Development of a closed-circuit transurethral resection system for effective capture of harmful surgical smoke

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KEY WORDS

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ABSTRACT

Exposure to harmful gases in the operating room (OR) is an occupational risk for health care personnel; however, it remains insufficiently recognized during transurethral resection (TUR) procedures. This study aimed to develop a simple closed-circuit TUR system to prevent exposure to surgical smoke, and evaluate its effectiveness. The system was constructed by connecting a suction tube to a drainage port to contain gases generated during TUR of the prostate (TURP). The collected gases were analyzed using gas chromatography to identify potentially toxic substances. The effect of odor control was assessed by 14 OR staff members during 2 TURP procedures (2 performed with the closed-circuit system, and 2 with the conventional system) using a 6-point Likert scale. The closed-circuit technique was safely and effectively applied during clinical TURP procedures, successfully capturing surgical smoke containing carcinogenic compounds, such as benzene and ethylbenzene. Median (interquartile range) odor score during TURP was lower with the closed-circuit than conventional system (1 [1–1] vs 4; [3–4]; $P < 0.01$). These results indicate that the closed-circuit TUR system is a practical and effective method for reducing occupational exposure to surgical smoke during TURP.

INTRODUCTION Surgical smoke generated during ablation, resection, or coagulation of living tissues using various energy devices, such as electrocautery machines and lasers, contains gases that are harmful to medical staff in the operating room (OR).[1,2] Inhalation of these gases can cause health problems, particularly in the respiratory tract.[3] In addition to respiratory complications, surgical smoke can have a range of effects on OR personnel, including odor-related discomfort, headaches, visual disturbances, and nausea.[4] The International Federation of Perioperative Nurses recommends implementing smoke evacuation systems and wearing high-performance masks, such as N95 respirators, to reduce the risk of adverse effects associated with surgical smoke exposure.[5] The Japanese Association for Operative Medicine[6] has also issued practice guidelines to prevent exposure to surgical smoke during surgery, which include recommendations similar to those of the International Federation of Perioperative Nurses.

Despite efforts by academic societies to raise awareness about surgical smoke hazards, they remain widely unrecognized in urological procedures. One of the few reports addressing this issue was published by Chung et al,[7] who reported that gases generated during transurethral resection (TUR) are toxic and contain harmful substances, including nitrogen compounds and carcinogens, such as 1,3-butadiene, vinyl acetylene, and acrylonitrile.[7] During TUR of the prostate (TURP), urologists position themselves near the outlet where the gas escapes, thereby increasing the risk of inhaling high concentrations of toxic substances. However, many urologists and OR staff remain unaware of these potential dangers and fail to take adequate precautions. Currently, no effective methods have been reported to reliably prevent gas inhalation during TUR.

AIM This study had 3 primary objectives: to develop a simple TUR system to reduce gas exposure, to analyze the gases produced during TURP, and to assess the clinical

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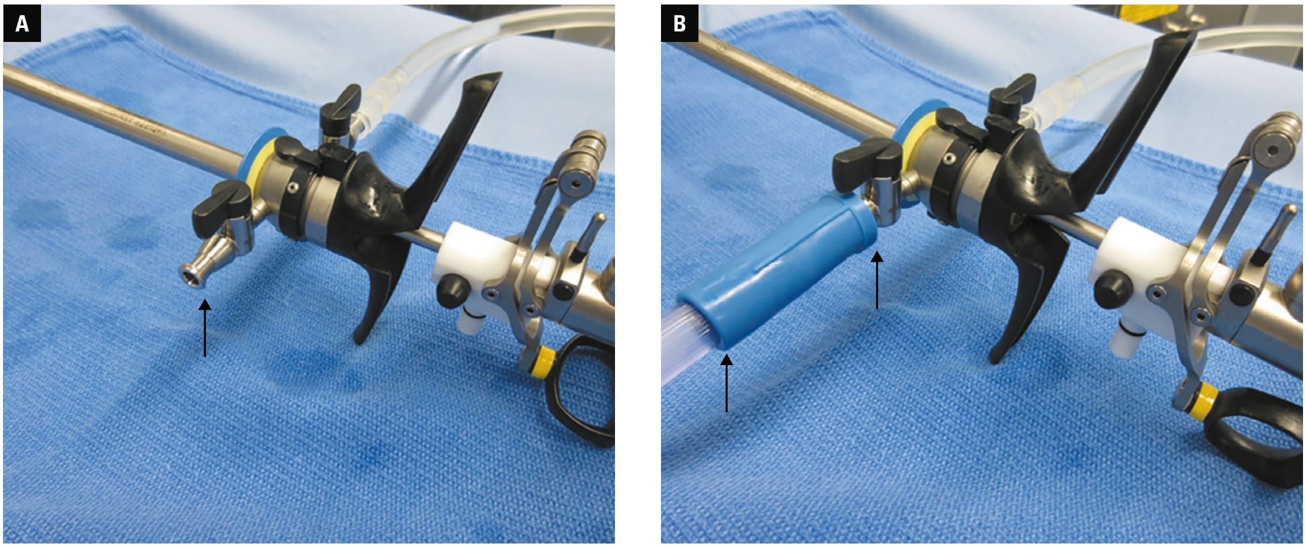

FIGURE 1 Overview of transurethral resection methods with different drainage systems; **A** – spontaneous irrigation with outlets (arrow) opened by natural pressure in the conventional system; **B** – forced irrigation with closed suction outlets (arrows) via continuous evacuation in the closed-circuit system

TABLE 1 Clinical data of the patients undergoing transurethral resection of the prostate with the closed-circuit and conventional systems

Variable	Closed-circuit system (n = 25)	Conventional system (n = 19)	*P* value
Age, y	75.8 (4.9)	72.3 (7)	0.07
Operative time, min	71.9 (26.9)	58.6 (22.3)	0.08
Resected tissue weight, g	30.3 (13.8)	20.3 (13)	0.02
Resected tissue weight over time, g/min	0.42 (0.11)	0.32 (0.13)	0.02
Preoperative hemoglobin, g/dl	13.24 (1.73)	13.55 (1.2)	0.5
Postoperative hemoglobin, g/dl	13.2 (1.86)	13.23 (1.43)	0.95
Relative decrease in hemoglobin, %	–0.01 (–0.04 to 0.02)	0.01 (–0.01 to 0.07)	0.13

Data are presented as mean (SD) or median (interquartile range).

SI conversion factors: to convert hemoglobin to g/l, multiply by 10.

applicability of the system and its impact on the OR environment.

MATERIALS AND METHODS **Development and clinical application of the closed-circuit transurethral resection system** A closed-circuit TUR system was developed by connecting a suction tube to the drainage outlet of the resectoscope (**FIGURE 1**). The fluid drained through the suction port was collected in a 3.5-l waste bottle, solidified with a coagulant, and subsequently discarded. Continuous suction of the drainage enabled processing of the gas components contained within the outflow without leakage into the OR environment.

Between April 2014 and October 2016, we performed TURPs in 25 patients using the closed-circuit technique. To assess its clinical feasibility, we compared the clinical parameters of these patients with those of 19 individuals who underwent surgery using a conventional system between December 2012 and March 2014. The clinical parameters analyzed included age, operative time, resected tissue weight, resected tissue weight over time (g/min), pre- and postoperative hemoglobin concentration, and relative decrease in hemoglobin levels. The relative decrease in hemoglobin levels was calculated as (preoperative hemoglobin – postoperative hemoglobin) / preoperative hemoglobin × 100%. Postoperative hemoglobin levels were measured on day 1 after surgery.

TURP was performed using the Olympus bipolar saline system (Tokyo, Japan), with the electrocautery set at 280 W for resection and 120 W for coagulation. All procedures were performed by a single surgeon (YO). Surgical quality was evaluated by examining the prostate resected tissue weight over time and pre- and postoperative serum hemoglobin levels.

Evaluation of gas compositions To identify gases potentially harmful to human health, qualitative gas analysis was conducted for 3 different TURP cases performed with the closed-circuit system. During TURP, waste fluid and gas were continuously collected from the closed outlet. The mixture of gas and irrigation solution discharged during the procedure was accumulated in a 3.5-l waste bottle. Subsequently, a portion of the gas phase above the liquid in the bottle was drawn through tubing and absorbed into a carbon tube (Shibata Chemical Company, Tokyo, Japan) via a vent for 30 minutes. The absorbed material was desorbed by introducing hydrogen sulfide into the collection tubes. Finally, the resulting liquid samples were qualitatively analyzed using gas chromatography–mass spectrometry (GCMS-TQ8030; Shimadzu Corporation, Kyoto, Japan). For comparison purposes, normal air was collected from the OR before surgery and analyzed using the same method. All samples were analyzed at Japan Testing Laboratories (Gifu, Japan).

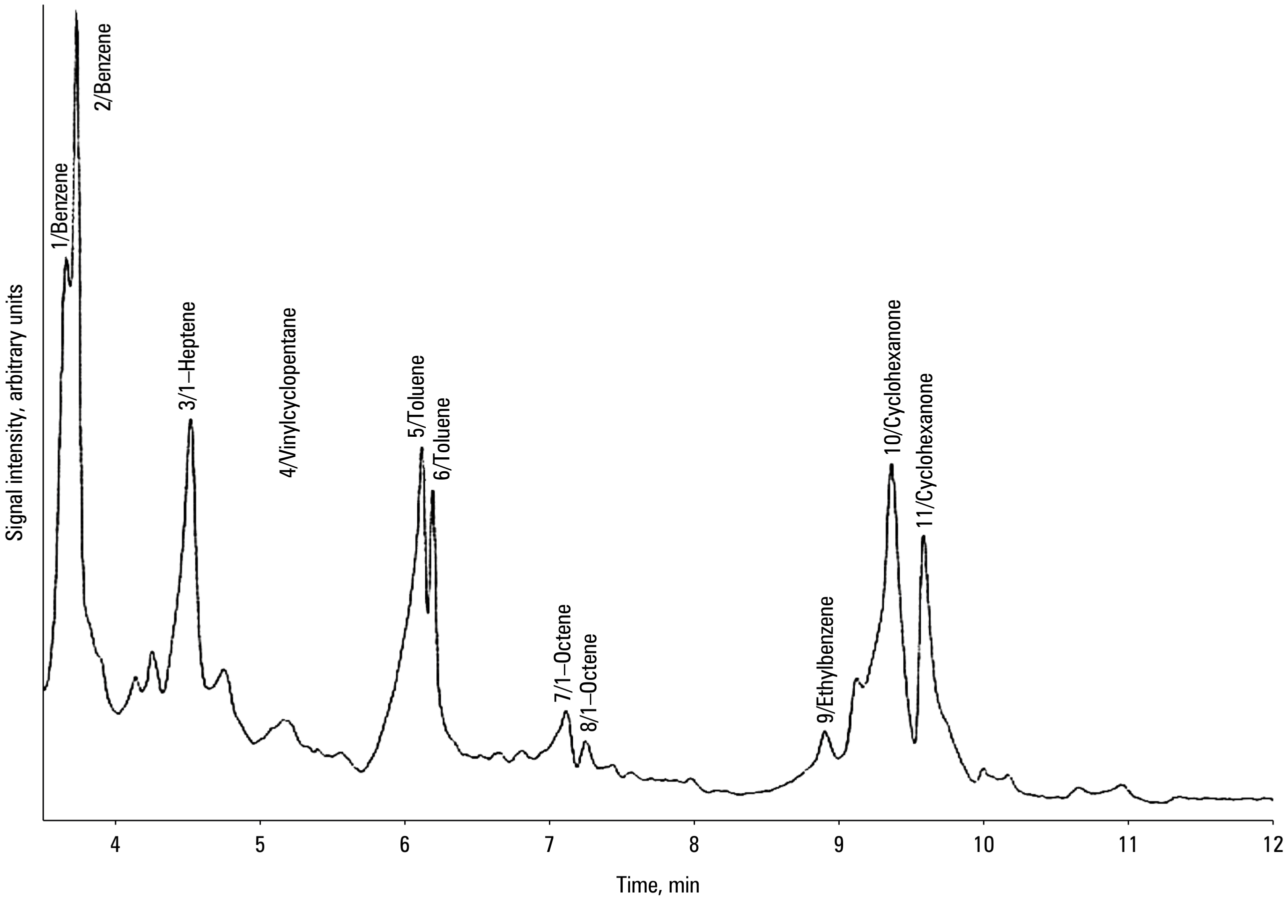

FIGURE 2 Representative chromatogram of surgical smoke during transurethral resection of the prostate performed with the closed-circuit system (case 1). The vertical axis represents signal intensity (arbitrary units), and the horizontal axis represents retention time.

Impact of the closed-circuit system on the operating room environment To evaluate the impact of the closed-circuit system on the OR environment, 14 OR staff members at the Sekisindo Hospital, all of whom wore standard surgical masks (not N95 respirators), assessed odor conditions during TURP procedures conducted between March and April 2014 using a 6-point Likert scale. Each staff member evaluated 2 TURP procedures performed with the conventional system and 2 procedures performed with the closed-circuit system, which were conducted on separate days. The Likert scale ranged from 0 ("no smell") to 5 ("intolerable").[8]

Statistical analysis Statistical analyses were performed using the *t* test for normally distributed variables and the Mann–Whitney test for non-normally distributed variables. The Mann–Whitney test was also used to compare the odor-scale data. All tests were 2-tailed, and statistical significance was set at a *P* value below 0.05. Data are presented as mean (SD) for normally distributed variables and median (interquartile range [IQR]) for non-normally distributed variables. All tatistical analyses were performed using JMP, version 18 (SAS Institute Inc., Cary, North Carolina, United States).

Ethics This study was approved by the institutional review boards of the Saitama Medical Center (1672, 2024–018) and the Sekisindo Hospital (270706–2). All enrolled patients provided written informed consent in accordance with institutional and institutional review board requirements. All procedures involving human participants were conducted in accordance with the ethical standards of the institutional and national research committees, and the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

RESULTS Among the evaluated variables, only resected tissue weight and resected tissue weight over time showed significant differences between the groups. All other clinical data were similar (**TABLE 1**).

Mean (SD) weight of the resected prostate tissue for the procedures performed with the closed--circuit system was 0.42 (0.11) g/min, and 0.32 (0.13) g/min for those performed with the conventional system ($P = 0.02$). Median (IQR) relative decrease in plasma hemoglobin concentration was –0.01% (–0.04% to 0.02%) and 0.01% (–0.01% to 0.07%), respectively ($P = 0.13$). These findings indicate that the closed-circuit system can be safely implemented in clinical settings without compromising surgical efficiency or safety.

A wide range of organic compounds was identified chromatographically in the 3 TURP cases that were subjected to a qualitative analysis,

TABLE 2 Chemical substances detected on chromatography in 3 cases of transurethral resection of the prostate performed with the closed-circuit system

Chemical substance	Molecular formula	Case 1	Case 2	Case 3
Benzene	C6H6	x	x	x
Toluene	C7H8	x	x	x
Vinylcyclopentane	C7H12	–	x	–
1-Heptene	C7H14	x	–	–
Cyclohexane, methyl-	C7H14	–	x	–
Cyclohexanone	C6H10O	x	x	x
Cyclopentane, 1,2-dimethyl-, cis-	C7H14	–	x	–
Heptane	C7H16	–	x	–
Ethylbenzene	C8H10	x	x	x
1-Octene	C8H16	x	x	–
1-Nonene	C9H18	–	x	–
Dimethyl trisulfide	C2H6S3	–	x	–
1-Hexanol, 2-ethyl-	C8H18O	x	–	x
1-Pentanol, 2-ethyl--4-methyl-	C8H18O	–	x	–
1-Dodecene	C12H24	–	x	–
Dodecane	C12H26	x	–	–
Heptane, 2,2,4,6,6-pentamethyl-	C12H26	x	x	x
Undecane, 2-methyl-	C12H26	–	–	x
1-Undecanol	C11H24O	x	–	–

and a representative case is shown in **FIGURE 2**. The chemical names and molecular formulas determined by chromatography are listed in **TABLE 2**. The compounds consistently detected in all 3 cases included benzene, cyclohexane, toluene, ethylbenzene, and 2,2,4,6,6-pentamethylheptane. In addition, 1-octene and 2-ethyl-1-hexanol were detected in 2 cases. Benzene and ethylbenzene have been classified as carcinogens by the International Agency for Research on Cancer.[9,10] None of these carcinogens were detected in the control samples.

Median (IQR) Likert scale score for odor rating in the OR during TURP was 1 (1–1) for the closed--circuit system and 4 (3–4) for the conventional system (P <0.001). These results indicate that the level of odor perception was markedly lower with the closed-circuit system than the conventional system.

DISCUSSION This study demonstrated clinical feasibility of the closed-circuit TUR system. Furthermore, the gas recovered contained carcinogenic components, and produced a strong, unpleasant odor. The proposed system has the potential to protect OR staff from exposure to odors and potential carcinogens.

Surgical smoke is generated during surgery when energy devices, such as electrocautery machines and lasers, are used.[11] Its gaseous components include water vapor and more than 150 substances, including viable bacteria, viruses, blood components, volatile organic compounds, hydrocarbons, tissue debris, and fatty acids. Exposure to these substances is associated with various health issues among health care workers. Surgical smoke with a particle size equal to or smaller than 2.5 μm can reach the lung periphery and cause respiratory complications, such as asthma and chronic obstructive pulmonary disease.[12] Regarding the risk of human papillomavirus infection, the development of laryngeal papillomas has been reported by surgeons performing laser therapy and OR nurses.[13,14] Surgical smoke also contains carcinogenic volatile organic compounds, such as benzene, which have been associated with a cancer risk.[15,16] However, few studies have investigated long-term risks of surgical smoke exposure, and further research is warranted to clarify its cumulative health effects.

Surgical smoke control is important in urological surgeries and requires further improvement. TUR is used to treat benign prostatic hyperplasia (BPH) and bladder cancer using an electrosurgical scalpel, with saline as the irrigation fluid. Surgical smoke generated by electrocautery devices accumulates in the bladder and is expelled through the irrigation fluid. Cases of bladder injury caused by explosions resulting from residual gas have been reported, highlighting the importance of efficient removal of trapped gas from the bladder.[17] In conventional systems, a significant amount of surgical gas often remains in the bladder dome, requiring intermittent gas discharge through the outlet. With the closed-circuit system, the gases remaining in the bladder dome can be expelled by voluntary evacuation.

Weston et al[18] identified several toxic substances, including volatile organic hydrocarbons, benzene, formaldehyde, and nitrous oxide, in an analysis of gas samples from patients with BPH undergoing TUR. Chung et al[7] performed a chemical analysis of toxic gases generated during both TURP and TUR-bladder tumor procedures using nonelectrolyte perfusion, and identified numerous toxic gases, including 3 carcinogens. Ferrari et al[19] reported the presence of tetradecane, hexadecane, 7-methylpentadecane, and 2,6-dimethyleptadecane in surgical smoke generated during the laser treatment of BPH. In this study, we analyzed gas samples from 3 patients who underwent TURP and consistently detected 5 organic substances: benzene, cyclohexane, toluene, ethylbenzene, and 2,2,4,6,6-pentamethylheptane. The International Agency for Research on Cancer classifies benzene and ethylbenzene as carcinogens, strongly indicating the toxic potential of these gases generated during TUR. Toluene and ethylbenzene produce strong, pungent odors. 2,2,4,6,6-pentamethylheptane is a branched alkane and flammable liquid. Cyclohexane is a volatile organic compound that serves as a nonpolar solvent, and is used as a raw material in nylon manufacturing.

Some studies have investigated the hazards associated with exposure to surgical smoke. Hurst et al[20] argued that previous studies may have overestimated the risk due to factors, such as the proximity of smoke collection points, lack of conclusive evidence regarding infectivity, and very low levels of contaminants in the OR environment. However, our data clearly indicate that surgical smoke contains harmful components and suggest that minimizing exposure is an important strategy for protecting health care workers. Many aspects of the basic and clinical significance of surgical smoke remain unknown and require further investigation, particularly regarding its long-term effects.

This study had several limitations. First, the sample size was relatively small for gas chromatography, which was performed in only 3 cases, limiting the scope of quantitative gas characterization. Second, neither quantitative measurements of OR air quality nor gas diffusion were performed within the OR. Therefore, conclusions regarding reduced occupational exposure are primarily based on subjective odor perception rather than objective environmental measurements. Additionally, compounds undetectable using gas chromatography, such as nitrogen and inert metals, were not evaluated. Third, conventional and closed-circuit systems were compared retrospectively across different time periods, which may have introduced unmeasured confounding factors. Furthermore, the open-label odor assessment, in which the OR staff were aware of which drainage system was being used, could have introduced subjective bias. However, evaluations were performed under identical conditions and the same staff members assessed both systems, partially mitigating this limitation. Finally, this study focused exclusively on bipolar TURP. The applicability of the closed-circuit system to other contemporary surgical modalities, including holmium laser enucleation of the prostate, thulium laser prostate vaporization, and prostatic urethral lifting, remains unresolved.[21] Further studies incorporating prospective designs, objective air quality measurements, and more surgical techniques are warranted to clarify long-term health effects of surgical smoke exposure and generalizability of this system.

CONCLUSIONS Surgical smoke generated during TURP contains carcinogenic gases. The use of the closed-circuit technique during TURP significantly improves OR conditions. This simple approach may help prevent surgeons and OR staff from exposure to carcinogenic surgical smoke during TUR.

ARTICLE INFORMATION

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CONTRIBUTION STATEMENT YO conceived the study concept, contributed to the study design, and participated in the data collection and analysis. YO and HT drafted the original manuscript. All authors reviewed, edited, and approved the final version of the manuscript.

CONFLICT OF INTEREST None declared.

AI STATEMENT Artificial intelligence was not used in the preparation of this manuscript.

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JOURNAL INFORMATION

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