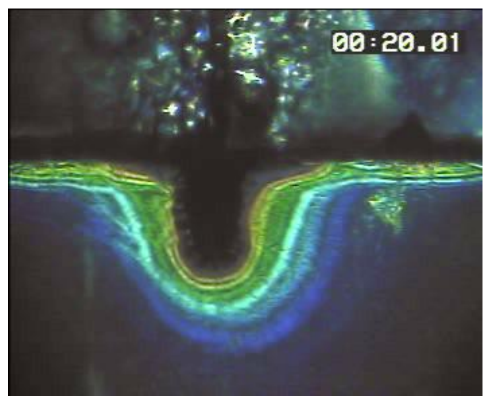

Figure 5. Fiber tip in contact mode with Nd:YAG laser at 10 W

In figure 6, coagulation mode is simulated with the Thulium laser at 10 W. The temperature gradient is visualized after 5 sec and it is clearly visible that even in a non contact mode, ablation is seen in the gel. In figure 7, a cutting mode is simulated at 10W. A deeper and narrower ablative zone is visible. Compared to the Nd:YAG laser, it is clearly visible that the Thulium laser has a very efficient tissue effect. In one quarter of the time, the Thulium laser is capable of ablating more tissue than the Nd:YAG laser with the same energy settings.

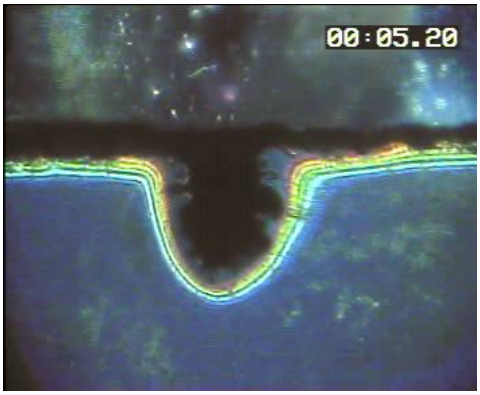

Figure 6. Fiber tip in non-contact mode with the Thulium laser at 10W

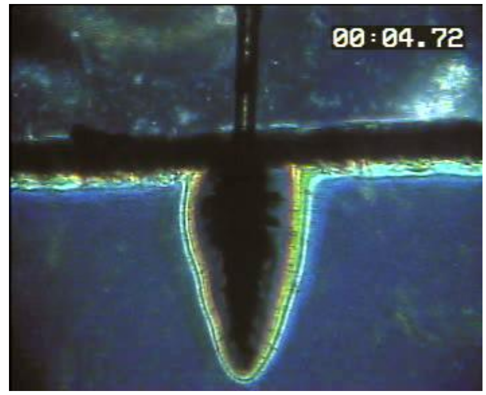

Figure 7. Fiber tip in contact mode with the Thulium laser at 10W

In figure 8, a 10 W CO_2 beam focused at gel surface ablates a hole of >5 mm within a few pulses. In a defocused mode the CO_2 laser has a less penetrating effect. Focused mode has good cutting properties and the defocused mode has superficial coagulation properties.

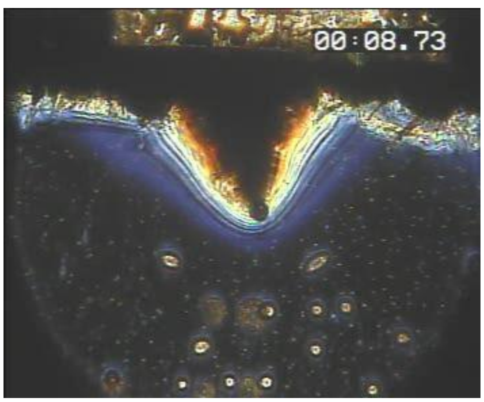

Figure 8: Focused CO_2 laser beam resulting in effective ablation

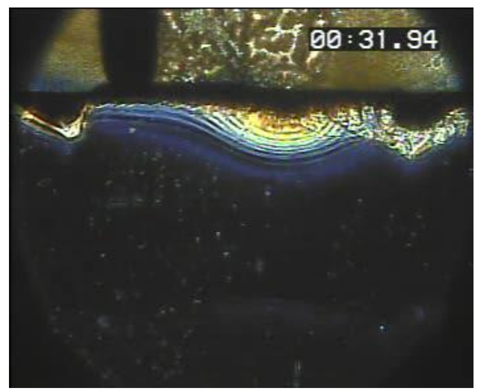

Figure 9: Defocused CO_2 laser beam resulting in a superficial coagulation zone.

Comparison of working mechanism of Nd:Yag, and Thulium: Scanning over the surface of tissue under water.
In figure 10 a clean fiber is connected to the Nd:YAG laser. The tip of the fiber is translated over the surface of the model tissue with a speed of 5 mm/s from left to right. The power setting was 20W. The heat generation clearly visible into the depth of the model tissue and subsequently a trail of thermal effect is left behind while scanning the fiber tip over the surface.

Figure 10. Thermal gradient induced by a clean fiber tip translated over a tissue phantom during exposure of 20 W Nd:YAG.

In figure 11, a Nd:YAG 'black tip' fiber is compared to a Thulium 'clean tip' fiber scanning over the tissue surface. The power setting same 20 W. The Nd:YAG laser is no longer penetrating deep in the tissue model when a 'black tip' fiber is applied. The difference is clearly visible comparing figure 11 and 12: the Thulium laser has more effective tissue ablation compared to the Nd:YAG laser in combination with a superficial coagulation zone.

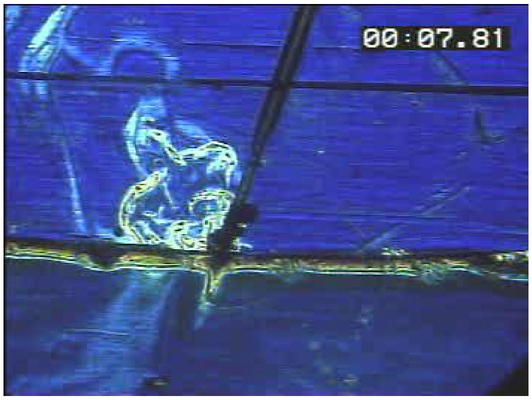

Figure 11: Nd:YAG 'black tip' 20 W (scanning)

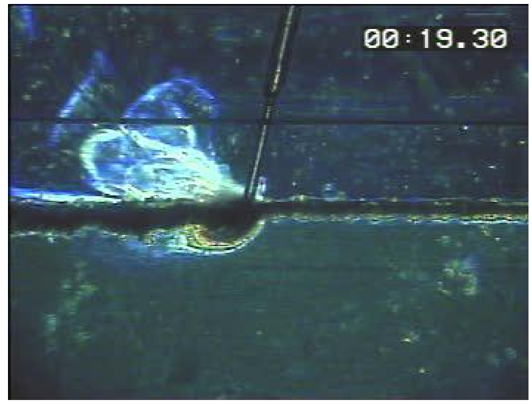

Figure 12: Thulium bare tip 20W (scanning)

3. CLINICAL APPLICATIONS OF THE 2 μm LASER

3.1 Appendix vesico stoma stenosis.

A 27 year old patient has a history of spina bifida. This patient had corrections for menigocele and had bladder problems of neuropathic origin. In the early nineties, this patient was treated with urinary diversion with appendicovesicostomy (Mitrofanoff procedure). The bladder neck was closed. Clean intermitted catheterization (CIC) is applied and there were no problems until 2003. After difficulties with catheterization, a stenosis was discovered and dilated with a ch 14 catheter. A routine control in early 2006, showed a stenosis at 10 cm after introduction of the flexible scope. This formed an obstruction for catheterization. The obstruction was treated with the Thulium laser in June 2006.

A 400 μm laser fiber was introduced through a 4 mm diameter rigid scope. When the obstruction was in view, it was ablated at 4.5 W using a total energy of 1272 J. After multiple passes a wider lumen was achieved and a successful desobstruction was realized. At a routine control in September 2006 no problems were encountered with catheterization and there was no leakage of urine from the stoma.

Figure 13: View at the start of the desobstruction. The laser fiber is introduced and the tissue of the stenosis is clearly visible in the middle

Figure 14: View during the procedure. A large part of the stenosis has already been removed. The bubbles in the picture is vapor produced by the Thulium laser.

3.2 Uretral hair growth and uretral stricture.

A 37 year old male patient who underwent urethroplasty in the past, suffered from a urethra stricture and hair growth in the urethra. He was treated in March 2006 for removing the strictures and the hair growth.

A 400 µm laser fiber was introduced through the endoscope and the strictures were cut/ablated with the fiber in contact mode. The laser setting was only 3W using a total of 400 J to minimize deeper thermal trauma. Also the hair growth was treated with the same laser fiber. The tip of the laser fiber was aimed at the urethra wall containing the hair root and that area is coagulated. Until now the patient has no residuals. The risk of causing thermal damage to deeper surrounding tissue is less compared to the Nd:YAG laser. Hair removal in the urethra is usually performed with either the Nd:YAG or diode laser which have deeper heat penetration compared to the Thulium laser. Although a deeper penetration of heat is preferred for hair removal in order to destroy the complete hair follicle, the risk of damaging underlying structures is also present. The results with the Thulium laser indicate that intra urethral hair removal can be performed safely and effectively.

Figure 15: The laser fiber is positioned at the stricture

Figure 16: After multiple passes the stricture is opened and coagulated.

Figure 17: Hair growth in the urethraplasty

Figure 18: Near the top of the image a coagulated spot can be seen. In the middle, a laser fiber is pressed into a hair shaft.

3.3 Wall stent desobstruction.

A 77 year old male has been involved in a serious accident in the eighties. As a consequence of a pelvic fracture, the man suffered from a urethra rupture. After recovery, the patient had to use CIC with as a consequence multiple urethra strictures. In the early nineties a wall stent is placed in the membranous urethra. In 2005 suprapubic drainage was required due to an obstruction of the wall stent. In March 2006 a desobstruction was performed with the Thulium laser at 7.0 W and a total energy of 5671 J. A ch18 silicone catheter was placed post operatively. Early May 2006, a control showed that the wall stent was open and an inspection of the bladder could be performed. The residual of obstructing tissue was removed again using the Thulium laser. The suprapubic catheter was left behind though closed. Early June the patient returned for control inspection and was still satisfied with the result. He did not suffer from incontinence and did not have residues after catheterization. There were no sediments in the urine either.

Figure 19: The narrow obstruction in the wall stent is passed with a ureter catheter to prevent a false route during laser treatment.

Figure 20: After laser treatment, the wall stent is.nearly open. The laser fiber is moved along the obstructive tissue in order to evaporate the tissue.

3.4 Atheromata cysts on the scrotum

A 19 year old male patient suffered from multiple atheromata cysts on the scrotum. The cysts were incised with the Thulium laser, delivered by a 550 µm laser fiber. The laser was set on 4.5 W and a total amount of 1307 J was used. The content was removed mechanically. Additionally, the bottom of the cyst was coagulated with the Thulium laser to prevent residuals. The advantage of the Thulium laser is that the bottom of the cyst can be coagulated in a controlled and effective way, compared to conventional treatment using a scalpel. Multiple cysts were removed and after a routine control at 5 months, none of the treated cysts had returned.

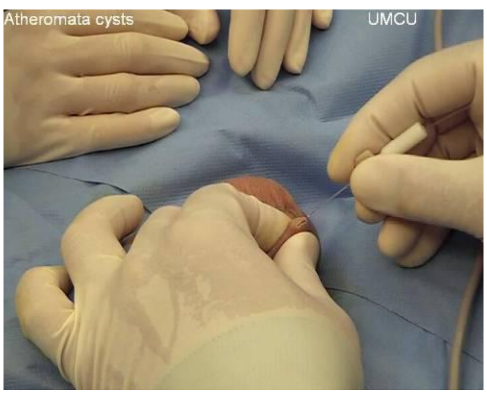

Figure 21: A cyst is incised with the Thulium laser

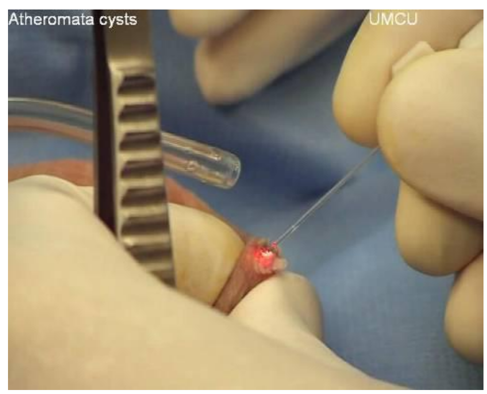

Figure 22: The bottom of the cyst is coagulated.

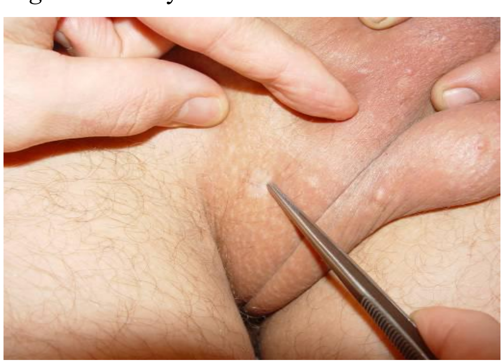

Figure 23: A routine control shows a small scar at the treatment site

3.5 Condylomata acuminata.
A 28 year old male suffered from condylomata acuminata. The condyloma was resected with a knife and the wound was coagulated with the Thulium laser using a 400 µm laser fiber at 5.0 W and 300 J total energy. The Thulium laser has nice superficial coagulation properties and reducing the chance of residuals. The post operative healing is different compared to areas treated with diathermia. Incisions that are coagulated with the Thulium laser are post operative more painful and patients are more worried about wound healing. Wound surface dries less quickly. However, the final results are more aesthetic compared to electro surgery or stitching.

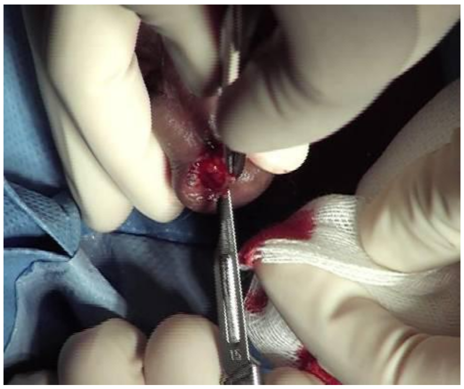

Figure 24: condylomata are resected with a knife.

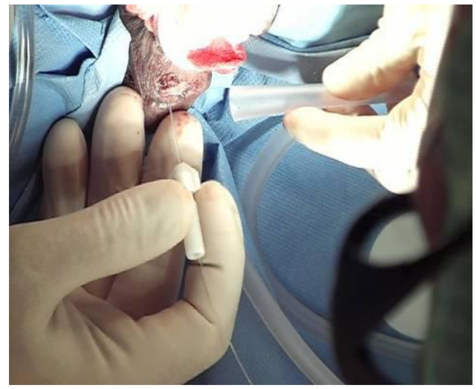

Figure 25: The wound area is coagulated with the Thulium laser.

3.6 Circumcision
A 56 year old patient who suffered from Lichen sclerosus et atrophicus underwent a circumcision with the Thulium laser. A 550 µm laser fiber was used at 9.0 W and a total energy 4199 J. During this procedure, it is clearly visible that precise tissue cutting can be performed with this laser. Superficial cutting prevent damage to underlying tissue. Even veins can effectively be coagulated. Working blood free with good visibility of the treatment area is a great advantage for precision surgery. However, the procedure seems more time consuming compared to the 'standard' way circumcision is performed not accounting complications as bleeding. The healing process was without complications. This procedure proofs that the Thulium laser can be used as a precision cutting instrument.

Figure 26: incision in fore skin performed with the Thulium laser

Figure 27: Coagulation of a vein is effective using the Thulium laser

4. DISCUSSION

From the experiments in vitro, it has been clearly shown that the Thulium laser is more effective in ablating the model tissue. Tissue ablation can be achieved at lower power levels compared to the Nd:YAG laser. Also in vivo, lower power levels of the Thulium laser can be used to obtain comparable tissue effects similar to the Nd:YAG laser.

A controlled coagulation effect can be obtained by pre-carbonising the fiber tip of the Nd:YAG laser. The in vitro results show that the Thulium laser is far more effective at the same power levels. A disadvantage of the carbonised fiber tip is the instability. When the Nd:YAG laser is activated in air, the carbon layer is "burned off" and the controllability of the tissue effect is reduced. The Thulium laser has a stable controllability of the tissue effect because of the high absorbance of energy in water.

The Nd:YAG laser has a deeper penetration effect than the Thulium laser. Especially when a Nd:YAG laser fiber is not blackened, energy will penetrate deeper into the tissue. All the energy of the Thulium laser will be absorbed by superficial tissue. The Nd:YAG laser tissue effect is less predictable compared to the Thulium laser. A surgeon does has minimal feedback if effective coagulation has occurred. The depth of heat penetration is not visible. The superficial effect of the Thulium laser is reproducible since it depends on the water contents of the tissue and time of exposure.

In vivo results have shown a better healing response of laser treated incisions compared to diathermia. The reason for tissue to heal in a more smooth en aesthetic more attractive scar is attributed to the preservation of microvasculature near the incision, Using electro surgery, this vasculature is damage primarily being the path of lowest electrical resistance. Histological studies show that wound healing by laser surgery can take longer depending on laser penetration. Lasers with a deeper heat penetration effect will cause more tissue necrosis therefore tissue healing will take longer compared to a wound that has been treated with a laser that has less heat penetration depth. Further histological research is needed to find out the mechanism behind wound healing of laser treated incisions.

	Thulium	CO2	NdYAG/ Diode	blacktip
water compatible	+	--	+	+
effective cutting	++	++	--	~
effective coagulation	~/+	+	++	+
speed of procedure	+	+	+	~
general purpose	++	~/+	+	--

Table 1. Comparison of lasers and efficiency in particular tissue effects based on in vitro and in vivo experience of the authors

5. CONCLUSIONS

The 2 μm cw laser has shown to be a versatile instrument for effective treatment of various urological indications. More patients and long term results are needed to prove the clinical significance compared to other treatment modalities

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