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Application of Side-Port Smoke Evacuation Device in Laparoendoscopic Single-Site Surgery: A Prospective Comparative Study

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Abstract

Objective: To evaluate the clinical efficacy of a side-port smoke evacuation device during laparoendoscopic single-site (LESS) total laparoscopic hysterectomy with bilateral salpingectomy. **Methods:** A total of 24 female patients undergoing LESS total laparoscopic hysterectomy with bilateral salpingectomy from July 2023 to September 2024 were enrolled and randomly assigned to an experimental group (n = 12) or control group (n = 12). The experimental group used a custom-designed side-port smoke evacuation device, while the control group used the conventional built-in smoke channel of the single-port platform. Intraoperative metrics such as total operation time, cumulative surgical pause time, blood loss, and postoperative anal exhaust time were recorded. Postoperative questionnaires were used to evaluate surgical field clarity by the primary surgeon and assistant. **Results:** No significant differences were observed in age, blood loss, or postoperative exhaust time between the two groups ($P > 0.05$). However, the experimental group had significantly shorter operation time (70.75 ± 19.32 min vs. 98.16 ± 31.16 min, $P = 0.015$) and pause time (17.33 ± 12.75 sec vs. 37 ± 16.32 sec, $P = 0.015$). Subjective clarity scores from both surgeon and assistant were significantly higher in the experimental group ($P < 0.05$). **Conclusion:** The side-port smoke evacuation device enhances surgical visibility during LESS procedures, reduces intraoperative pauses, and contributes to safer, more efficient operations. It also reduces surgical smoke exposure, thereby protecting healthcare staff and improving occupational safety.

Keywords

Laparoendoscopic Single-Site Surgery, Smoke Evacuation, Side-Port Device, Surgical Visibility, Minimally Invasive Gynecology

1. Introduction

Minimally invasive surgical techniques have revolutionized gynecologic procedures, offering patients faster recovery, reduced postoperative pain, fewer wound complications, and superior cosmetic outcomes [1]. Among them, laparoendoscopic single-site surgery (LESS) has emerged as an advanced form of laparoscopy that utilizes a single incision, typically at the umbilicus, to perform complex intra-abdominal operations [2]. LESS is increasingly applied in benign and malignant gynecologic surgeries, including hysterectomy, adnexectomy, and myomectomy, owing to its reduced invasiveness and favorable aesthetic results [3].

However, the technical demands of LESS remain high. Unlike conventional multiport laparoscopy, where instruments are triangulated through separate ports (where instruments are operated in a triangular shape through separate holes), LESS relies on parallel instrumentation through a single site. This approach leads to instrument crowding, reduced range of motion, and the so-called "chopstick effect" [4], significantly increasing the difficulty of maintaining a clear operative field. Moreover, due to the linear field of vision and reliance on two-dimensional imaging systems (still prevalent in many hospitals in China and elsewhere) [5], LESS imposes a greater demand on intraoperative visualization.

A key but often underappreciated factor that further impairs visualization in laparoscopic surgery is surgical smoke. Generated by electrocautery, bipolar coagulation, and ultrasonic dissection, surgical smoke contains water vapor, carbonized tissue particles, toxic chemicals, and even viable cellular material [6]. If not efficiently evacuated, this smoke accumulates within the peritoneal cavity, obscures the surgical field, increases operative time, and may even contribute to inadvertent tissue damage [7]. Furthermore, prolonged exposure to surgical smoke has been associated with respiratory symptoms, eye irritation, and potential long-term health risks among operating room personnel [8]-[10].

While commercial single-port platforms often include a central smoke evacuation channel, their effectiveness is limited by the distance between the smoke source and the suction site [11]. In LESS, where instrument tips operate deep within the pelvic cavity, smoke clearance from the field of dissection is frequently inadequate, necessitating repeated lens cleaning or surgical pauses [12]. These interruptions not only prolong surgery but also disrupt procedural flow and may compromise surgical outcomes.

To address this issue, we designed a side-port smoke evacuation device that integrates a lateral suction channel near the distal end of the laparoscopic instrument. This device consists of a silicone tube (diameter: 5 mm, length: 30 cm) and a surgical instrument with multiple side holes (diameter: 0.3 mm) located 5 cm away from the distal end of the instrument, as well as a three-way connector that can be connected to a suction tube and a controllable valve. The suction flow was regulated using a standard adjustable negative pressure valve to maintain consistent suction pressure between cases. A schematic diagram of the device is presented in **Figure 1**.

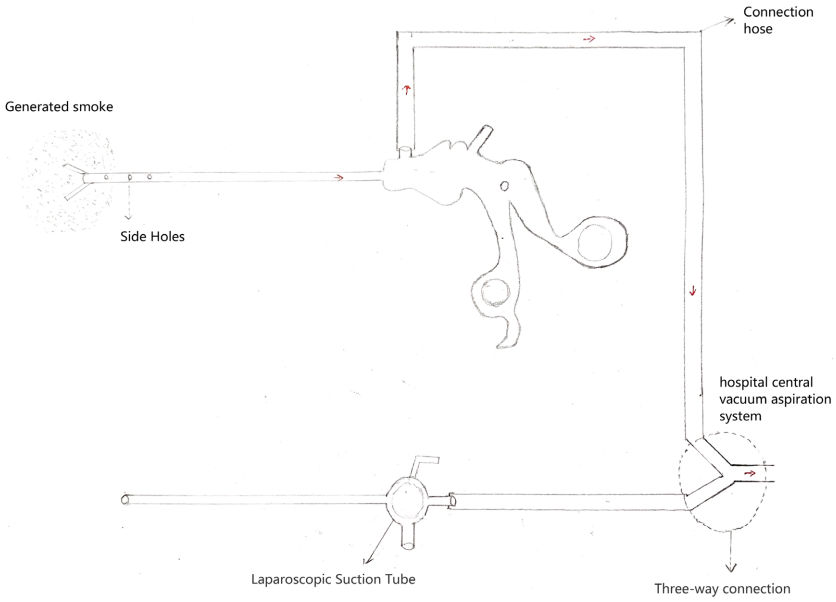

Figure 1. Laparoscopic smoke evacuation system with side-hole suction and three-way connector.

To objectively evaluate its suction performance, a supplementary in vitro validation was conducted using a simulated abdominal cavity filled with standardized smoke generated from electrosurgical activity on animal tissue. The amount of smoke evacuated over a 60-second period and the flow rate were measured and compared with the standard built-in channel. The side-port device demonstrated an average flow rate of 4.2 L/min compared to 2.5 L/min with the built-in channel and achieved near-complete clearance of visible smoke within 45 seconds.

The current study aimed to evaluate the clinical utility and effectiveness of this device in a prospective cohort of patients undergoing LESS total laparoscopic hysterectomy with bilateral salpingectomy. Specifically, we compared operative efficiency, intraoperative pause time, blood loss, postoperative recovery, and subjective clarity scores between surgeries performed with and without the side-port evacuation system.

We hypothesize that this novel device will significantly improve intraoperative visibility, reduce operative time, and enhance surgical safety without introducing additional complications or workflow burdens.

2. Materials and Methods

2.1. Patient Selection

Twenty-four female patients who underwent elective single-port laparoscopic total hysterectomy with bilateral salpingectomy at our institution between July 2023 and September 2024 were included. Patients were randomized into two groups (n = 12 each) using SPSS-generated random numbers.

Inclusion criteria:

- Age 40 - 55 years

- Uterine size <16 gestational weeks
- Stable vital signs, elective surgery
- LESS total hysterectomy + bilateral salpingectomy

Exclusion criteria:

- Conversion to multi-port or open surgery
- Severe cardiopulmonary disease
- ≥2 prior lower abdominal surgeries
- Coagulopathy
- Severe pelvic adhesions
- Equipment failure or intraoperative ultrasonic scalpel use
- ICU admission post-surgery

All patients provided written informed consent. The study protocol was approved by the hospital's ethics committee.

2.2. Surgical Method

All surgeries were performed by the same surgical team. During surgery, the patient adopted the position of bladder lithotomy. A 3 cm vertical incision was made at the umbilicus, and a single-port access device (Beijing Aerospace Cardi, China) was inserted.

In the experimental group, the side-port smoke evacuation device was inserted through one instrument channel and connected to a central suction system with a controllable valve. The control group used the built-in exhaust pipe of the single-port system.

Surgical steps: round ligament resection, salpingectomy, Ligamentum ovarii proprium Incision, Opening the broad ligament, Dissection of vesicouterine peritoneal reflection, Ligation and transection of uterine vessels, cardinal ligament and uterosacral ligament Excision, and Circumferential incision at vaginal fornix. The top of vaginal was closed with barbed sutures. Blood loss was measured using suction bottle and volumetric cylinder (no irrigation used).

In order to minimize the impact of placing a single-port and removing surgical specimens on the experiment, the operation time was from the placement of the single-port to the complete circumcision of the vaginal dome.

2.3. Outcome Measures

Primary Outcomes:

- Operation time (minutes)
- Surgical pause time (seconds, defined as lens removal and reinsertion duration for cleaning)
- Intraoperative blood loss (mL)
- Postoperative anal exhaust time (hours)

Secondary Outcome:

- Surgical field clarity scores (5-point scale: 5 = very clear, 1 = poor visibility), rated independently by the lead surgeon and first assistant

2.4. Statistical Analysis

Data were analyzed using SPSS 27.0. Continuous variables were expressed as mean ± SD. Independent sample t-tests were used for intergroup comparisons. A P-value < 0.05 was considered statistically significant.

3. Results

3.1. Baseline Characteristics of Patients

No statistically significant differences were found between the two groups in terms of age, BMI, history of previous abdominal surgery, or ASA classification (Table 1).

Table 1. Baseline demographic and clinical characteristics of the two groups.

Characteristic	Experimental Group (n = 12)	Control Group (n = 12)	P-value
Age (years)	52.16 ± 4.26	51.25 ± 3.27	0.501
BMI (kg/m^2)	24.51 ± 2.18	25.86 ± 2.33	0.383
Previous abdominal surgery (n)	4	3	0.674
ASA Score (I/II)	1/11/0	2/8/2	0.674

3.2. Intraoperative Parameters

The experimental group had significantly shorter operation time and pause time than the control group (P < 0.05). There were no significant differences in intraoperative blood loss or postoperative anal exhaust time between the groups (Table 2).

Table 2. Comparison of intraoperative outcomes between groups.

Group	Operation Time (min)	Blood Loss (mL)	Pause Time (sec)	Anal Exhaust Time (h)
Experimental	70.75 ± 19.32	104.16 ± 77.86	17.33 ± 12.75	30.83 ± 10.76
Control	98.16 ± 31.16	86.66 ± 74.26	37.00 ± 16.32	36.83 ± 15.00
P-value	**0.015**	0.612	**0.015**	0.314

3.3. Surgeon's Evaluation of Surgical Field Clarity

The mean clarity score given by the surgeons was significantly higher in the experimental group than in the control group (Table 3).

Table 3. Surgeon-reported clarity scores between groups.

Group	5 pts	4 pts	3 pts	2 pts	1 pt	Mean ± SD	P-value
Experimental	5	7	0	0	0	4.41 ± 0.51	0.005
Control	0	8	4	0	0	3.67 ± 0.49	

3.4. Assistant's Evaluation of Surgical Field Clarity

The assistant's clarity scores were also significantly higher in the experimental group compared to the control group (Table 4).

Table 4. Assistant-reported clarity scores between groups.

Group	5 pts	4 pts	3 pts	2 pts	1 pt	Mean ± SD	P-value
Experimental	2	8	2	0	0	4.00 ± 0.60	0.046
Control	0	5	7	0	0	3.42 ± 0.51	

4. Discussion

The findings of this study suggest that the application of a side-port smoke evacuation device significantly improves surgical performance and visual clarity during laparoendoscopic single-site (LESS) hysterectomy. Compared to conventional smoke evacuation systems built into single-port kits, this novel device demonstrated clear intraoperative advantages without introducing additional operative risk.

The significant reduction in operation time in the experimental group reflects improved procedural efficiency, likely resulting from uninterrupted visualization and smoother instrument handling. Surgical smoke has long been recognized as a critical obstacle in laparoscopic procedures, especially in LESS where instrument congestion and limited working space already challenge operative fluency [13]. By removing smoke directly at the source, the side-port design minimizes the need to pause and clean the lens, thereby shortening the cumulative pause time. The data confirmed this effect, with a more than 50% reduction in surgical pause time observed in the experimental group.

Another key benefit observed was the improvement in visual clarity, as reported independently by both the lead surgeon and the first assistant. The enhanced visibility not only reduces the mental and visual strain on the operating team but also potentially contributes to safer tissue dissection and fewer inadvertent injuries. These subjective improvements in clarity scores are consistent with previous studies emphasizing the importance of efficient smoke evacuation in endoscopic surgery.

Interestingly, no significant differences were found in intraoperative blood loss or postoperative gastrointestinal function recovery between groups. This supports the view that the side-port evacuation device exerts its influence primarily through optimizing the visual and ergonomic aspects of the procedure, rather than directly altering the physiological parameters of the surgery or the patient.

Importantly, the device was well tolerated and easily integrated into the surgical workflow. There were no recorded intraoperative complications related to the device, nor did it interfere with instrument manipulation, port stability, or tissue exposure. This suggests good operational compatibility with existing LESS platforms, an essential factor for clinical adoption.

From an occupational safety perspective, improving smoke evacuation is also critical to reduce the exposure of surgical staff to harmful byproducts of electrosurgical instruments, including carcinogenic and mutagenic particles [14]. While this study did not measure environmental exposure levels, the improved intraoperative clarity indirectly supports the notion of reduced smoke accumulation

within the peritoneal cavity and surrounding airspace.

Nonetheless, several limitations of this study should be acknowledged. First, the sample size was small and limited to a single surgical indication (hysterectomy). Larger, multicenter studies are warranted to validate these findings across diverse surgical scenarios. Second, the study focused on short-term intraoperative outcomes, and long-term implications such as postoperative complications, port-site infection, or overall recovery time were not assessed.

Future research should also explore the optimization of the device's design—for example, integrating sensors to allow automated suction adjustments based on real-time smoke density, or combining the system with smart visualization technologies to further enhance operative safety and precision [15] [16]. Additionally, comparative cost-effectiveness analyses would help determine the broader clinical value and economic feasibility of this intervention [17].

In summary, the side-port smoke evacuation device represents a practical and effective adjunct in LESS procedures. It significantly improves surgical visibility, reduces operative interruptions, and contributes to a more efficient and safer surgical environment. With further refinement and broader validation, such innovations may play an important role in advancing the safety and precision of minimally invasive gynecologic surgery.

Author Contributions

Conceptualization and study design: Huang Hailong;

Data collection and surgery execution: Qing Xuemei, Xie Min, Deng Xiaofeng;

Data analysis and interpretation: Zhang Linyun.

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Conflicts of Interest

The authors declare that they have no competing interests or financial relationships relevant to the content of this article.

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