CANADIAN JOURNAL OF UROLOGY
Tech Science Press

Doi:10.32604/cju.2026.070096
ARTICLE

Evaluating surgical smoke in laser-assisted laparoscopic partial nephrectomy with a novel handle: an in Vitro study

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Ma L, Li T, Sun R, Du Q, Jiang D, He D, Fu X, Li N, Xu X, Liu G. Evaluating surgical smoke in laser-assisted laparoscopic partial nephrectomy with a novel handle: an *in Vitro* study. *Can J Urol* 2026;33(4):943–950.

Objectives: *Lasers show promising application in partial nephrectomy due to their excellent hemostatic effect. This study aimed to evaluate the suction effect of the novel laser operating handle on the smoke generated by a 980-nm diode laser (DL) and a 532-nm potassium-titanyl-phosphate (KTP) green laser (GL) in laparoscopic partial nephrectomy (LPN) and to analyse the surgical smoke generated by the laser treatment.*

Methods: *Fresh porcine kidneys were purchased from a slaughterhouse. Electrocoagulation knife (EK), ultrasonic knife (UK), DL, and GL were utilised in LPN. The operation time and the composition and concentration of the surgical smoke were recorded. HE staining was performed to observe the degree of thermal damage.*

Results: *In terms of smoke generation, the 532-nm KTP laser results in the largest amount of smoke. The surgical field of DL-LPN was adequately improved with the aid of the instrument with the novel handle. The thickness of the coagulation layer, which ranged from thick to thin, was DL, GL, EK, and UK. The coagulation of EK, UK, DL, and GL was 0.35 ± 0.08 mm, 0.52 ± 0.08 mm, 4.16 ± 0.21 mm, and 1.55 ± 0.21 mm, respectively. For formaldehyde, total volatile organic compounds (TVOC), and carbon monoxide (CO), there was a marked reduction after the application of the aspirator. For the DL group, the Formaldehyde TVOC and CO were 4.95 ± 0.48 mg/m^3 and 1.69 ± 0.46 mg/m^3, 8.34 ± 0.72 mg/m^3 and 1.11 ± 0.33 mg/m^3, 124.14 ± 9.58 PPM and 23.71 ± 3.9 PPM, respectively.*

Conclusions: *As shown in the present study, though a large amount of harmful smoke was generated during laser-assisted laparoscopic partial nephrectomy (LALPN), the novel laser handle can be sucked effectively and provides a clear surgical field. As to the harmful gases released, an effective protective mask is needed.*

Key Words: 980-nm diode laser, 532-nm potassium-titanyl-phosphate (KTP) green laser, laparoscopic partial nephrectomy (LPN), surgical smoke, *in vitro* study

Received date 08 July 2025
Accepted for publication 28 May 2026
Published online 21 August 2026

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Introduction

Lasers have been applied as alternative instruments in partial nephrectomy (PN) for approximately four decades, and laser-assisted laparoscopic partial nephrectomy (LALPN) has occupied an important position in PN due to its outstanding efficacy in haemostasis.[1–3] The advantage of haemostasis produced by the coagulation induced by laser-tissue interactions must be utilised. Therefore, without clamping of the renal vessels, LALPN was reported while utilising different lasers.[1] However, limitations of LALPN have been reported, such as the production of a large amount of smoke, which might influence the operating field and prolong the operation time to some extent, and surgical smoke produced by laser-tissue interactions also causes hazards.[4,5] In laparoscopic partial nephrectomy with lasers, surgical smoke is unavoidable. The 980 nm and 532 nm lasers interact with tissue, and generate smoke containing airborne particles and harmful compounds. The smoke can obscure the surgeon's view. It may also affect surgical precision. Its potential biological hazards are a growing concern. Building on these considerations, recent advancements have sought to mitigate the challenges posed by surgical smoke in LALPN. Innovations such as optimized laser settings, improved smoke evacuation systems, and the use of alternate laser wavelengths aim to reduce particulate generation while preserving hemostatic efficiency. Furthermore, emerging evidence emphasizes the importance of intraoperative strategies to minimize smoke exposure for both patients and surgical staff, including enhanced filtration and real-time monitoring of air quality within the operative field. Addressing these limitations is essential not only for refining surgical outcomes but also for establishing standardized safety protocols. As laser technology continues to evolve, balancing efficacy with safety will remain a central focus in expanding the clinical applicability of LALPN.

This study aims to measure and compare the particle concentrations and components of smoke from both laser types. It seeks to define their specific pollution characteristics. The goal is to provide evidence for better smoke management. This will help protect the health of both patients and medical staff and improve surgical safety. In this study, we use a novel laser operating handle for which a national patent has been applied (CN208709983U), and the original design intention of this aspirator is that when performing laparoscopic surgery using laser, even if a large amount of smoke is produced, using the same operating tool can both vaporize and cut, while also clearing the smoke and providing a clear view, achieving twice the result with half the effort, to reduce the surgical smoke during LALPN, and a brief analysis of the components of surgical smoke was performed.

Materials and Methods

Study design

All of the experimental procedures were approved by the Institutional Animal Care and Use Committee of Xianyang Central Hospital (No. 2021-IRB-19).

Figure 1 shows the specific surgical procedures used in this study. Twenty-eight fresh porcine kidneys were purchased from a slaughterhouse (Xi'an Fangxin Slaughterhouse, Xi'an, Shaanxi Province). Before the experiment, the fresh pig kidneys were placed on the experimental table and fixed in position to simulate the situation of the kidneys in the abdominal cavity. There were four groups and each group consists of seven kidneys, including group A (electric knife LPN), group B (ultrasound knife LPN), group C (532 nm green laser LPN, using the novel haddle or not), and group D (980 nm diode laser LPN, using the novel haddle or not). The fresh pig kidneys used were all of normal size, with a volume approximately 8–10 cm in length, 5–6 cm in width, and 2–3 cm in thickness. Twenty-eight kidneys were randomly and evenly divided into four groups for the experiment.

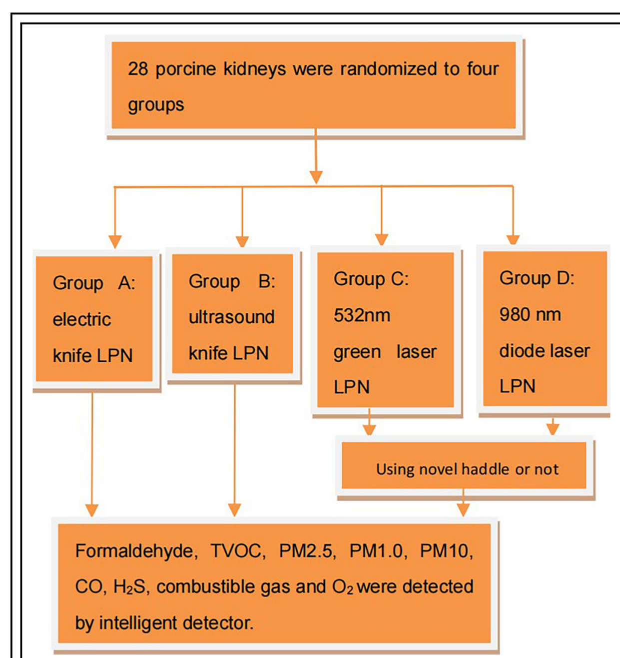

FIGURE 1. Flow chart of the types and contents of the smoke produced by different surgical instruments. Note. LPN, laparoscopic partial nephrectomy; TVOC, total volatile organic compounds.

Instruments and equipment

A 980-nm diode laser (MULTIDIODE PL3D, INTERMedic, Spain) equipped with a fibre diameter of 550 nm, a 532-nm KTP (potassium titanyl phosphate) laser (Beijing Realtonlaser Technology Co., Ltd., Haidian District, Beijing, China) equipped with a fibre diameter of 600 nm (Beijing Realtonlaser Technology Co., Ltd., Haidian District, Beijing, China), an ultrasonic knife (**ESG-400,** Olympus Medical Systems Corp., Tokyo, Japan), and an electrocoagulation surgery system (**SJ-DN05,** Hangzhou Kangji Medical Instrument Co., Ltd., Hangzhou, China) were used for the LPN procedure. Other equipment included a laparoscopy system (**OTV-S300,**Olympus Medical Systems Corp., Tokyo, Japan), gas detection equipment (homemade) (Figure 2) and a transparent storage box (length, width, and height of 33 cm, 24 cm, and 18 cm, respectively) with a volume of 8 L. Three trocars were fixed to the top of the box in an equilateral triangle with a side length of approximately 8 cm, which were used to place the laparoscope, bipolar forceps and other instruments (Figure 2).

Surgical procedure and detection method

Three trocars were built on top of the transparent box, and CO_2 gas flowed into the box through the trocars to simulate the operation under the laparoscope. The gas detector was placed in the box before the operation.

The overall operation was performed by the same surgeon. Surgery was performed to partially excise the target kidney, with approximately 1/3 of the total volume removed during the excision. Each device was used for seven partial nephrectomies. For the laser groups, one porcine kidney underwent LALPN twice, and the superior group used the novel laser operating handle, while the inferior group did not. The laser power was set to 80 W. Stable data for the gases detected were recorded for each partial nephrectomy three times, and the time of operation was recorded. The clarity of the surgical field was observed, and the gas concentrations of formaldehyde, total volatile organic compounds (TVOC), PM2.5, PM1.0, PM10, carbon monoxide (CO), combustible gas, H_2S, and O_2 were recorded.

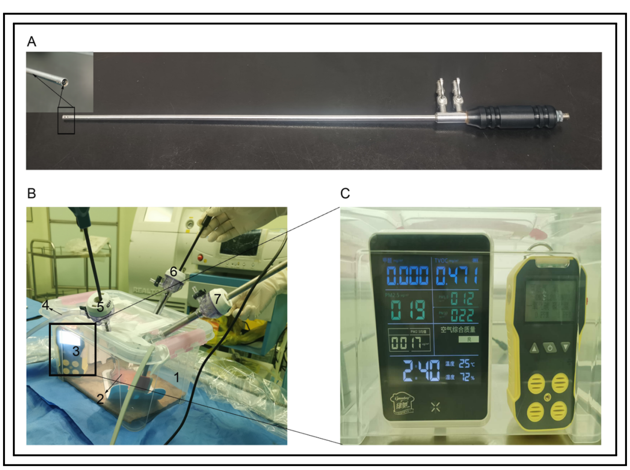

FIGURE 2. Laparoscopic model of partial nephrectomy and smoke component detection instrument. (A) The novel laser operating handle. (B) LPN operation. (1) Transparent box that simulates the abdominal cavity; (2) porcine kidney; (3) gas composition monitoring instruments; (4) negative pressure suction tube; (5) haemostatic forceps for laparoscopy; (6) surgical instruments used for the partial nephrectomy; and (7) laparoscope. (C) Instruments used to monitor the composition of gases

Statistical analysis

SPSS 18.0 (IBM Corp., Armonk, NY, USA) was used for the univariate analysis. Multiway ANOVA was used for comparisons among groups. $p < 0.05$ indicated that the difference among the groups was statistically significant. Figures were prepared using GraphPad Prism 5.0 (GraphPad Software Inc., La Jolla, CA, USA) and Adobe Photoshop CS5 (Adobe Systems Inc., San Jose, CA, USA).

Results

As shown in Figure 1, 28 porcine kidneys were used for the whole experiment. When PN was performed using different instruments, the gas composition was monitored and recorded in real time (Figure 2). As shown in Figure 3, we used an electrocoagulation knife, an ultrasonic knife, a 980-nm diode laser, and a 532-nm KTP laser to perform partial nephrectomy on the established extracorporeal laparoscopic model. Different instruments resulted in different levels of clarity of the surgical field in the procedure, although smoke was evacuated. EK and UK LPN were completed (Figures 3A, 3B), but DL and GL LPN produced a large amount of smoke (Figures 3C, 3D). The suction of the novel laser operating handle obviously improved the clarity of the DL procedure (Figures 3E, 3F). Because large amounts of smoke were produced by GL, gas exhaust, and suction of the novel handle did not change the surgical field of view significantly (Figure 3E). During the operation, the clearness of the surgical field of view was determined

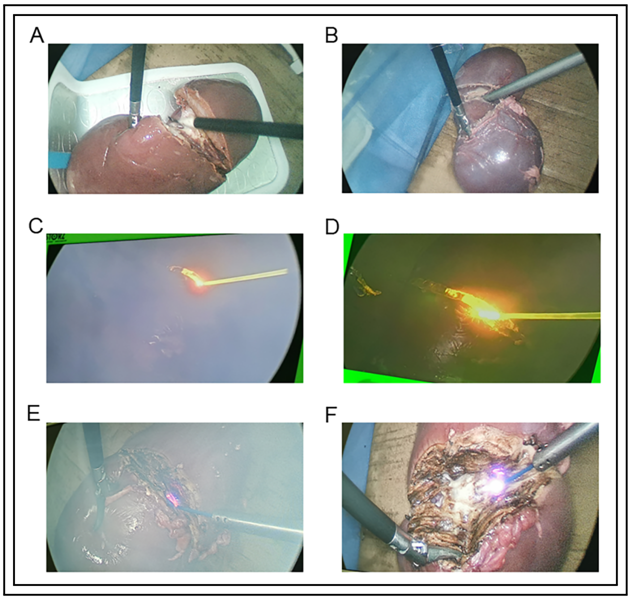

FIGURE 3. Laparoscopic partial nephrectomy with different instruments. (A) Partial nephrectomy with an electrocoagulation hook. (B) Partial nephrectomy with an ultrasonic knife (UK). (C) Partial nephrectomy with a green laser. (D) partial nephrectomy with a 980 nm diode laser. (E) Partial nephrectomy with a green laser + the novel laser operating handle. (F) Partial nephrectomy with a 980 nm diode laser + the novel laser operating handle

for the UK, 980-nm diode laser, electrocoagulation knife, and 532-nm KTP laser.

The composition and content of smoke are shown in Figure 4. Two gas detectors were used to monitor the smoke in every LPN, and the results are shown in Figures 4A–4I. Significantly less gas was produced from UK LPN than from the other sources. Formaldehyde, TVOC, and CO levels were significantly reduced when utilising the novel laser operating handle. The concentrations of PM2.5, PM1.0, and PM10 reached the maximum limit of testing equipment in procedures performed with all instruments, except the UK. Combustible gas was not detected. H_2S was not detected during the UK LPN procedure, and compared with the EK LPN, the other procedures generated significantly lower amounts of this gas. The percentage volume of O_2 was obviously reduced in the procedures, except for UK LPN.

As shown in Figures 5A–5E, in terms of the thickness of the solidified layer, the instruments from the thickest to the thinnest were the 980-nm diode laser, 532-nm KTP laser, ultrasonic blade, and electrocoagulation knife. The instruments with operation times from fast to slow were the electrocoagulation knife, UK, 532-nm KTP laser, and 980-nm diode laser (Figure 5F).

Discussion

As surgical smoke is increasingly valued by researchers and surgical department managers,[4,6–8] this study also focuses on solving the problem of a large amount of smoke produced during laser partial nephrectomy and performs a qualitative and quantitative analysis of the generated surgical smoke to clarify whether surgical smoke generated by the laser is different from commonly used surgical instruments in partial nephrectomy.

Regardless of whether the laser can vapourize the target tissue to the maximum extent, the main difficulty is how to guide the optical fibre to the target and use the optical fibre flexibly, such that it exerts its due function and achieves a multiplier effect. More than ten years ago, some clinicians performed diode laser-assisted laparoscopic partial nephrectomy and used a suction device to assist in laser vapourization, but a large amount of smoke was recently reported to interfere with the surgical field of view.[9] Although simultaneous flushing during the experiment using a laser to vapourize and cut the isolated kidney may reduce smoke generation, a risk of tumour implantation and metastasis exists. Research reports have documented the outstanding effect of laser partial nephrectomy,[3] especially in terms of haemostasis, but corresponding surgical instruments remain to be developed and designed to suit the application environment.[10] For example, a laser combined with endoscopic submucosal dissection endoscopic submucosal dissection (ESD) was reported to compensate for the conductive complications caused by traditional ESD.[11] Therefore, this study presented a novel laser handle with the function of suction, which not only suctions the surgical smoke but also irrigates the tissue to clarify the surgical field. Based on our idea, we applied for a national new utility patent for this novel laser-assisted partial nephrectomy handle (CN208709983U).

Various instruments produce different amounts of surgical smoke when operating on different tissues.[12] Although the operating room has a purification system, the surgeon and other related personnel will still be threatened by surgical smoke.[8,13] Therefore, we must clarify the characteristics of surgical smoke generated by the operation of the tissue using each surgical instrument to implement specific protective measures. In addition, a stationary suction system, a

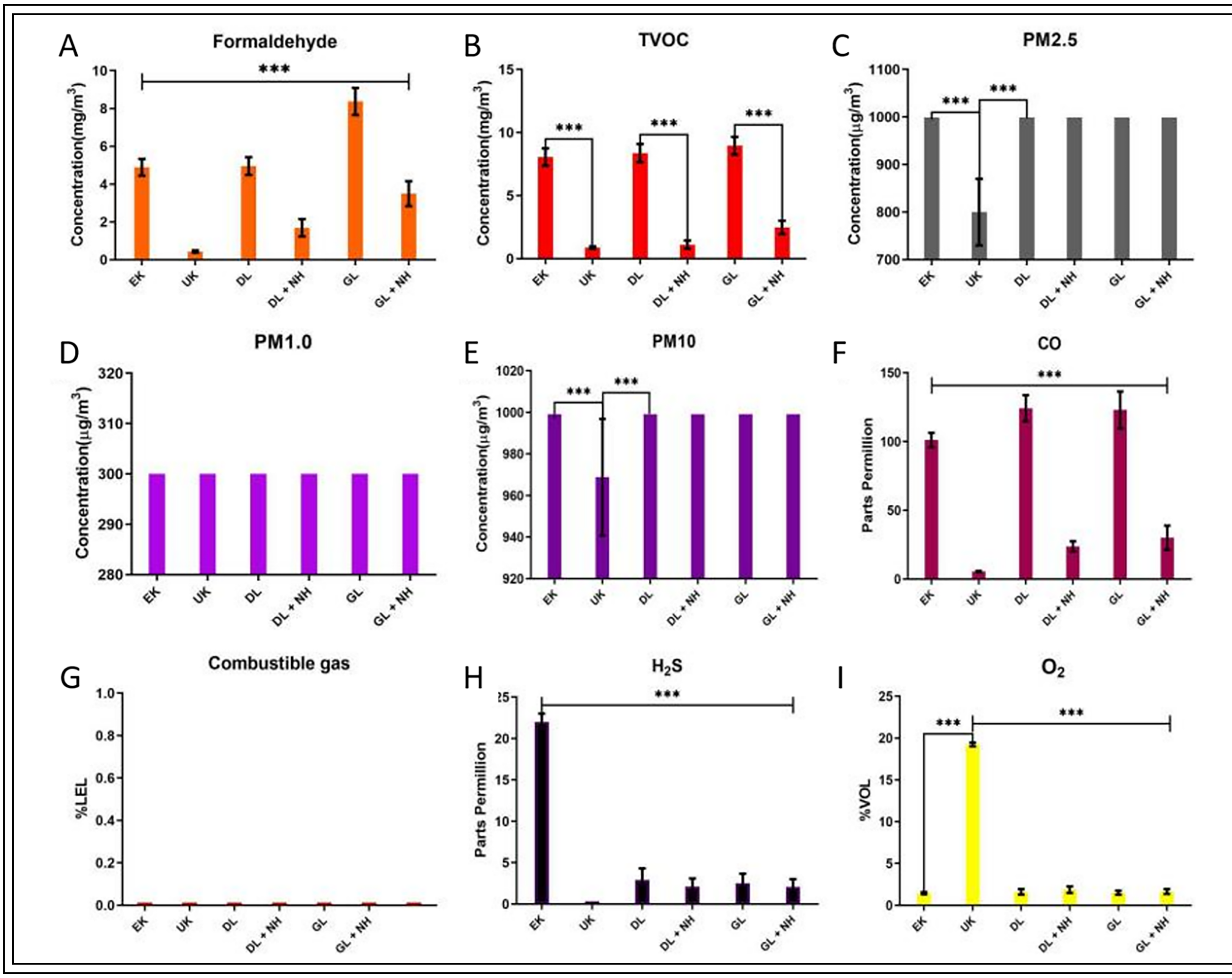

FIGURE 4. Types and contents of smoke produced by different surgical instruments. (A–E) The concentrations of (A) Formaldehyde, (B) TVOC, (C) PM2.5, (D) PM1.0, and (E) PM10, respectively. (F–I) The assay results of (F) CO, (G) combustible gas, (H) H_2S, and (I) O_2. Note. ***$p < 0.001$. EK, electrocoagulation knife; UK, ultrasonic knife; DL, 980-nm diode laser; GL, 532-nm KTP green laser; NH, novel handle; LEL, lower explosive limit; VOL, volume.

portable suction system, personal protective equipment, and a special protective mask, such as an N95 mask or filter mask, were needed.[14] In our study, the amount of smoke generated by the two types of lasers was relatively large, and it contained a large amount of harmful gases, such as formaldehyde, TVOC, and PM2.5. According to previous articles, byproducts generated during surgical procedures, especially during laser surgery, include different sizes of particles, chemical substances, and cells or cell parts. Surgical masks do not prevent the small particles produced by lasers and other instruments from being inhaled.[14] Human papillomavirus, one of these health hazards from surgical smoke, may be the greatest risk hazard that attracts the attention of operating room staff and the authorities.[4,15]

However, we believe that the surgical smoke produced during the procedure may be effectively prevented from spreading to the operating room by increasing the awareness of personnel in the operating room, improving the suction devices, and devising surgical smoke-related regulations.

In addition, when performing surgery with a green laser in our experiment, the intense green light filled the whole operating room, and everyone in the operating room needed to wear goggles to operate accurately and avoid potential vision damage. Related reports also indicate that eye protection is necessary during laser surgery.[16,17]

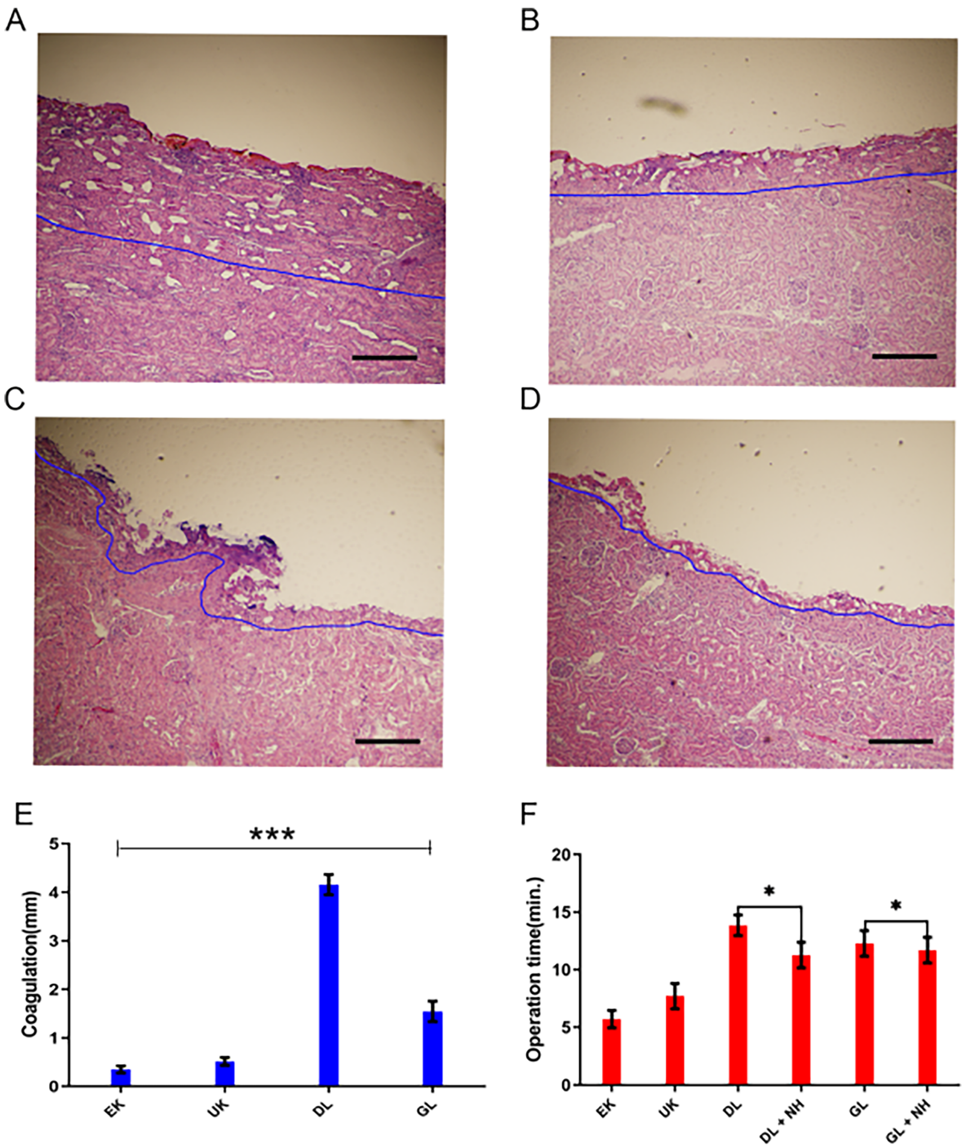

FIGURE 5. Coagulation layer thickness and operative time with different devices. (A–E) Thickness of coagulation of (A) 980-nm diode laser (DL), (B) 532-nm KTP green laser (GL), (C) ultrasonic knife (UK), and (D) electrocoagulation knife (EK). (F) Time of operation after laparoscopic-assisted partial nephrectomy with various instruments. Note. $^{*}p < 0.05$, $^{***}p < 0.001$. Scale bar: 1.5 mm. NH, novel handle.

Beyond the immediate intraoperative challenges and health hazards, the long-term operational and clinical implications of laser type selection warrant further consideration. The 980 nm and 532 nm lasers, while both effective for resection, exhibit distinct photothermal profiles.[18,19] The 532 nm (green) laser, for instance, is highly absorbed by hemoglobin, offering superior hemostasis.[20,21] Conversely, the 980 nm laser has a higher affinity for water, which may result in a greater thickness of the coagulation.[18,22] This deeper coagulation effect can be advantageous for sealing larger vessels but may also result in a larger zone of thermal necrosis in the remaining kidney tissue, potentially impacting long-term renal function. Our findings regarding smoke composition for these fundamental tissue-laser interactions suggest that the ideal laser choice may depend on auxiliary equipment. Furthermore, the development of specialized instrumentation, such as the suction-integrated handle we have patented, represents a crucial step toward mitigating surgical risks. However, the adoption of such devices necessitates a parallel evolution in surgical technique and training. The learning curve associated with new laser handpieces and smoke evacuation protocols must be addressed to ensure that the potential for a clearer surgical field and reduced contaminant exposure is fully realized. Finally, establishing standardized benchmarks for acceptable smoke levels and uniform safety protocols across urological departments is imperative.

In addition to the above, the operation times caused by the four types of surgical instruments are significantly different. According to our team's discovery, apart from the reasons of the instruments themselves, the smoke also affected the surgical field of view to varying degrees and significantly shortened the operation time. This finding introduces a critical, self-perpetuating cycle: a poor visual field caused by accumulated smoke forces the surgeon to operate more slowly and cautiously to avoid complications. In contrast, an instrument that generates less smoke, or is paired with an effective evacuation system, maintains a clear visual field, allowing for more confident and rapid dissection. Thus, the indirect effect of smoke on operative time can be as clinically significant as the direct cutting efficiency of the instrument itself. The thickness of the coagulation layer is determined by the working principle of the instrument itself and has no obvious management effect on surgical smoke. This distinction is important: while coagulation depth is an intrinsic property of the energy device, smoke production is an extrinsic byproduct that can be managed through external means (i.e., suction). This reinforces the concept that optimizing the surgical instrument ecosystem—by combining a device with a certain coagulation profile with a highly effective smoke management system—can yield better overall outcomes than focusing on either aspect in isolation.

The main drawbacks are as follows: (1) Design aspect: We use simulated surgery instead of conducting it in a live experiment; while an *ex vivo* model allows for controlled, repeatable measurements of smoke generation without the confounding variables present in a living organism (such as bleeding), it cannot fully replicate the complex tissue interactions and physiological conditions of an *in vivo* surgery. The results, therefore, serve as a crucial benchmark but require validation in a live animal model or clinical setting. (2) The measurement of harmful gas concentrations mainly focuses on the close-range range and does not target nursing staff and anesthesiologists. This does not provide a complete picture of how the smoke disperses throughout the entire opration room, leaving the exposure levels of the scrub nurse at the back table or the anesthesiologist near the head of the patient unquantified. (3) The precision of the equipment for measuring harmful gases is limited, which may lead to an insufficient types of harmful gases being measured. The use of more sophisticated analytical techniques, such as gas chromatography-mass spectrometry (GC-MS), would likely reveal a more complex cocktail of organic compounds and pyrolysis byproducts than our current sensors could detect. This limitation means our analysis, while indicative of major hazards, is likely an underestimate of the total chemical exposure. (4) Although laser surgery generates a large amount of surgical smoke during kidney cutting, the smoke aspirator we designed is effective, but there are still areas that need improvement. Our current prototype, while proving the concept, could be optimized for better ergonomics, potentially incorporating a more flexible tip for better maneuverability, or a variable suction control integrated into the handle itself. Future iterations will focus on refining the design based on user feedback to maximize both functionality and user comfort.

Conclusions

By improving the auxiliary optical fibre used in the operation of LALPN, the amount of smoke is effectively reduced, and the effect of clearing the surgical field of view is achieved. And we found that once the harmful smoke produced is not well absorbed, the surgical smoke of laser PN may still pose a health threat to the surrounding medical staff.

Acknowledgement

We thank Dr. Yun Wangong and Zhai Miaomiao in the Department of Anaesthesia Surgery Center, Xianyang Central Hospital, Xianyang, China.

Funding Statement

This study was financially supported by the Key Research and Development Program of Shaanxi Province (2019SF-108, 2020SF-126, and 2021SF-269).

Author Contributions

Study design: Nan Li, Xiaofeng Xu, and Guoxiong Liu. Data collection: Long Ma, Tao Li. Data analysis: Quan Du, Ruohao Sun. Drafting the manuscript: Guoxiong Liu, Dali Jiang. Project supervision: Dalin He, Xiaoliang Fu. All authors reviewed and approved the final version of the manuscript.

Availability of Data and Materials

The original contributions presented in this study are included in the article, further inquiries can be answered by the corresponding author.

Ethics Approval

All of the experimental procedures were approved by the Institutional Animal Care and Use Committee of Xianyang Central Hospital (No. 2021-IRB-19).

Conflicts of Interest

The authors declare no conflicts of interest.

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