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ORIGINAL ARTICLE

In vitro comparison of the vaporesection of human benign prostatic hyperplasia using 70- and 120-W 2-μm lasers

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The purpose of the current *ex vivo* study was to compare the speed of vaporesection of human prostatic tissue with benign prostatic hyperplasia (BPH) and the depth of tissue damage using 70- and 120-W 2-μm laser devices. Fresh prostatic tissue specimens were obtained from five patients by open prostatectomy, and were divided into separate groups (70 and 120 W) based on the energy of the laser output (70 and 120 W, respectively). The vaporesection speed, coagulation zone depth and the necrotic tissue layer in the prostatic tissue were evaluated. The current result showed that the speeds (mean±s.d.) of vaporesection were 5.21±0.66 and 10.39±1.15 g/5 min for the 70 and 120 W groups, respectively (P=0.000). There was no difference in the depth of necrosis/coagulation (0.98±0.13/0.30±0.09 and 0.99±0.12/0.31±0.08 mm) for the 70 and 120 W groups, respectively. In conclusion, both 70- and 120-W 2-μm laser devices had superficial tissue damage during the vaporesection of human prostate tissue; moreover, the 120-W laser offers a higher vaporesection speed than the 70-W laser.
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INTRODUCTION

In 2004, the thulium laser was used to treat patients with benign prostatic hyperplasia (BPH),[1] and the 2-μm continuous-wave laser is an improvement over the thulium laser. Recently, Bach *et al.*[2] and Mattioli *et al.*[3] showed that vaporesection using a 70-Watt (70-W) 2-μm laser was safe and could markedly improve lower urinary tract symptom of patients with BPH. Our early clinical trials demonstrated that the 2-μm laser treatment for BPH was associated with minimal haemorrhage and limited morbidity.[4,5] Fu *et al.*[6,7] observed that the 70-W 2-μm laser was highly effective for transurethral prostatic resection in patients with BPH. With the upgrade of 2-μm laser device from 70 to 120 W, the investigator was interested in the difference between two kinds of output laser.[8] However, due to different power outputs, the clinical effects are likely different. However, the comparison of the two laser outputs with regard to their clinical efficacy, vaporesection speed and penetration depth remains unclear. Therefore, the *ex vivo* evaluation of 2-μm laser systems is essential to understand the clinical outcome and possible complications associated with their use and to minimize the risk of unexpected side effects. The purpose of the current *ex vivo* study was to compare the speed of vaporesection of human prostatic tissue with BPH and the depth of tissue damage using 70- and 120-W 2-μm laser devices.

MATERIALS AND METHODS

General data

Five patients with large-volume BPH were selected to receive open prostatectomy. The mean weight of the prostates was 100.37±27.82 (88–156) g. The mean age of the patients was 72.19±5.78 (68–76) years. Preoperation data were collected, including International Prostate Symptom Score, digital rectal examination, transrectal ultrasonography and prostate-specific antigen determination. The mean International Prostate Symptom Score was 24.08±3.54 (20–31), and the prostate-specific antigen of all patients was less than 4 ng l^{-1}.

Laser vaporesection techniques

Laser vaporesection was performed using a 2-μm continuous-wave Tm:YAG laser (RevoLix; Lisa Laser Products, Katlenburg, Germany). The laser energy was emitted at 2.013 μm in a continuous-wave mode, and a 70-W or 120-W output energy was used in the trial. For the delivery of laser energy, flexible 550-μm optical-core bare-ended fibre was used in a contact mode for tissue vaporesection. The fresh specimens from patients were immediately washed with 0.9% saline at 37 °C and then dried with gauze. After the prostatic tissues were weighed, the specimens were stored in an acryl basin containing 0.9% saline at 37 °C for further vaporesection. The prostatic tissue vaporesection procedure was the same as that used for routine transurethral 2-μm laser vaporesection, and the settings of the working laser were the same as those used in formal surgical procedures. During the vaporesection procedure, the laser fibre was moved in a half-moon-shaped path that we called the 'half-moon vaporesection mode', which took 5 min to finish. The same surgeon performed all of the operations. The weight of the vaporesected prostatic tissue was calculated, and the speed of vaporesection was calculated after each operation. The study was divided into two groups (70 and 120 W) based on the energy of the laser output.

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Histological evaluation

Samples of the ablated prostate tissue were removed, cut and fixed in 4% formalin. After embedding in paraffin, the blocks were sectioned and stained using haematoxylin and eosin to measure the depth of the coagulation zone. To further evaluate the cellular viability and the depth of the necrotic tissue zone, nicotinamide adenine dinucleotide (NADH) staining was also applied to tissue frozen at −80 °C after fixation. The depths of coagulation and necrotic tissue zones induced by the laser energy were determined by microscopy using a calibrated calliper. Specimen preparation and assessment of the coagulation and necrotic zones were performed by a single observer.

STATISTICAL ANALYSIS

SPSS 14.0 software (SPSS Inc., Chicago, IL, USA) was used for all statistical tests, and the statistical data are presented as mean±s.d. The statistical difference was evaluated using the independent-samples unpaired *t*-test, with $P<0.05$ considered statistically significant.

RESULTS

The details of the prostatic tissue weight for the 70- and 120-W groups are listed in **Table 1**. The speed of vaporesection of prostatic tissue was 5.21±0.66 g/5 min for the 70-W group and 10.39±1.15 g/5 min for the 120-W group; the 120-W 2-μm laser showed higher vaporesection rates than the 70-W laser ($P=0.000$) (**Table 2**). More prostatic tissue was vaporesected in the 120-W group compared with that in the 70-W group (**Figure 1**). There was no difference in the depth of necrosis and coagulation between the 70- and 120-W groups ($P>0.05$) (**Table 2**). The depth of the coagulation zone was identified by haematoxylin and eosin staining (**Figure 2a and b**), and the depth of the necrotic tissue was confirmed by NADH staining (**Figure 2c and d**). Both the coagulation zone and necrotic tissue were superficial. Histological examination also revealed necrotic tissue underlying the coagulation zone.

DISCUSSION

Treatment for BPH using a 2-μm laser is becoming more accepted because of its promising clinical data.[9–11] The increase in output energy of the laser from 70 to 120 W strengthens the ability to vaporesect prostatic tissue. Bach *et al.*[8] first compared the difference between 70- and 120-W 2-μm laser vaporesection using porcine kidneys. Their results showed that the amount of tissue ablation increased with the increased laser power output, although little is known about the effects of these outputs on the speed of vaporesection and the depth of necrosis in human prostatic tissue. In the current study, we evaluated and compared the speed of tissue vaporesection and the depth of tissue damage using 70- and 120-W 2-μm laser in human prostate tissue *ex vivo*.

In this study, we made every effort to mimic the *in vivo* procedure. The prostatic tissues were vaporesected in an acryl basin containing 0.9% saline at 37 °C, which was similar to transurethral 2-μm laser vaporesection.[11] The work setting used in the study was the same as that in formal surgical procedures. The laser fibre was moved along a half-moon-shaped path that we called the 'half-moon vaporesection mode'. The results presented here demonstrated that both the 70- and 120-W 2-μm laser devices performed well in vaporesecting human prostate tissue.

Table 1 Weights of different prostatic portions before and after operation

No.	*Peroperative (g)*	*Postoperative (g)*	*Vaporesection (g)*
70-W group			
1	42.13	37.92	4.21
2	38.23	32.66	5.57
3	63.58	58.02	5.56
4	74.77	68.93	5.84
5	70.45	65.57	4.88
Mean±s.d.	57.83±17.56	56.62±16.41	5.21±0.66
120-W group			
1	54.31	44.15	10.16
2	34.55	23.87	10.68
3	76.89	64.65	12.24
4	55.43	45.98	9.45
5	75.65	63.97	9.45
Mean±s.d.	59.36±17.53	48.52±16.82	10.39±1.15

Table 2 The depth of tissue damage and the speed of vaporesection

Depth and speed	*2-μm laser*		P value
	70-W group	*120-W group*	
Necrotic tissue layer (mm)	0.98±0.13	0.99±0.12	0.760
Coagulation zone (mm)	0.30±0.09	0.31±0.08	0.605
Vaporesection speed (g/5 min)	5.21±0.66	10.39±1.15	0.000

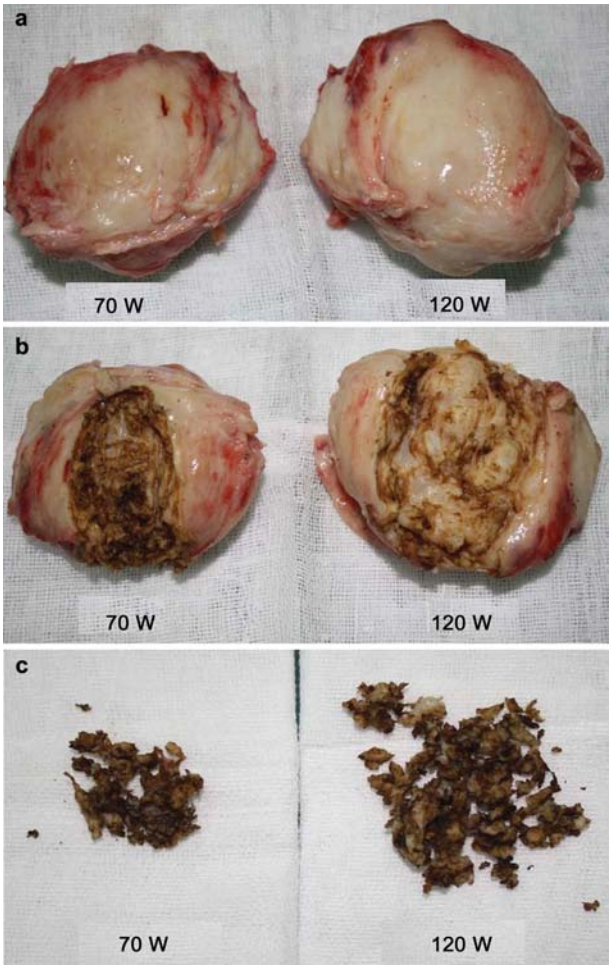

Figure 1 Pre- and postoperative prostatic changes. (**a**) Preoperative prostatic tissue. (**b**) Postoperative prostatic tissue. (**c**) Resected prostatic tissue. A larger amount of human prostatic tissue was removed in the 120-W group than in the 70-W group.

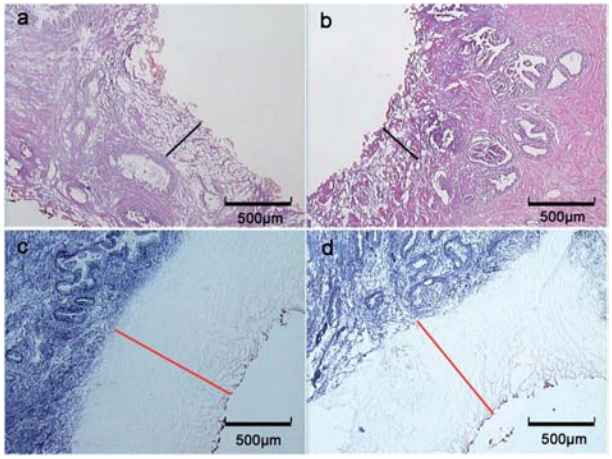

Figure 2 Histological findings after the vaporesection of the human prostatic tissue using a 2-μm laser. (**a**, **b**) H&E staining (×40) of superficial coagulation zones (black line) in the 70- and 120-W groups, respectively. (**c**, **d**) NADH-stained cryosections (×40) after 2-μm laser vaporesection in the 70- and 120-W groups, respectively. The outer zone is indicated by necrotic tissue (red line), and the inner zone is indicated by viable tissue (blue-stained layer). H&E, haematoxylin and eosin; NADH, nicotinamide adenine dinucleotide.

The major technical advantage of vaporesection is the simultaneous vaporisation and resection of the prostate because the 2-μm laser works in a continuous-wave mode.[12] Persistent movement of the laser probe not only increases the vaporizing effect but also reduces the heat damage to tissue. Keeping prostatic tissue in front of the laser fibre at all times during the procedure would accelerate the vaporesection. Certainly, the mode of vaporesection mentioned above differs from VapoEnucleation as reported by Herrmann *et al.*,[10] which enucleates the whole prostate.

The other major technical advantage of the 2-μm laser is the ability to precisely incise the desired prostate tissue for histopathological examination; the resection mode begins once the laser fibre touches tissue. Vaporesection is used to reduce prostate tissue into small pieces as demonstrated in the transurethral prostatic resection protocol; these tissue chips are small enough to allow easy evacuation through the resectoscope sheath with no need for morcellation.[11]

Patients with large-sized prostates were selected for this study to obtain prime specimens for histopathological evaluation and also to allow a smooth operation to take place.

A major question of this study was whether the speed of vaporesection of human prostate tissue could be improved by increasing the laser power from 70 to 120 W. Bach *et al.*[8] reported that the mean speed of resection of porcine kidneys was 9.80±3.03 g/10 min for 70 W and 16.41±5.20 g/10 min for 120 W, demonstrating that the 120-W Tm:YAG laser (RevoLix; Lisa Laser Products) offered significantly higher ablation rates than the 70-W device. In our current study, the speed of vaporesection of prostatic tissue was 5.21±0.66 g/5 min for the 70-W group and 10.39±1.15 g/5 min for the 120-W group, indicating that the 120-W 2-μm laser exhibited higher vaporesected rates than the 70-W laser; the mean speed of vaporesection with the 120-W laser increased twofold over that with the 70-W laser.

Independent of the specific energy device used to treat BPH, thermal penetration of the tissue and coagulation artefacts were also produced. Some of these artefacts were visible, such as white surface due to surface carbonisation or denaturation of haemoglobin.[13] The laser energy causes tissue to be heated and vaporized, and below this vaporisation zone lies the coagulation layer. High tissue penetration would lead to unintended collateral damage in the deeper tissue layers.[14] Therefore, knowledge about the depth of damaged tissue is essential to estimate the risk of unintended collateral tissue damage. Our results showed that the extent of the coagulation zone was similar between the 70- and 120-W groups (0.30±0.09 and 0.31±0.08 mm, respectively), which is consistent with the report by Bach *et al.*[8] using porcine kidney tissue (0.36±0.02 mm for 70-W laser and 0.40±0.04 mm using a 120-W laser). Furthermore, the tissue below this coagulation zone inevitably experiences some heat penetration, which might cause cellular damage. Seitz *et al.*[15] described these damage zones as an inner and outer layer of coagulated tissue. The effect of heating does not end at the border of the coagulation zone. The damage of tissue penetration is undoubtedly a crucial source of necrotic tissue during laser therapy of the lower urinary tract, which might cause subsequent complications. The necrotic tissue easily causes uncomfortable postoperative symptoms, including urinary frequency, urgency and urodynia, and is also the prime culprit of reoperations. The results presented in this study indicate an outer coagulation zone and an inner zone of tissue (necrotic zone) found in the human prostatic tissue post-laser vaporisation. To further evaluate this effect, NADH staining was used to evaluate the histological effects of the 2-μm lasers; NADH staining is currently the best means of determining cellular viability and has the potential to clearly identify energy effects in these two layers. In the current study, the penetration depth (necrotic layer) remained unchanged with increasing laser power output (0.98±0.13 and 0.99±0.12 mm at 70 and 120 W, respectively), and these results are consistent with those reported by Bach *et al.*[8] in porcine kidneys (1.09±0.14 and 1.09±0.24 mm at 70 and 120 W, respectively). Both the coagulation zone and necrotic tissue were superficial because most of the heat that originated during vaporesection was lost by a continuous saline flush during the operation; the effect of heat penetration is therefore very weak.

Finally, any comparison between different laser devices and different studies must be analysed carefully, as different environmental conditions or investigator-related variations would result in different measured results. Significant effects on the ablation capacity include the distance between the laser fibre and the targeted tissue and the velocity at which the fibre is moved across the tissue. Therefore, the speed of vaporesection and the depth of tissue damage would vary between studies and investigators.

In conclusion, in an *ex vivo* setting, the increased energy output of a 2-μm laser from 70 to 120 W can accelerate human prostatic vaporesection with no apparent increase in tissue penetration.

AUTHOR CONTRIBUTIONS

LGH designed and performed the *in vitro* test, and drafted the paper. XSJ analysed the data and revised the paper. SZL selected patients and performed open surgery.

COMPETING FINANCIAL INTERESTS

The authors declare no competing financial interests.

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