

THE CORRELATION STUDY OF 2 MICRON CONTINUOUS WAVE LASER BETWEEN RELEASED LASER ENERGY AND VAPORIZED PROSTATE TISSUE WEIGHTS

GUO H., LI J., LIU H., ZHOU G., SUN B., YAO Z. AND MU D.
Department of Urology, General Hospital of the Air Force, PLA, Beijing, China

ABSTRACT

Background and Objectives: To explore the effective method to calculate vaporized tissues during endoscopic prostate surgery using a 2 micron continuous wave laser, by observing the association between vaporized canine prostate tissue weight and released laser energy in an ex-vivo study. The aim was also to assess the extent of thermal damage at different laser power and different modes.

Methods: A total of 20 canine prostates were divided into four groups randomly. 2 micron continuous wave laser with output power of 40 W and 70 W was used to ablate tissues in vaporesction or vaporization mode. Vaporized canine prostate tissue weights were measured by recording the pre-and post-ablation sample weight.

Results and Conclusions: With the increase of output power from 40 W to 70 W, ablation efficiency in the vaporesction mode decreased ($P = 0.027$, while the ablation efficiency increased in the vaporization mode ($P = 0.001$). Our data showed a linear relationship between vaporized prostate tissue weights and released laser energy (Pearson correlation coefficient $r = 0.8689$ $P = 0.001$) at 70 W output power. Therefore, the amount of prostatic tissues vaporized by 2 micron continuous wave lasers could be calculated from the released laser energy through the linear relationship between vaporized prostate tissue weights and released laser energy. Under the same operating mode there were no significant differences in corresponding depths of coagulation zone. Under the same output power, vaporization produced a significantly deeper coagulation zone than that produced by vaporesction ($P < 0.001$), but still within the safety limit.

Key words: Laser; prostate; energy; canine; tissue damage.

INTRODUCTION

Two μm Laser is a Thulium laser with a wavelength of 2,013 nm which was developed by LISA Laser Products in Germany in 2003. With its high efficiency, precise cutting performance, excellent hemostasis ability, and limited thermal damage (1 – 3), it has been widely used in benign prostatic hyperplasia (BPH) surgical treatment. Currently there are four 2 μm laser surgical methods to treat BPH: vaporization (Tm: YAG vaporisation of the prostate, Thu – VAP), vaporesction (Tm: YAG vaporesction, Thu – VARP), vapoenucleation (Tm: YAG vapoenucleation, Thu – VEP), and laser enucleation (Tm: YAG laser enucleation of the prostate, Thu – LEP). Percentage of vaporized prostate tissue varies depending on surgical methods. Currently, the percentage of prostate tissue removed by surgery was estimated mainly through the indirect projections based on the reduction of postoperative PSA.³ It was clinically observed that during surgeries the consumption of the 2 μm laser energy and the size of the prostate are related. However, to the best of our knowledge, there

is no research to project the weight of the vaporized prostate tissue using laser energy consumption. Our study tried to simulate the prostate ablation surgery in vitro at different powers using different operating modes and quantitatively studied the correlation between the consumption of laser energy and the weight of the vaporized prostate tissue.

MATERIALS AND METHODS

Materials and Equipment

We used a 70 W 2 μm continuous wave laser (RevoLix, LISA, Katlenburg, Germany). The output power was set at 40 W and 70 W. Optic fibers were quartz fiber with a core diameter of 550 μm (RigiFib, LISA, Katlenburg, Germany). The operating module was handmade from a F16 fascia dilator, a three-way tube and a rubber cap. All 20 canine prostates were obtained from adult mongrel dogs that died from unrelated causes at Beijing area Experimental Animal Centers.

All prostates were harvested within 6 hours of animal death and were preserved in saline at 0 – 14°C.

Laser surgery was completed within 24 hours of the sample removal.

Experimental Procedures

Both the prostate and the laser output end were completely immersed in a basin filled with saline. Vaporization of the prostate was performed underwater. The operation module was washed continuously with saline using a three – way connector. The flush fluid was suspended 80 cm above the operating bench and the fluid was connected via a disposable blood transfusion device to the three-way connector with the flow control valve fully open. Saline was preheated to 37°C and all prostate tissue was placed in a 37°C saline bath for 15 min before the start of ablation. All surgical procedures were carried out by the same surgeon. Laser surgery was performed with either vaporessection or vaporization method. During vaporessection, prostate was cut into pieces with diameter less than 1 cm. The vaporization method requires the optic fiber surface to move in circle around the starting point while tissue became ablated until a tissue ablation pit with a diameter of about 2 cm formed. All prostate samples were numbered according to the order they were received. Following the numbering, prostate samples took turning to go through a 40 W vaporessection, a 70 W vaporessection, a 40 W vaporization, or a 70 W vaporization surgery. Each treatment group consisted of 5 samples. Laser emitting time and released laser energy were recorded from the equipment display. After the operation, each sample was dried with gauze to remove saline, which was followed by weighing the sample on an analytical balance. The pre- and post-ablation weight difference is the vaporized prostate tissue weights. Ablation rate (g /min) was calculated by dividing the vaporized prostate tissue weight by laser emission time. Ablation efficiency (g/KJ) was obtained by dividing the vaporized prostate tissue weight by released laser energy. The relationship between vaporized prostate tissue weights and the total laser energy consumption was analyzed by statistical methods. After the operation, prostate tissue was soaked and fixed in a 10% formalin solution, paraffin – embedded, sectioned, followed by histological analysis with hematoxylin and eosin staining. The depth of coagulation zones was measured to compare two power settings and two operating modes. The experiments were carried out at the Department of Urology, General Hospital of the Air Force, PLA, Beijing from Jan 2012 to December 2013.

Statistical Methods

Data were analyzed using SPSS 17.0. Processed data are shown as mean \pm standard deviation. Shapiro – Wilk normality test, Levene test of homogeneity, ANOVA, and LSD multiple comparison were performed on data of each group. Pearson correlation and linear regression analyses were performed between the

vaporized prostate tissue weights and released laser energy in the 70 W output group. $P < 0.05$ was considered statistically significant.

RESULTS

The results of vaporessection and vaporization at 40 W and 70 W output power were shown in Table 1. With 40 W output power, ablation rate and ablation efficiency of the vaporessection are statistically significantly ($P < 0.001$) higher than those of the vaporization group. With 70 W output power, ablation rate and ablation efficiency between the vaporessection group and the vaporization group are not statistically significant ($P = 0.290$ and $P = 0.416$, respectively). In the vaporessection mode, the ablation rate of the 70 W output group is higher than that of the 40 W group, but the ablation efficiency is the opposite. The differences were statistically significant ($P = 0.000$ and $P = 0.027$, respectively). In the vaporization mode, ablation rate and ablation efficiency of the 70 W group are higher than those of the 40 W group ($P = 0.000$ and $P = 0.001$). Because with 70 W output power, there is no statistical difference in both ablation rate and ablation efficiency between the vaporessection and the vaporization group, vaporized tissue weight (y), and released laser energy (x) were plotted in a scatter graph, showing a linear correlation. Linear correlation analysis between the two indicates a good linear relationship (Pearson correlation coefficient $r = 0.868$, $P = 0.001$). The linear regression equation is $y = 0.151 \times x + 1.985$, $t = 4.941$, $P = 0.001$ (Figure 1).

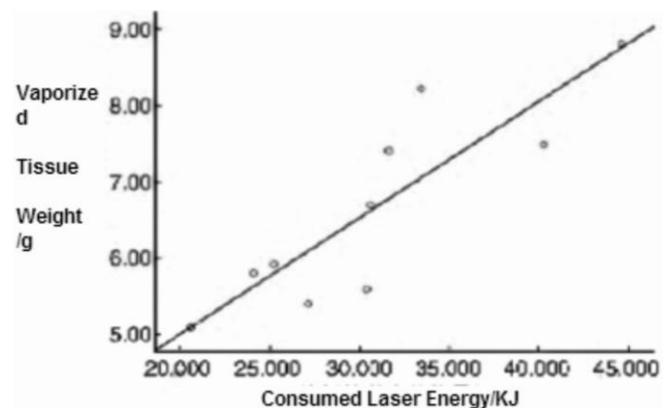


Fig. 1: The linear relationship between vaporized tissue weight and released energy in the 70 W group.

After 2 μ m laser ablation of canine prostate tissue, the histological changes are shown in Figure 2. A small amount of carbonated tissue scattered around the outermost layer. Next to it is the thermal coagulation zone where stain deepened with tightly packed cells. In this layer, normal tissue structure disappeared and cytoplasmic began to fuse. The depth of thermal coagulation zone was measured at the smooth ablation

area under microscope. The results are shown in Table 1. With 40 W or 70 W output power, the depth of the coagulation layer in the vaporization mode is greater than that in the vaporesection mode. In either the vaporesection or vaporization mode, there was no statistical difference in the coagulation layer depth between 40 W and 70 W output power.

DISCUSSION

During transurethral prostate surgeries using 2 µm lasers, surgeons can obtain the following data: laser power, running time, released laser energy, and sample weight. The first three parameters can be automatically recorded by equipment or be set before hand. Resected tissue weight has to be calculated from the available four data points. Resected tissue weight includes sample weight and vaporized tissue weight. The former can be obtained by weighing after the surgery. Consequently, estimating vaporized tissue weight is the key to calculate the weight of the resected tissue.

Vaporization and resection at the same time is the advantage of 2 µm laser. Since there are difference in how long lasers stay and work

Table 1: Ablation rate, ablation efficiency, and thermal coagulation zone depth of 2 µm continuous wave laser at different mode and power.

| Laser Operation Mode | 2 µm Laser | | P value |
|-----------------------------------------------------------|-------------|-------------|---------|
| | 40 w | 70 w | |
| Ablation Rate (g/min) Vaporesection | 0.65 (0.10) | 0.95 (0.08) | < 0.001 |
| Vaporization | 0.33 (0.05) | 0.89 (0.13) | < 0.001 |
| P value | < 0.001 | 0.290 | |
| Ablation Efficiency (g/KJ) Vaporesection | 0.27 (0.04) | 0.23 (0.02) | 0.027 |
| Vaporization | 0.14 (0.02) | 0.21 (0.03) | 0.001 |
| P value | < 0.001 | 0.416 | |
| Depth of thermal coagulation zones mm Vaporesection | 0.33 (0.06) | 0.33 (0.07) | 0.948 |
| Vaporization | 0.48 (0.06) | 0.47 (0.05) | 0.580 |
| P value | < 0.001 | < 0.001 | |

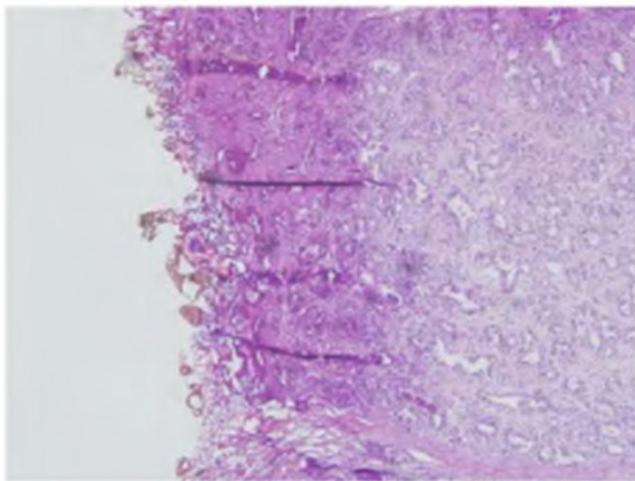


Fig. 2: Histological changes of canine prostate tissues after 2 µm laser ablation.

on tissue surface at different mode, we divided the operations into vaporessection and vaporization groups in this experiment to observe the difference in ablation efficiency and tissue damage depths of 2 µm lasers at different modes. To simulate the actual operating environment, we continuously irrigated the tissue with 37°C saline. Another important difference between in vivo and in vitro experiments is blood supply. As the absorption medium of 2 µm laser is water we stored tissue in saline at low temperature and the operation

was completed within 24 hours of the sample removal to maintain the maximum freshness of the tissue.

In this experiment the weight of vaporized tissue was calculated by the weight difference before and after the laser operation. The weight difference includes the weight of the glandular contents spilled out of the prostate gland. In both clinical transurethral surgeries and this experiment, the “toothpaste squeezing” phenomenon can be observed. The weight of glandular contents squeezed out of the gland and the duct accounted for a large proportion of weight loss. Szopinski, et al,⁵ cut the surgically enucleated prostate tissue into small pieces and found 28% of the weight was missing after the chopping process. The in vitro experiments from Wendt – Nordahl, et al^{1,2} and Bach, et al, showed that, with 2 µm laser output power increasing, ablation rate significantly increased. Since vaporization process was confined to a small area, the pressure is relatively minor, thus reducing the impacts of glandular contents spill on the experimental result. In this experiment, as ablation is relatively slow in the 40 W group and prostate tissue was squeezed for a longer time, glandular content lost was greater, leading to a higher ablation rate in the 40 W vaporessection group than in the 40 W vaporization group. In the 70 W group, there is little difference in ablation rate between two modes. In the vaporization group, the ablation rate of the 70 W group was higher than the 40 W group, an observation similar to what Wendt – Nordahl, et al,¹ and Bach et al obtained in their in vitro blood – perfused porcine kid-

ney experiments.

In the vaporization mode, ablation efficiency of the 70 W is significantly higher than the 40 W group. This is because with the same optic fiber, the higher the laser power, the higher the laser energy density on the tissue surface and the more powerful the laser ablation becomes. In Bach's,² 2 μ m laser in vitro experiments, it was reported that within 10 minutes the blood – perfused porcine kidney lost 9.80 g and 16.41 g through vaporization with 70 W or 120 W output, respectively. The laser energy consumption was 42.01 KJ and 72.25 KJ, respectively, with no report of ablation efficiency. It was calculated that the ablation efficiency is about 0.233 g/KJ and 0.227 g/KJ from two sets of data. The small difference is probably because Bach, et al,² study was to assess the hemostatic function of 2 μ m laser. The operation was paused during the operation in order to stop bleeding, which will consume some additional energy.

We found that there is an obvious correlation between ablation rate and ablation efficiency. The quantitative relationship is as follows:

$$v = \frac{m}{t}, e = \frac{m}{E}, E = W \cdot t$$

where W is ablation rate, m is vaporized tissue weight, t is laser running time, e is laser ablation efficiency, E is total laser energy consumption, W is laser power. From above three equations we can derive $v = e \cdot W$.

After unit conversions, following relationship can be drawn (units were marked in brackets).

Ablation rate (g /min) = 0.06 \times Ablation efficiency (g/KJ) \times Laser Power (Watt).

Ablation rate calculated using this equation and experimental data is consistent with experimental results. This also explains why in this experiment the ablation rate in the 70 W group is higher than that in the 40 W group while ablation efficiency is the opposite. It should be noted that in the formula above the ablation rate is not the average ablation rate through the whole surgery process. Instead, it's the average ablation rate during the laser emission process. It's different from the ablation rate reported in the literature, in which the ablation rate is the pre- and post-operative weight difference divided by operation time.

In transurethral prostatic surgery, with the same output power, laser energy consumption is related to the weight of vaporized prostate tissue while laser running time is also related to the weight of vaporized tissue. Given the existence of the above quantitative relationship between ablation rate and ablation efficiency in our experiment, we only analyzed the relationship between the weight of vaporized tissue and ablation rate. Because there is no difference in ablation rate and ablation efficiency between the vaporesection and vaporization group with 70 W output, experimental data from the 70 W group were used for above analysis. The results indicated that there is an excellent linear correlation between the weight of vaporized tissue and laser

energy consumption with Pearson correlation coefficient of 0.868. The regression equation was shown in Figure 1. Sun et al demonstrated that in the in vitro simulation of 2 μ m laser transurethral prostate surgery, there was a good linear relationship between the preoperative prostate sample weight and the postoperative weight of prostate tissue.⁶ With the derived linear regression equation, the weight of the vaporized prostate tissue can be estimated from the weight of postoperative prostate tissue. However, this equation applies only to Thu VARP, not the other three surgical procedures.

Our equation uses energy consumption as the variable and isn't affected by surgical procedures. It applies to Thu VAP, Thu-VARP, Thu VEP and Thu LEP. The fact that in our experiment with 70 W output, there is no ablation efficiency difference between vaporesection and vaporization mode proves it. However, since in transurethral surgery prostate tubular content loss from pressure cannot be calculated, we can only estimate the vaporized tissue weight. Using this equation, the weight of vaporized tissue can be estimated. When combined with the sample weight, the total resected prostate tissue weight and the resection rate can be estimated, which can be used to predict postoperative surgical results. When considered together with postoperative PSA levels, they can be used to predict the probability of prostate cancer (PCa) in BPH patients with high preoperative PSA levels but negative biopsies results. Several reports have found that in BPH patients' plasma PSA levels was significantly related to prostate volume and the amount of resected prostate tissue was highly correlated to plasma PSA level changes.⁷⁻¹⁰ By comparing the actual postoperative plasma PSA level and the predicted level based on the resected prostate tissue weight, it is possible to identify potential PCa. It was found that the amount of tissue removed in TURP surgery is significantly positively related to IPSS score change and postoperative IPSS score. Thus calculation of the amount of resected prostate tissue may predict postoperative outcomes.

Using in vitro blood – perfused porcine kidney, Wendt – Nordahl, et al¹ and Bach et al found that as laser energy increased, there was no significant difference in the depth of thermal coagulation layer with 2 μ m laser. In our experiment, similar results were obtained under the same operating mode. But for the same laser output power, different operating mode produced different tissue damage. Laser left a coagulation layer at the surface of the tissue which guarantees good hemostatic results. But since the absorption medium of 2 μ m laser is water, there is still enough water in the coagulation layer to ensure effective absorption of laser energy. Therefore, vaporization will cause heat to continue to transfer and a thicker coagulation layer. This suggests that when a 2 μ m laser was used for prostate surgery, the need to avoid in situ con-

tinuous vaporization in order to avoid significant damage to nerve tissue around it.

In summary, for 2 μm laser transurethral prostate surgery, laser energy consumption and vaporized tissue weight showed a good linear correlation. From laser energy consumption vaporized tissue weight can be calculated. At the same operating mode, 2 μm laser power output does not affect thermal damage depth. With the same power, compared to vaporesction, vaporization will deepen thermal damage of 2 μm laser. But the damage is still within the range of surgical safety.

ACKNOWLEDGMENTS

The present investigation was supported by a grant Beijing Science and Technology research project (Z09-0507017709031) of The Beijing Municipal Science and Technology Commission.

Contribution of Authors

H. G. and J. L. collected the data; H. L. and G. Z. prepared the manuscript information; B. S. and Z. Y. wrote the paper; D. M. analysed the data.

REFERENCES

1. Wendt – Nordahl G, Huckele S, Honeck P. Systemic evaluation of a recently introduced 2m continuous wave thulium laser for vaporesction of the prostate [J]. *J Endourol.* 2008; 22: 1041-5.
2. Bach T, Huck N, Wezel F, Hacker A, Gross AJ, Michel MS. 70 vs. 120 W thulium: yttrium – aluminium – garnet 2 micromcontinuouswave laser for the treatment of benign prostatic hyperplasia:a systematic ex-vivo evaluation [J]. *B J U Int.* 2010; 106: 368-72.
3. Pothen AJ, Evenboer J, Swartz JE, Willems SM, Van Cann EM, Janssen LM, van der Heijden GJ, Grolman W. Use of the 2- μm continuous wave thulium laser for the resection of oral squamous cell carcinomas does not impair pathological assessment. *Lasers Surg Med.* 2014; 46: 608-13.
4. Herrmann TR, Liatsikos E N, Nagele U, Traxer O, Merseburger AS. E A U guidelines on laser technologies [J]. *Eur Urol.* 2012; 61: 783-95.
5. Szopinski T, Golabek T, Chlosta P, Borówka A. Determination of prostate adenoma weight reduction due to vapourisation process occurring during transurethral resection of the prostate. *Wideochir Inne Tech Maloinwazyjne,* 2014; 9: 404-8.
6. Sun Dongban, Wei Zhitao, Xu Feng. The ex vivo study of human prostate ablation ratio by 2 μm laser [J]. *Chinese Journal of surgery,* 2010; 48: 42-4.
7. Geavlete B, Stanescu F, Iacobaie C, Geavlete P. Bipolar plasma enucleation of the prostate vs. open prostatectomy in large benign prostatic hyperplasia cases – a medium term, prospective, randomized comparison. *BJU Int.* 2013; 111: 793-803.
8. Hosseini S Y, Salimi M, Hosseini Moghaddam S M. Changes in serum prostate – specific antigen level after prostatectomy in patients with benign prostatic hyperplasia [J]. *Urol J.* 2005; 2: 183 -8.
9. Pahwa M, Pahwa M, Pahwa A R. Changes in SPS A after transurethral resection of prostate and its correlation to postoperative outcome [J]. *Int Urol Nephrol.* 2013; 45: 943-9.
10. Fonseca R C, Gomes C M, Meireles E B, Freire GC, Srougi M. Prostate specific antigen levels following transurethral resection of the prostate [J], *Int Braz J Urol.* 2008; 34: 41-8.