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Research article

Related factors of perioperative low body temperature and incidence of postoperative shivering in patients undergoing complex percutaneous nephrolithotomy and the effect analysis of composite insulation nursing intervention

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A B S T R A C T

This study aimed to analyze the factors associated with intraoperative hypothermia and postoperative shivering rates in patients undergoing complex percutaneous nephrolithotomy (PCNL) and investigate the effects of combined insulation nursing intervention. A total of 168 patients were included, with 103 patients in the control (Ctrl) group receiving routine care and 65 patients in the nursing (Nur) group receiving combined insulation nursing intervention measures. General information, surgical data, temperature, intraoperative hypothermia incidence, postoperative shivering, and complication rates were statistically analyzed between the two groups. Patient temperature, blood pressure, and blood gas indicators including pH value, bicarbonate, and lactate levels were recorded at admission (T0), before anesthesia (T1), 30 min after spinal-epidural combined anesthesia (T2), 60 min (T3), 90 min (T4), 120 min (T5), and postoperatively (T6). The results demonstrated that the average intraoperative temperature of patients in the Nur group was significantly higher than that of the Ctrl group ($P < 0.001$), and their incidence of hypothermia was significantly lower than that of the Ctrl group ($P < 0.01$). Additionally, the Nur group exhibited shorter recovery time (18.36 ± 3.58 min), extubation time (28.01 ± 3.12 min), and length of hospital stay (8.45 ± 2.14 days) compared to the Ctrl group ($P < 0.05$). The incidence of postoperative shivering was 4.62 %, significantly lower than that of the Ctrl group ($P < 0.001$). Multifactorial analysis revealed that age ≥60 years, stone diameter ≥3.0 cm, irrigation volume ≥3000 mL, nursing intervention measures, and surgical duration were the main factors influencing the occurrence of intraoperative hypothermia. Age ≥60 years, nursing intervention measures, surgical duration, and intraoperative temperature<36 °C are identified as major risk factors for postoperative shivering. This indicates that specialized nursing care and combined insulation nursing intervention measures in patients undergoing complex percutaneous nephrolithotomy contribute to reducing the incidence of intraoperative hypothermia and postoperative shivering. It is recommended to promptly address the risk factors associated with hypothermia and shivering during and after surgery to mitigate the risk of perioperative complications.

1. Introduction

Kidney stones are a highly prevalent condition within the urinary system, with an incidence ranging from 1 % to 5 % [1]. Annually, there are approximately 0.04 %–0.3 % new cases, with a recurrence rate exceeding 50 % within a decade [2]. Traditional open kidney surgery is associated with significant surgical trauma and extended recovery times, while laparoscopic procedures are constrained by limitations in surgical field and perspective [3]. In recent years, with continuous advancements in medical technology, percutaneous nephrolithotomy (PCNL) has progressively emerged as a favored surgical approach for managing complex upper urinary tract stones, owing to its benefits of reduced trauma and faster recovery [4]. Nevertheless, this procedure can lead to perioperative complications

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such as hypothermia and postoperative shivering [5]. Perioperative temperature abnormalities in patients undergoing this procedure are multifactorial and can be influenced by age, gender, surgical duration, anesthetic techniques, and environmental factors, among others [6]. Following percutaneous cholangiography, it has been reported that patients undergoing percutaneous renal puncture lithotripsy or those with concomitant ureteral stones have a higher incidence of perioperative hypothermia, ranging from 40 % to 60 % [7]. Hypothermia in complex PCNL is associated with various factors, including patient age, anesthetic techniques, surgical duration, and operating room temperature [8]. In recent years, methodological improvements have enhanced temperature monitoring; however, an ideal treatment approach remains lacking [9]. Postoperative shivering is a common and high-incidence complication during the perioperative period of complex PCNL. According to relevant studies, the proportion of patients experiencing postoperative shivering ranges from approximately 39 %–99 % [10]. Factors influencing the occurrence of postoperative shivering in complex PCNL primarily include temperature reduction, age, gender, pre-existing systemic conditions, infection status, surgical duration, and individual factors [11]. Research indicates that local anesthesia during the surgical process and postoperative analgesic consumption can lead to temperature reduction, making it one of the most common factors triggering shivering [12]. Shivering, a common complication during the perioperative period of complex PCNL, along with other side effects, can extend the patients' hospital stay. Therefore, effective interventions for intraoperative hypothermia, postoperative shivering, and quality of life can have a positive impact on patients undergoing complex PCNL surgery.

Perioperative hypothermia refers to a series of complications caused by a drop in body temperature during or after surgery. To prevent these adverse reactions, appropriate hypothermia care measures should be taken during the perioperative period. Composite insulation nursing interventions include improving the temperature and humidity of the operating room and increasing insulation materials in the operating room, with the aim of reducing the risk of postoperative infection, improving treatment efficacy, and shortening the patient's hospital stay. Composite insulation nursing measures have the advantages of good insulation, good breathability, short nursing time, and simple operation, and therefore have wide clinical applications. In recent years, studies have noted that adopting composite insulation measures can effectively reduce the incidence of perioperative hypothermia, and reduce the occurrence of postoperative shivering and other complications [13]. Nevertheless, there is still limited research on composite insulation nursing for complex PCNL patients, especially for the intervention of perioperative hypothermia in patients undergoing PCNL. Hence, this study aimed to explore in-depth the incidence and influencing factors of intraoperative hypothermia and postoperative shivering in patients undergoing complex PCNL, and evaluate the effectiveness of composite insulation nursing interventions, to provide clinicians with more targeted and scientific diagnosis and treatment methodologies, achieve better treatment outcomes, and improve patients' quality of life.

2. Materials and methodologies

2.1. Research data

The data for this study included 103 confirmed kidney stone patients who underwent complex PCNL treatment at the University Hospital of Shenzhen-Hong Kong University from January 2021 to December 2021, forming the control (Ctrl) group. Additionally, electronic medical records of 65 kidney stone patients who received complex PCNL treatment from January 2022 to December 2022 were utilized for the nursing (Nur) group. The Ctrl group received standard care, while the Nur group received a combination of thermal care. In the Ctrl group, there were 46 male and 57 female patients, with an average age of 51.88 years. The Nur group consisted of 41 females and 24 males, with an average age of 56.72 years. The experimental procedures of this study were approved by the hospital's ethics committee, and all participants included in this study provided informed consent. All methods are carried out in accordance with the relevant guidelines and regulations.

Inclusion criteria: (1) patients with confirmed diagnosis of kidney stones and meeting the indications for PCNL [14]; (2) patients undergoing complex PCNL treatment; (3) patients aged between 18 and 70 years old, without intellectual disabilities or communication difficulties; (4) patients with no severe systemic diseases affecting the cardiovascular, respiratory, endocrine, and other systems; (5) preoperative routine electrocardiogram was generally normal, without notable dysfunction of vital organs; (6) hypertension and diabetes patients had their blood pressure and blood sugar controlled within the normal range.

Exclusion criteria: (1) patients with central nervous system diseases or other related diseases requiring drug treatment before surgery; (2) patients with postoperative infections that affect data collection; (3) patients undergoing emergency surgery or switching to other surgical methodologies during the operation; (4) patients with abnormal body temperature before surgery (temperature $\geq$37.5 °C or $\leq$36.0 °C); (5) patients with abnormal electrocardiogram before surgery; (6) patients with heart, lung, mental, or neurological diseases; (7) patients with contraindications for PCNL surgery.

2.2. Complex PCNL methodology

The patients underwent general anesthesia with endotracheal intubation. They were positioned in a prone split-leg posture with a 20-degree elevation of the upper body. Preoperative ultrasound examination determined the appropriate puncture site and direction. General endotracheal anesthesia was administered. Following successful anesthesia induction, an F6/7.5 ureteroscope with a guide wire (F5-6) was introduced into the affected-side ureter and renal pelvis, with continuous instillation of normal saline to induce artificial renal pelvis distension, facilitating puncture and confirming its success. The puncture site on the skin was disinfected. An 18G puncture needle guided by Aloka ultrasound (ARIETTA 60) was used for the puncture procedure. The puncture site was determined under ultrasound guidance, typically located in the region between the 11th intercostal space or the lower margin of the 12th rib and the scapular line to the posterior axillary line. The 18G renal puncture needle was advanced into the collecting system. After the needle core was removed, urine flow was observed to confirm the success of the puncture. It was essential to determine whether it was necessary to establish multiple access routes during the stone clearance process. The zebra guide wire was introduced through the sheath and advanced into the renal collecting system, and its safe position was further confirmed under fluoroscopic guidance following successful puncture. It was preferable to introduce the guide wire parallel to the ureteral catheter in the ureter. If there were intrarenal bends, it was advisable to extend the guide wire to a length of at least 6 cm. After the sheath was removed, sequential dilation from F8 to F12 and expansion to F14 or F16 was achieved using fascial dilators. The working sheath was retained, and the F8/9.8 ureteroscope was introduced alongside the sheath. Under television system monitoring, holmium laser lithotripsy was performed upon stone confirmation. Following stone identification, the forensic personnel employed holmium laser lithotripsy (Holmium Laser Fiber EZ200). After stone retrieval, a double-J stent (5F, 26 cm) was left in place, and an F16 silicone drainage tube was retained in the renal pelvis.

2.3. Nursing intervention measures

Ctrl group patients received routine nursing interventions, including: (1) preoperative routine examination: medical staff conducted a comprehensive examination and assessment of the patients, including medical history, physical examination, and necessary auxiliary examinations,to determine whether the patients were suitable for surgery and to provide strong support for the surgery; (2) explanation of knowledge on upper urinary tract stone disease and related surgical knowledge: medical staff introduced the relevant knowledge about upper urinary tract stone disease that the patient needed to know, as well as the surgical treatment plan for this disease, so that the patient and their family can fully understand the postoperative situation and coping strategies; (3) psychological counseling: medical staff provided psychological counseling for patients before surgery to alleviate their anxiety, nervousness, and other negative emotions caused by the surgery and help them better adapt to the surgical process; (4) cooperation with surgeons to complete surgical procedures: medical staff cooperated with surgeons to complete surgical procedures during surgery, timely delivering necessary items such as surgical instruments to the surgeons, ensuring smooth progress of the surgery; (5) introduction of postoperative precautions: medical staff provided detailed postoperative nursing knowledge to patients, including precautions in diet, rest, and medication use, and informed patients how to seek timely help if abnormal situations occur after surgery.

The Nur group was subjected to composite insulation intervention measures on the basis of routine care. The composite insulation methodology included: (1) during surgery, the temperature in the operating room may decrease due to personnel gathering, among other reasons. Nurses or other medical personnel can maintain a stable temperature in the operating room by adjusting the temperature of the air conditioning and adding heaters. A heater can be placed in the operating room and the wind speed adjusted to a gentle state to make the air flow more smoothly, while also increasing the humidity of the air and improving the patient's experience. The temperature should generally be maintained between 22 °C and 25 °C, and the humidity within the range of 40 %–60 %; (2) the day before surgery, medical personnel needed to place bagged isotonic saline solution and compound sodium chloride solution in a controllable constant temperature box, and adjusted the temperature to 37 °C. This was to ensure that the flushing solution and liquid were uniformly warm and close to the patient's body temperature, thereby reducing postoperative discomfort. The skin disinfectant was heated to around 40 °C, which can increase its penetration and improve its bactericidal efficiency, thereby reducing surgical risks; (3) to maintain the patient's body temperature stability, medical personnel can adopt various methodologies, such as covering the patient's limbs and trunk with an inflatable insulation blanket, and laying a 38 °C circulating water blanket under the patient's body to keep warm, while ensuring that the patient does not feel cold during the operation. During the operation, a 3L adhesive plaster commonly utilized in neurosurgery should be applied to the surgical field, with one plaster applied to each side of the waist. This can effectively prevent flushing solution leakage, surgical area contamination, cross-infection risks, and other issues.

2.4. Observation indexes

(1) General information, including age, gender, size of stones, preoperative hydronephrosis, and renal function, was analyzed.
(2) Observations were made regarding surgical duration, fragment extraction time, intraoperative blood loss, length of hospital stay, postoperative complications, and postoperative renal function.
(3) Patient temperature changes were monitored using nasal temperature measurement. Temperature data were recorded at specific time points, including upon admission (T0), before anesthesia (T1), 30 min after full anesthesia (T2), 60 min after full anesthesia (T3), 90 min after full anesthesia (T4), 120 min after full anesthesia (T5), and postoperatively (T6). Dynamic monitoring of core temperature during the surgical period was performed, and temperature was continuously measured using a monitor. Hypothermia was defined as a temperature below 36 °C.
(4) Intraoperative fluid volume recording was made. The amount of fluid and irrigation given to patients in both groups from admission to the end of surgery was recorded.
(5) Intraoperative blood pressure and heart rate monitoring were conducted as follows. Heart rate (HR), diastolic blood pressure (DBP), and systolic blood pressure (SBP) were recorded for both groups of patients at specific time points: upon entry to the operating room (T0), before anesthesia (T1), 30 min after full anesthesia (T2), 60 min after full anesthesia (T3), 90 min after full anesthesia (T4), and 120 min after full anesthesia (T5).
(6) Blood gas analysis was performed. pH value, base excess (BE), and lactate (LA) levels were analyzed at admission (T0), before anesthesia (T1), 30 min after spinal-epidural combined anesthesia (T2), 60 min (T3), 90 min (T4), and 120 min (T5).
(7) Anesthesia recovery time and extubationtimewere recorded for both groups of patients.

(8) Postoperative shivering was recorded. The occurrence of postoperative shivering symptoms was observed. The shivering assessment criteria were divided into 5 grades, with grade 4 indicating continuous and strong muscle activity, grade 3 indicating moderate muscle activity, grade 2 indicating mild muscle activity, grade 1 indicating peripheral vasoconstriction, and grade 0 indicating no shivering. Patients with grade 1 or above were considered to have experienced shivering.
(9) Postoperative complication rate was calculated. The incidence of postoperative complications such as infection and bleeding in both groups of patients was recorded.

2.5. Statistical methodologies

The data were analyzed using SPSS 22.0. Normally distributed continuous data were presented as means ± standard deviation and were compared using independent sample *t*-tests if the variances were homogeneous. Non-normally distributed continuous data were presented as $M(Q_1,Q_3)$ and were compared using Mann-Whitney U-tests. Categorical data were presented as percentages (%) and were compared using chi-square tests. Binary logistic regression analysis was adopted to identify the main factors affecting recurrence, with a significance level of $P < 0.05$ indicating statistical significance.

3. Results

3.1. Comparison of the general situation

A comparative analysis was performed on general demographic data for the Nur and Ctrl groups. The results are presented in Table 1. In the Nur group, there were 46 male patients (44.66 %), while the Ctrl group had 41 male patients (63.08 %). The difference in gender distribution between the two groups was statistically significant ($P < 0.05$). There were no statistically significant differences between the two groups in terms of age, weight, surgical duration, intraoperative fluid infusion, and irrigation fluid volume ($P > 0.05$).

3.2. Analysis of temperature changes in patients at various time periods

A sphericity test (Mauchly's test) was conducted to compare the temperature values of the two groups at various time points. The result indicated that the temperature values at various time points did not meet the assumption of sphericity ($P < 0.001$). The Greenhouse-Geisser correction was applied, and the repeated measures ANOVA was utilized to analyze the temperature values. The results revealed a marked main effect of time on the temperature values within groups ($F = 320.219$, $P < 0.001$), a notable interaction effect between time and group ($F = 110.293$, $P < 0.001$), and a considerable difference in temperature values between the intervention and Ctrl groups at various time points ($F = 3.995$, $P = 0.041$) (Table 2).

The temperature variations in both groups of patients at different time intervals are depicted in Fig. 1. As the surgical duration extended, patients in the Ctrl group exhibited a sharp decline in body temperature, whereas the Nur group patients generally maintained stable temperatures. At T0 and T1, the body temperatures of both Nur and Ctrl group patients were within the normal range, with a slight between-group difference ($P > 0.05$). Starting from T4, the Nur group patients' temperatures decreased to below 36 °C, remaining mildly hypothermic. At T2, T3, T4, T5, and T6, the body temperatures of Ctrl group patients were significantly lower than those of the Nur group ($P < 0.001$).

3.3. Comparison of incidence of intraoperative hypothermia between groups at various time periods

The overall incidence of hypothermia during the observation period was 61.17 % (63/103) in Ctrl group and 13.85 % (9/65) in Nur group, with a considerable difference between groups ($\chi^2 = 4.893$, $P = 0.029$). The overall incidence of hypothermia at various time points during the surgery is illustrated in Fig. 2. At T2, the incidence of hypothermia in Nur group was 0, which was inferior to the 7.77 % (8/103) in Ctrl group. At T3, the incidence of hypothermia in Nur group was 3.08 % (2/103), which was greatly inferior to the 14.56 % (15/103) in Ctrl group. At T4, T5, and T6, the incidence of hypothermia in Nur group was 6.15 % (4/103), 10.77 % (7/103), and 13.85 % (9/103), respectively, while the incidence in Ctrl group at the same time points was 26.21 % (27/103), 38.83 % (40/103), and

Table 1
Comparison of basic data of included objects.

Factor	Ctrl group (n = 103)	Nur group (n = 65)	χ^2/t	*P*
Gender [example (%)]			5.414	0.020*
Male	46 (44.66 %)	41 (63.08 %)		
Female	57 (55.33 %)	24 (36.92 %)		
Age (years old)	51.88 ± 6.34	46.72 ± 5.57	0.364	0.726
Body weight (Kg)	65.32 ± 7.24	64.46 ± 7.51	0.847	0.424
Operation time (min)	145.46 ± 12.11	146.03 ± 10.29	0.482	0.661
Infusion volume (mL)	1355.46 ± 139.75	1349.97 ± 148.47	0.268	0.792
Perfusion volume (mL)	17441.05 ± 4359.86	16864.76 ± 3839.42	1.029	0.063
Stone diameter (cm)	2.25 ± 0.28	2.54 ± 0.19	0.891	0.358

Note: $^*P < 0.05$ vs. Ctrl.

Table 2
Analysis of variance of repeated measurements of patient temperature after Greenhouse-Geisser correction.

Source of variation	SS	*df*	*MS*	*F*	*P*
Intergroup intervention factors	3.023	1	2.876	3.996	0.041
Intergroup error	67.928	93	0.743		
Intra-group time	13.013	1.952	6.609	320.219	<0.001
Interaction between intervention factors and time	4.532	1.952	2.164	110.293	<0.001
Intra-group error	3.827	190.37	0.019		

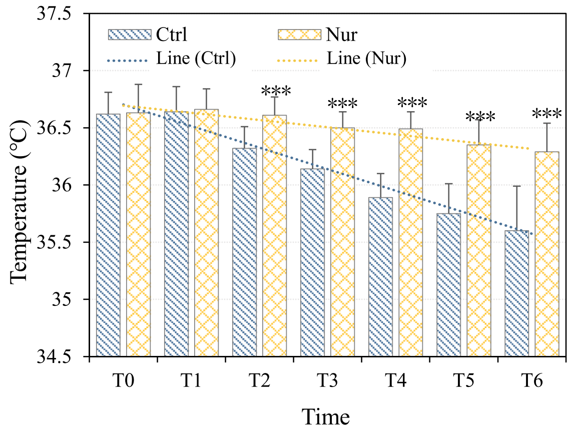

Fig. 1. Comparison of body temperature changes in two groups of patients at various time points. (***$P < 0.001$ vs. Ctrl.).

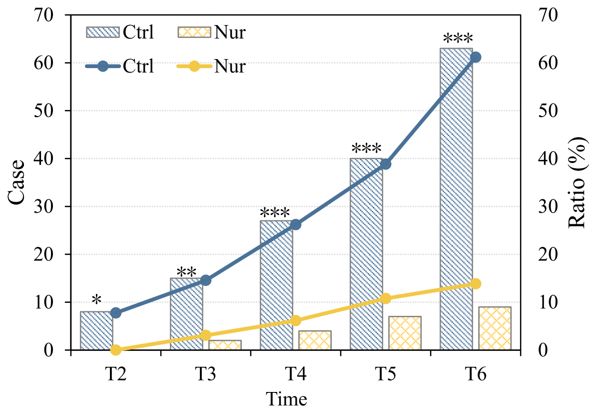

Fig. 2. Comparison of the incidence of intraoperative hypothermia in two groups at various time points. (*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$ vs. Ctrl.).

Table 3
Analysis of variance of repeated measures of patient HR after Greenhouse-Geisser correction.

Source of variation	SS	*df*	*MS*	*F*	*P*
Intergroup intervention factors	1.511	0.725	1.004	3.226	0.008
Intergroup error	15.421	42.023	1.021		
Intra-group time	11.258	0.853	0.265	21.930	<0.001
Interaction between intervention factors and time	0.125	2.012	1.011	0.257	0.924
Intra-group error	2.036	32.58	0.201		

61.17 % (63/103), respectively. The incidence of hypothermia in Nur group at T4, T5, and T6 was notably inferior to that in Ctrl group ($P < 0.001$).

3.4. Comparison of operation center rate between groups at various time periods

The results of the sphericity test indicate that the covariance matrix of the HR detection values at various time periods did not meet the assumption of sphericity ($P < 0.001$). Hence, a Greenhouse-Geisser correction was necessary when repeated measures analysis of variance was performed on the HR values of the two groups of patients at various time periods. The results revealed that for the HR values of the intervention and Ctrl group patients at various time periods, the within-group time effect was $F = 21.930$, $P < 0.001$, and the interaction effect was $F = 0.257$, $P = 0.924$. The HR values of the Int and Ctrl group patients differed considerably at various time periods ($F = 3.226$, $P = 0.008$) (Table 3).

According to the results presented in Fig. 3, there were notable differences in the intraoperative heart rate changes between the two patient groups. Throughout the entire observation period, patients in the Ctrl group exhibited an upward trend in heart rate, while the Nur group patients' heart rate remained relatively stable. At the time points T0 and T1, the heart rates of both Nur and Ctrl group patients were within the normal range, and the difference between the two groups was not significant ($P > 0.05$). However, at T2, T3, and T4, the heart rates of Ctrl group patients were significantly higher than those of the Nur group, with statistical significance ($P < 0.05$). At T5 and T6, the heart rates of Ctrl group patients were markedly higher than those of the Nur group ($P < 0.01$).

3.5. Comparison of intraoperative blood pressure between groups at various time periods

Based on the data illustrated in Fig. 4, there was a difference in the trend of intraoperative SBP changes between groups of patients. The SBP of Ctrl group patients showed a decreasing trend throughout the entire observation period, while the SBP of Nur group patients remained relatively stable. Nevertheless, inconsiderable difference was found in SBP between Ctrl and Nur groups during the T0~T6 period ($P > 0.05$).

The statistical results from Fig. 5 indicate that there was an overall decreasing trend in intraoperative DBP for both groups of patients. Nevertheless, the DBP differed slightly between Ctrl and Nur groups during the T0~T6 period ($P > 0.05$).

Comparison of blood gas indicators between the two groups at different time points:

The trends in blood gas indicators, including pH value, BE, and LA levels, differed between the two groups at different time points. In Fig. 6A, patients in the Ctrl group exhibited a decreasing trend in pH value throughout the entire observation period, while patients in the Nur group showed a slower decline, tending towards stability. Furthermore, during the time intervals T4 to T6, the pH value in the Ctrl group was lower than that in the Nur group ($P < 0.05$). In Fig. 6B, both Ctrl and Nur group patients demonstrated an increasing trend in LA levels throughout the observation period, albeit the rise in LA levels in the Nur group was more gradual. Additionally, during the time intervals T4 to T6, the LA levels in the Ctrl group were higher than those in the Nur group ($P < 0.05$). From Fig. 6C, it can be observed that both Ctrl and Nur group patients showed a decreasing trend in BE levels throughout the entire observation period, although the decline in BE levels in the Nur group was slower. Moreover, during the time intervals T4 to T6, the BE levels in the Ctrl group were lower than those in the Nur group ($P < 0.05$).

3.6. Comparison of intraoperative and postoperative related indexes

By comparing and analyzing the data of stone extraction time, intraoperative blood loss, anesthesia recovery time, extubation time, postoperative hospital stay, postoperative BUN, and postoperative Cre for patients in the Ctrl group and Nur group (Table 4), it was found that there were no statistically significant differences in stone extraction time, intraoperative blood loss, postoperative BUN, and postoperative Cre between patients in the Ctrl group and Nur group ($P > 0.05$) when comparing them pairwise. The anesthesia

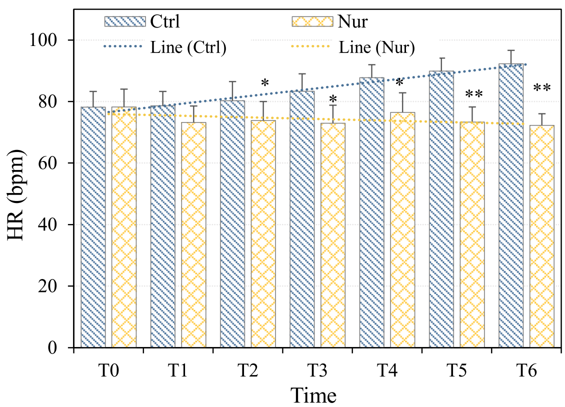

Fig. 3. Comparison of operation center rates of patients between groups in various time periods. (*$P < 0.05$, **$P < 0.01$ vs. Ctrl.).

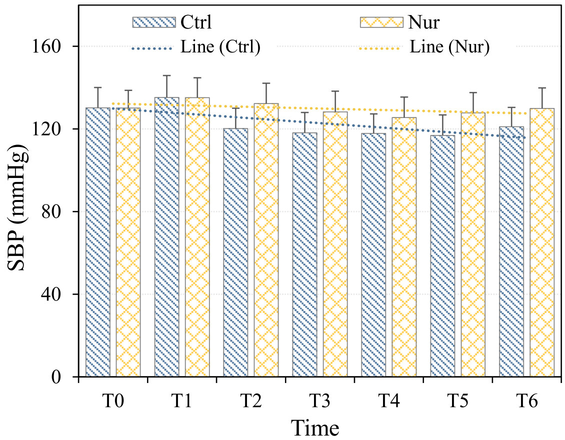

Fig. 4. Comparison of intraoperative SBP in two groups of patients at various time points.

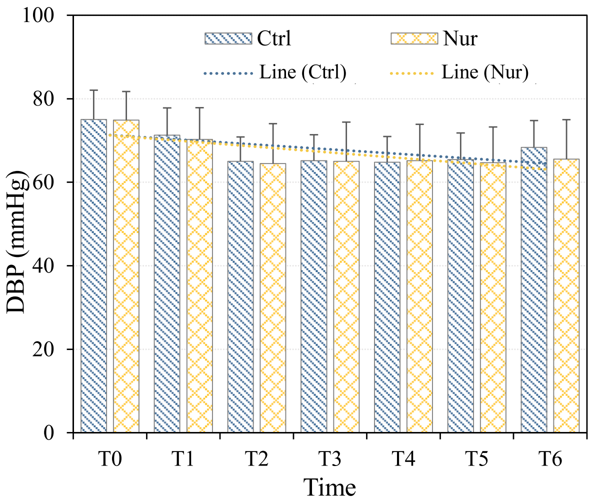

Fig. 5. Comparison of intraoperative DBP in two groups of patients at various time points.

recovery time for the Nur group was 18.36 ± 3.58 min, which was significantly lower than that of the Ctrl group (24.03 ± 3.97 min) ($P < 0.001$). The postoperative extubation time and hospital stay for the Ctrl group were 28.01 ± 3.12 min and 6.45 ± 2.14 days, respectively, while for the Nur group, they were 21.45 ± 3.29 min and 4.06 ± 1.33 days, respectively. The extubation time for the Nur group was significantly shorter than that of the Ctrl group ($P < 0.01$), whereas the postoperative hospital stay for the Ctrl group was longer than that of the Nur group, and this difference was statistically significant ($P < 0.05$).

3.7. Incidence of postoperative shivering and complications in two groups

The statistical results of the incidence of postoperative shivering and complications in Ctrl group and Nur group are illustrated in Table 5. The incidence of postoperative shivering in Ctrl group was 21.13 %, which was notably superior to the 4.62 % in Nur group ($P < 0.001$). There was an extremely marked difference in the proportion of patients with different levels of chills between groups ($P < 0.001$). The incidence rates of postoperative urinary fistula, bleeding, and infection in Ctrl group were 2.91 % (3/103), 5.83 % (6/103), and 4.85 % (5/103), respectively, while no patients with urinary fistula or infection were found in Nur group. One patient (1.54 %) in Nur group developed bleeding complications. The overall incidence rate of complications in Nur group was 13.59 % (14/103) and 1.54 % (1/65) respectively, and the overall incidence rate of complications in Nur group was remarkably inferior to that in Ctrl group ($P < 0.01$).

3.8. Analysis of risk factors of intraoperative hypothermia

A total of 72 patients experienced intraoperative hypothermia, while 96 patients did not. Clinical data of the two groups were collected and a univariate analysis was performed to compare the factors associated with intraoperative hypothermia (Table 6). The

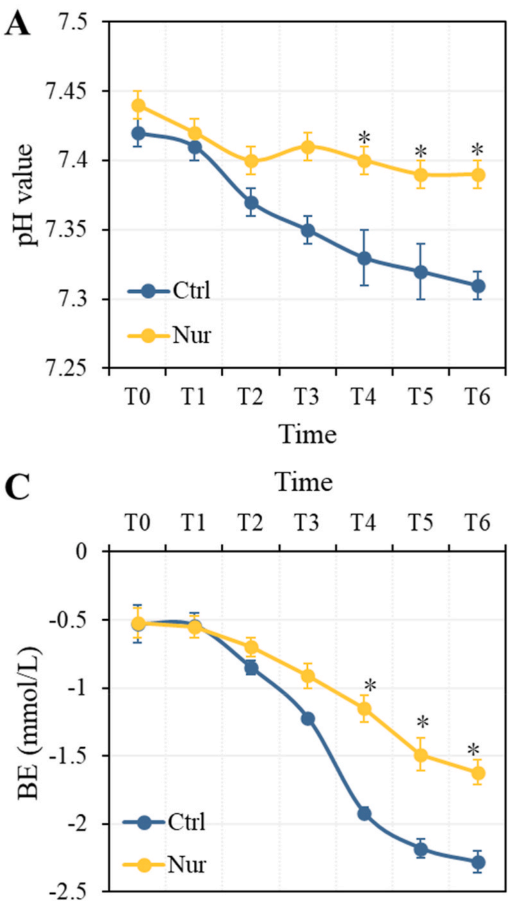

Fig. 6. Comparison of blood gas indicators between the two groups at different time points. (A: pH value; B: base excess; C: lactate levels) (*$P < 0.05$ vs. Ctrl.).

Table 4
Comparison of intraoperative and postoperative indexes between groups.

Factor	Ctrl group (n = 103)	Nur group (n = 65)	χ^2/t	*P*
Gravel removal time (min)	95.29 ± 18.17	97.51 ± 20.22	0.453	0.269
Intraoperative blood loss (mL)	52.48 ± 5.06	51.93 ± 5.72	0.287	0.785
Anesthesia recovery time (min)	24.03 ± 3.97	18.36 ± 3.58	3.493	0.001***
Postoperative extubation time (min)	28.01 ± 3.12	21.45 ± 3.29	3.196	0.003**
Hospital stay (d)	6.45 ± 2.14	4.06 ± 1.33	1.847	0.035*
Postoperative BUN (mmol/L)	4.78 ± 2.03	4.65 ± 1.52	0.256	0.661
Postoperative Cre (μmol/L)	80.19 ± 9.29	78.93 ± 12.45	0.459	0.715

Note: *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$ vs. Ctrl.

proportion of patients over 60 years old in the hypothermia group was 33.33 %, which was notably superior to that in the non-hypothermia group ($\chi^2 = 12.003$, $P = 0.001$). The hypothermia group had 28 patients (80.60 %) with stone diameter greater than 3.0 cm, which was superior to the 30.20 % in the non-hypothermia group ($\chi^2 = 39.777$, $P < 0.001$). The proportion of patients with infusion volume greater than 3,000 mL in the hypothermia group was 41.70 %, which was higher than the 22.90 % in the non-hypothermia group ($\chi^2 = 95.919$, $P = 0.015$). The proportion of patients in the hypothermia group who received composite insulation nursing intervention measures was 12.50 %, which was higher than the 58.30 % in the non-hypothermia group ($\chi^2 = 34.436$, $P < 0.001$). The average operation time in the hypothermia group was 173.55 ± 15.29 min, which was longer than the 130.14 ± 12.67 min in the non-hypothermia group ($t = 4.526$, $P = 0.018$).

Table 5
Comparison of intraoperative chills and complications between groups.

Factors	Ctrl group (n = 103)	Nur group (n = 65)	χ^2/Z	*P*
Occurrence rate of chills [n (%)]	30 (29.13 %)	3 (4.62 %)	18.426	<0.001
Chilling level [n (%)]			−3.856	<0.001
0 point	73 (70.87 %)	62 (95.38 %)		
1 point	18 (17.48 %)	2 (3.08 %)		
2 points	7 (6.80 %)	1 (1.54 %)		
3 points	5 (4.85 %)	0 (0.00 %)		
Complication [n (%)]			6.485	0.008
Urinary fistula	3 (2.91 %)	0 (0.00 %)		
Bleeding	6 (5.83 %)	1 (1.54 %)		
Infection	5 (4.85 %)	0 (0.00 %)		

Note: *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$ vs. Ctrl.

Table 6
Analysis of factors related to intraoperative hypothermia.

Factors	Hypothermia group (n = 72)	Non-hypothermic group (n = 96)	χ^2/t	*P*
Gender [cases (%)]			1.719	0.191
Male	37 (51.39 %)	50 (52.08 %)		
Female	35 (48.61 %)	46 (47.92 %)		
Age ≥60 years old	24 (33.33 %)	10 (10.42 %)	12.003	0.001**
Stone diameter (cm)			39.777	<0.001***
≥3.0	28 (80.60 %)	29 (30.20 %)		
Weight (Kg)	64.75 ± 8.13	65.03 ± 7.69	−0.363	0.722
Perfusion volume (mL)				
≥3000	30 (41.70 %)	22 (22.90 %)	95.919	0.015*
Intraoperative bleeding volume (mL)	52.15 ± 5.21	51.47 ± 6.53	0.127	0.914
Infusion volume (mL)	1341.87 ± 151.29	1329.03 ± 145.26	0.753	0.382
Preoperative urinary tract infection			0.268	0.605
Yes	33 (45.80 %)	39 (40.60 %)		
Composite insulation care			34.436	<0.001***
Yes	9 (12.50 %)	56 (58.30 %)		
Operative time (min)	173.55 ± 15.29	130.14 ± 12.67	4.526	0.018*
Intraoperative HR (times/min)	80.45 ± 4.93	75.36 ± 5.45	0.158	0.782
Intraoperative SBP (mmHg)	125.83 ± 9.82	128.54 ± 9.65	−0.856	0.364
Intraoperative DBP (mmHg)	67.87 ± 6.36	67.14 ± 8.59	−0.683	0.331
pH	7.38 ± 0.03	7.37 ± 0.02	0.163	0.825
BE (mmol/L)	−1.26 ± 0.12	−1.19 ± 0.23	0.695	0.414
LA level (mmol/L)	1.35 ± 0.26	1.40 ± 0.31	0.130	0.907

3.9. Binary logistic regression analysis of intraoperative hypothermia risk factors

Through a univariate analysis, it was found that the main factors related to intraoperative hypothermia in patients undergoing complex PCNL were age ≥60 years, stone diameter ≥3.0 cm, infusion volume ≥3000 mL, nursing intervention measures, and surgery time. Using each of these influencing factors as independent variables, a logistic multivariate regression analysis was performed on intraoperative hypothermia in patients undergoing complex PCNL, and the results are illustrated in Table 7. Age ≥60 years (OR = 0.565, 95 % CI: 0.296–0.927), stone diameter ≥3.0 cm (OR = 1.226, 95 % CI: 1.1024–1.537), infusion volume ≥3000 mL (OR = 2.028, 95 % CI: 1.149–3.494), nursing intervention measures (OR = 0.829, 95 % CI: 0.774–0.996), and operation time (OR = 1.029, 95 % CI: 1.003–1.547) were all found to be correlated with intraoperative hypothermia in patients undergoing complex PCNL ($P < 0.05$). Among them, nursing intervention measures were the most notable factor related to intraoperative hypothermia in patients undergoing complex PCNL ($P < 0.01$). Hence, age ≥60 years, stone diameter ≥3.0 cm, infusion volume ≥3000 mL, nursing intervention measures, and surgery time were the main risk factors for intraoperative hypothermia in patients undergoing complex PCNL, and can be utilized as risk indicators for intraoperative hypothermia in these patients.

Table 7
Logistic regression analysis of risk factors of hypothermia in patients undergoing complicated PCNL.

Factor	Regression coefficient	Standard error	Wald χ^2	OR	95%CI	*P*
Age ≥60 years old	−0.987	0.296	1.378	0.565	0.296–0.927	0.042
Stone diameter ≥3.0 cm	0.219	0.153	5.982	1.226	1.024–1.537	0.036
Perfusion volume ≥3000 mL	0.246	0.192	6.019	2.028	1.149–3.494	0.028
Nursing intervention	−0.029	0.234	11.014	0.829	0.774–0.996	0.003
Operation time	0.026	0.008	5.231	1.029	1.003–1.547	0.021

3.10. Analysis of risk factors for postoperative shivering occurrence

There was a total of 33 cases of postoperative shivering occurrence and 135 cases without hypothermia. Clinical data of the two groups were analyzed, and univariate comparisons of postoperative shivering were conducted (Table 8). In the shivering group, patients aged over 60 years accounted for 54.55 %, significantly higher than the 11.85 % in the non-shivering group ($\chi^2 = 10.952$, $P < 0.001$); the proportion of patients receiving combined insulation measures in the shivering group was 15.15 %, lower than the 58.30 % in the non-shivering group ($\chi^2 = 12.661$, $P < 0.001$); the proportion of patients with intraoperative temperature below 36 °C in the shivering group was 66.67 %, higher than the 37.04 % in the non-shivering group ($\chi^2 = 10.129$, $P < 0.001$); the average surgical duration in the shivering group was 172.93 ± 14.99 min, higher than the 128.19 ± 13.56 min in the non-shivering group ($t = 5.113$, $P = 0.012$).

3.11. Binary logistic regression analysis of risk factors for postoperative shivering occurrence

Through univariate analysis, the main factors associated with postoperative shivering in patients undergoing complex percutaneous nephrolithotomy were identified as: age ≥60 years, nursing intervention measures, intraoperative temperature, and surgical duration. Using each factor as an independent variable, a logistic multivariate regression analysis was conducted to explore postoperative shivering in patients undergoing complex percutaneous nephrolithotomy, as shown in Table 9. Results revealed that age ≥60 years (OR = 4.015, 95 % CI: 3.194–9.783), nursing intervention measures (OR = 1.812, 95 % CI: 1.313–8.484), surgical duration (OR = 1.422, 95 % CI: 1.056–6.525), and intraoperative temperature<36 °C (OR = 3.051, 95 % CI: 2.294–7.606) were all significantly correlated with postoperative shivering in patients undergoing complex percutaneous nephrolithotomy ($P < 0.05$). Therefore, age ≥60 years, nursing intervention measures, surgical duration, and intraoperative temperature<36 °C were the main risk factors for postoperative shivering in patients undergoing complex percutaneous nephrolithotomy, serving as potential indicators of postoperative shivering risk in these patients.

4. Discussion

Body temperature is a crucial vital sign that must be maintained within a specific range to ensure normal human metabolism. Hypothermia refers to abnormally low body temperature, often resulting from various factors during the perioperative period [15]. Studies have shown that approximately 50 %–70 % of patients experience varying degrees of hypothermia [16]. Hypothermia is a common occurrence during surgery, and it not only reduces a patient's physiological resistance but also increases the risk of postoperative complications [17]. Once perioperative hypothermia sets in, it takes at least 4 h after anesthesia cessation for body temperature to recover [18]. Current research indicates that factors such as anesthesia, patient anxiety, fear, psychological factors, operating room temperature, and the temperature of infused fluids are all correlated with intraoperative hypothermia in patients [19]. However, there are differing research findings and debates on this topic. Therefore, paying attention to the occurrence of intraoperative hypothermia in patients and implementing relevant nursing intervention measures is of significant importance. In the Nur group, the average intraoperative body temperature was higher than that in the Ctrl group ($P < 0.001$), and the overall incidence of hypothermia was 13.85 %, significantly lower than the 61.17 % in the Ctrl group ($\chi^2 = 4.893$, $P = 0.029$). These study findings indicate that the implementation of comprehensive thermal care measures can significantly reduce the incidence of intraoperative hypothermia in patients undergoing complex PCNL, effectively maintaining their normal intraoperative body temperature. Current research suggests that 60 %–90 % of patients experience inadvertent hypothermia in the operating room environment [20], while maintaining the operating room temperature above 24 °C can prevent hypothermia in patients [21]. This study, based on current research results, involved adjusting the operating room temperature to a range of 22–25 °C during the nursing intervention process, enhancing air circulation and increasing air humidity to improve patient comfort. Research by Cibinel et al. (2021) [22] suggested that, independent of patient age, adjusting the operating room temperature to around 26 °C is an effective measure for preventing the occurrence of hypothermia in patients. Simultaneously, some studies have indicated that it is challenging to maintain operating room temperatures above 26 °C, as higher temperatures can cause discomfort among medical staff [23]. During the implementation of comprehensive thermal care interventions in this study, the skin disinfectant was warmed to approximately 40 °C, which enhances its penetrative capabilities and improves its bactericidal efficiency, consequently reducing surgical risks. The day before surgery, the irrigation solution and compound sodium chloride solution were placed in an adjustable constant temperature chamber and adjusted to a temperature close to that of the patient's body, thereby preventing external fluids from affecting the patient's temperature stability. According to reports [24], preheating the surgical irrigation solution to 37 °C and using devices such as a temperature-controlled heater, warming cabinet, or blood product warmer to heat fluids and blood products administered to the patient to 37 °C can effectively prevent intraoperative hypothermia. Jin et al. (2020) [25] found that during PCNL procedures, 78 % of patients experience significant absorption of irrigation fluid, which is one of the key factors contributing to a decrease in body temperature. Therefore, warming the irrigation solution, intravenous fluids, and blood products is one of the effective methods for preventing hypothermia during PCNL. In this study, inflatable thermal blankets were used to cover the patient's limbs and trunk, and a circulating water blanket at 38 °C was placed under the patient to provide warmth, ensuring that the patient did not experience cold during the surgical procedure. The use of a 3L dressing effectively prevented the leakage of irrigation fluid, thereby reducing the risk of contamination in the surgical area and the occurrence of cross-infections.

Postoperative shivering is attributed to reduced body temperature and the vasoconstriction of arteriovenous shunts [26]. Factors such as inadequate air circulation in the operating room or exposure of surgical sites to cold conditions during the procedure can

Table 8
Analysis of risk factors for postoperative shivering occurrence.

Factors	Shivering group (n = 33)	Non-shivering group (n = 135)	χ^2/t	*P*
Gender [cases (%)]			0.782	0.376
Male	20 (60.61 %)	85 (62.96 %)		
Female	13 (39.39 %)	50 (37.04 %)		
Age ≥60 years	18 (54.55 %)	16 (11.85 %)	10.952	<0.001***
Stone diameter (cm)			1.023	0.365
≥3.0	12 (36.33 %)	45 (33.33 %)		
Weight (Kg)	65.11 ± 7.29	64.92 ± 6.84	0.289	0.644
Irrigation volume (mL)				
≥3000	10 (30.30 %)	42 (31.11 %)	0.824	0.965
Intraoperative blood loss (mL)	51.98 ± 4.98	51.62 ± 5.85	0.135	0.857
Fluid infusion volume (mL)	1338.59 ± 120.14	1325.46 ± 123.52	0.785	0.142
Preoperative urinary tract infection			0.303	0.598
Yes	14 (42.42 %)	55 (40.74 %)		
Combined insulation nursing			12.661	<0.001***
Yes	5 (15.15 %)	60 (44.44 %)		
Intraoperative temperature			10.129	<0.001***
<36 °C	22 (66.67 %)	50 (37.04 %)		
Surgical duration (min)	172.93 ± 14.99	128.19 ± 13.56	5.113	0.012*
Intraoperative HR (beats/min)	79.85 ± 6.01	77.45 ± 6.55	0.172	0.803
Intraoperative SBP (mmHg)	126.63 ± 11.52	127.95 ± 13.67	−0.926	0.406
Intraoperative DBP (mmHg)	68.01 ± 5.42	67.26 ± 6.77	0.716	0.325
pH value	7.36 ± 0.03	7.37 ± 0.01	0.521	0.932
BE (mmol/L)	−1.24 ± 0.14	−1.20 ± 0.19	0.702	0.401
LA levels (mmol/L)	1.36 ± 0.27	1.41 ± 0.33	0.141	0.917

Table 9
Binary logistic regression analysis of risk factors for postoperative shivering occurrence.

Factors	Regression coefficient	Standard error	Wald χ^2	OR	95 % CI	*P*
Age ≥60 years old	−1.356	0.416	10.529	4.015	3.194–9.783	0.037
Nursing intervention measures	0.603	0.826	14.085	1.812	1.313–8.481	0.028
Surgical duration	0.365	0.278	10.396	1.422	1.056–6.525	0.034
Intraoperative temperature<36 °C	1.117	0.333	11.243	3.051	2.294–7.606	0.041

stimulate the body with cold stress, leading to the initiation of shivering responses [27]. Postoperative use of analgesics and sedatives may influence the body's central thermoregulation and vascular dilation, potentially resulting in postoperative shivering [28]. During surgery, severe blood loss can lead to a rapid reduction in red blood cells, impacting the body's metabolic levels and temperature regulation capabilities. This, in turn, can cause circulatory dysfunction and potentially serious consequences such as acidosis [29]. Postoperative patients may experience fear of the surgical outcome, leading to feelings of anxiety and apprehension, which can trigger sympathetic nervous system responses and further exacerbate shivering [30]. The results revealed that the shivering incidence in the Ctrl group was 21.13 %, significantly higher than the 4.62 % in the Nur group ($P < 0.001$), and there was an extremely significant difference in the distribution of patients across different shivering grades between the two groups ($P < 0.001$). The overall incidence of postoperative complications in the Nur group was significantly lower than that in the Ctrl group ($P < 0.01$). This suggests that comprehensive nursing intervention measures can effectively reduce the incidence of postoperative shivering and complications in patients, which is consistent with the findings of Tang et al. (2018) [31]. Current research results indicated that intraoperative thermal care measures help to reduce the range of temperature fluctuations during and after surgery, maintaining the stability of patients' body temperature [32]. Increasing the room temperature in the operating theater and enhancing local thermal care in the surgical area can prevent heat dissipation from the body surface and slow down heat loss. Ensuring that patients wear devices like warm-water bags before surgery can raise the patient's body surface temperature, increase thermal reserves, and mitigate intraoperative temperature decline. Rational control of fluid output and medication use, particularly the frequency and dosage of cooling medications, can also alleviate intraoperative temperature decline [33]. Enhancing intraoperative nursing measures, such as actively massaging patients to stimulate heat production from the body surface and raise body temperature, can further reduce the incidence of intraoperative hypothermia [34]. In this study, the use of comprehensive thermal care measures in the Nur group significantly improved the quality and safety of surgical nursing, effectively reducing unnecessary risks and lowering the risk of postoperative complications.

Current research findings indicated that factors contributing to intraoperative hypothermia during PCNL for kidney stone treatment include anesthesia-related factors and the impact of fluids [35]. General anesthesia lowers the patient's thermoregulatory threshold and the administration of medications can lead to muscle relaxation, reducing the inhibitory effect on shivering [36]. Inadequate fluid temperature can result in "cold dilution", causing a significant drop in body temperature. The use of large volumes of irrigation fluid can induce hemodynamic changes, leading to heat loss within the body and the onset of hypothermia [37]. In this study, factors influencing intraoperative hypothermia in patients undergoing complex PCNL were used as independent variables. A logistic multivariable regression analysis was performed on intraoperative hypothermia. The results revealed that age ≥60 years (OR

= 0.565, 95 % CI: 0.296–0.927), stone diameter ≥3.0 cm (OR = 1.226, 95 % CI: 1.1024–1.537), irrigation volume ≥3000 mL (OR = 2.028, 95 % CI: 1.149–3.494), nursing interventions (OR = 0.829, 95 % CI: 0.774–0.996), and miRNA-27b (OR = 1.029, 95 % CI: 1.003–1.547) were all correlated with the occurrence of intraoperative hypothermia in patients undergoing complex PCNL ($P < 0.05$). These research findings indicated that age ≥60 years, stone diameter ≥3.0 cm, irrigation volume ≥3000 mL, nursing interventions, and surgery duration are the main risk factors for the occurrence of intraoperative hypothermia in patients undergoing complex PCNL. Elderly individuals often experience reduced physiological functioning and weakened immunity, making them more susceptible to the effects of low-temperature environments, which can result in lower body temperature or slower recovery. Therefore, when performing PCNL in elderly patients, physicians need to closely monitor intraoperative body temperature and adjust surgical procedures accordingly while paying special attention to temperature regulation in patients. During PCNL, patients receiving airway anesthesia and bladder irrigation need to empty their bladders for the surgical procedure and simultaneously require a significant infusion of fluids to maintain a normal bladder environment. However, in cases involving larger stones, longer surgical durations, and increased surgical complexity, disruptions in the body's temperature regulation can be anticipated, leading to intraoperative hypothermia in patients. To minimize the occurrence of intraoperative hypothermia, healthcare professionals must closely monitor changes in patients' positioning, blood pressure, blood oxygen levels, and promptly adjust room temperature and anesthesia dosage to maintain stable body temperature. In addition, for patients with larger stones, a thorough preoperative assessment of their condition is essential, and appropriate warming measures, such as the use of blankets, should be employed to assist in maintaining warmth and reduce the risk of intraoperative hypothermia. During PCNL, to achieve a clear view of the surgical area and minimize surgical risks, a certain volume of fluid irrigation is sometimes used. However, prolonged irrigation with fluids can lead to an excess of bodily fluids and excessive heat production during metabolism, which places a burden on the body's temperature regulation and increases the risk of intraoperative or postoperative temperature decrease. Nursing interventions are one of the influencing factors for the occurrence of intraoperative hypothermia in patients undergoing PCNL. PCNL is a minimally invasive surgery effective in treating conditions like kidney stones and urinary tract stones. During this procedure, patients are under general anesthesia, and the use of surgical equipment for cooling irrigation solutions can lead to a drop in body temperature, thereby increasing the risk of intraoperative hypothermia. In general, factors such as the prolonged duration of PCNL, high surgical complexity, and the occurrence of complications during the procedure may elevate the risk of intraoperative hypothermia in patients.

5. Conclusions

The risk factors for intraoperative hypothermia and postoperative shivering in complex PCNL patients during the perioperative period were analyzed,and the effects ofcomposite insulation nursing interventions were explored. The results revealed that age ≥60 years, stone diameter ≥3.0 cm, irrigation volume ≥3000 mL, nursing interventions, and operation time were the main risk factors for intraoperative hypothermia in complex PCNL patients. Thecomposite insulation nursing interventions were effective in reducing the incidence of intraoperative hypothermia, postoperative shivering, and complications in complex PCNL patients. Nevertheless, we did not analyze the clinical and biochemical indicators of patients. Future work will further analyze the relevant biochemical and clinical indicators of intraoperative hypothermia in complex PCNL patients. In conclusion, composite insulation nursing interventions have certain adoption value in the nursing of complex PCNL, and this study identified independent risk factors for intraoperative hypothermia in complex PCNL patients, providing clinical reference for the nursing and prognosis of complex PCNL patients.

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Ethics and consent

This study has been approved by the Ethics Approval Committee of Shenzhen Hospital of the University of Hong Kong with the approval number Len [2020]248. The approval date is February 8, 2020. At the same time, all experimental processes of the study were in accordance with the accreditation of relevant parts, and the informed consent of all participants was obtained.

Data availability statement

All data generated or analyzed during this study are included in this published article [and its supplementary information files].

CRediT authorship contribution statement

Yangxi Shen: Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis. **Xin Zhong:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e32126.

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