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Original Article

Effects of Lithotomy and Prone Positions on Hemodynamic Parameters, Respiratory Mechanics, and Arterial Oxygenation in Percutaneous Nephrolithotomy Performed under General Anesthesia

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Abstract

Aim: The position of the body during surgery may affect the patient's body functions, especially the hemodynamic parameters. We aimed to comparatively analyze the effects of lithotomy and prone position on respiratory mechanics, arterial oxygenation, and hemodynamic parameters in patients who underwent percutaneous nephrolithotomy (PNL).

Materials and methods: The study included 40 patients aged 16-63 years who underwent kidney stone surgery. The patients had no history of diabetes or cardiopulmonary disease and had an American Society of Anesthesiology (ASA) score of I–II. The pH, partial arterial oxygen pressure, partial arterial carbon dioxide pressure, HCO_3, arterial oxygen saturation, end-tidal carbon dioxide ($EtCO_2$), alveolar oxygen partial pressure, dead space volume/tidal volume ratio, $P(A\text{-}a)O_2$, peak inspiratory pressure (PIP), inspiratory plateau airway pressure (PPlt), systolic arterial pressure, diastolic arterial pressure, mean arterial pressure, and heart rate (HR) values were assessed simultaneously throughout the surgery and comparatively analyzed both for lithotomy and prone positions.

Results: There was a significant difference between lithotomy and prone positions with regard to pH and HCO_3 values, which are among the arterial blood gas parameters measured at 20 minutes ($p<0.05$ and $p<0.001$, respectively). There was a significant difference between lithotomy and prone positions with regard to $EtCO_2$, PIP, PPlt, and HR measured at 20 minutes ($p<0.05$, $p<0.001$, $p<0.001$, and $p<0.05$, respectively).

Conclusions: The prone position decreased dynamic and static compliance and increased the PIP and PPlt values in patients undergoing PNL. However, these changes do not have a negative effect on the hemodynamic parameters in low-risk patients.

Keywords

nephrolithotomy, percutaneous, prone position, respiratory mechanics, tidal volume

INTRODUCTION

Percutaneous nephrolithotomy (PNL), a minimally invasive method, has become one of the most preferred methods for treating kidney stones in recent years[1]. Percutaneous nephrolithotomy is often performed under general anesthesia and in the prone position. Prior to percutaneous access, the patient is placed in a lithotomy position and a ureter catheter is inserted. Afterward, the patient is changed to the prone position and percutaneous intervention is performed.

It is difficult to find a position that will facilitate the surgical approach but will not jeopardize cardiovascular and pulmonary functions. Surgical position can affect many body functions, such as the arterial blood gas. Thanks to the developments in monitoring and ventilator technologies, it has become easier to follow positional changes more closely and to perform rapid interventions when complications arise. The prone position is frequently used to improve oxygenation in the treatment of acute respiratory failure.[2] However, some different issues can arise when the patient is placed in a prone position. Increased pressure on the anterior structures of the chest and abdomen can result in complications associated with reduced abdominal and respiratory compliance, compression of the orbits and vital organs, and hemodynamic changes that require close monitoring.[3] In addition, risky conditions such as peripheral edema, oliguria, and hypertension may occur in patients.[4] These risks lead to more serious consequences, particularly in individuals with low cardiac reserve or peripheral circulatory failure. Supine PNL has been reported to have some advantages over prone PNL in terms of some hemodynamic changes (less hypotension and less fluid absorption).[5] Although there is some data on the comparison of different positions in separate surgeries, we have very limited information about the effects of different positions within the same surgery.

AIM

In the present study, we aimed to comparatively analyze the effects of lithotomy and prone position on respiratory mechanics, arterial oxygenation, and hemodynamic parameters in patients who underwent PNL. In this way, changes and problems arising from the position are prevented earlier and will be managed more successfully.

MATERIALS AND METHODS

Study design

The study included 40 patients aged 16–63 years who underwent kidney stone surgery in an endourology operating room of a tertiary referral center (XXX Training and Research Hospital, XXX). All the patients had no previous diabetes or cardiopulmonary disease and had an ASA score of I-II. Patients who developed intraoperative complications and those who had an ASA score of >II, were younger than 16 years or older than 65 years, had a previously known cardiopulmonary disease, Reynaud's disease, Buerger's disease, prior thoracic surgery, and a negative Modified Allen Test were excluded from the study. Preoperative demographic characteristics were recorded for each patient.

The hemodynamic parameters - systolic arterial pressure (SAP), diastolic arterial pressure (DAP), mean arterial pressure (MAP), and heart rate (HR), and respiratory parameters - pH, partial arterial oxygen pressure (PaO_2), partial arterial carbon dioxide pressure ($PaCO_2$), bicarbonate (HCO_3), arterial oxygen saturation (SaO_2), end-tidal carbon dioxide ($EtCO_2$), alveolar oxygen partial pressure (pAO_2), dead space volume/tidal volume (VD/VT ratio), alveolar-arterial oxygen tension difference ($P[A-a]O_2$), peak inspiratory pressure (PIP), and inspiratory plateau airway pressure (PPlt) were recorded for both the lithotomy position and the prone position, and their values at 20 minutes were comparatively analyzed.

Preoperative assessment

Each patient underwent a thorough examination the day before surgery, which included the patient's medical history, physical examination, vital signs, and laboratory measurements. All laboratory tests, including complete blood count (CBC), coagulation parameters, electrolyte values, liver enzyme values, blood urea nitrogen (BUN), creatinine, fasting blood glucose, and total bilirubin, were performed using standard methods. The Modified Allen Test was applied to all patients prior to surgery.[6]

Anesthesia technique

As a premedication, 0.25 mg/kg intravenous midazolam (Dormicum®; Roche, Basel, Switzerland) was administered. Routine monitoring, including electrocardiography (ECG), pulse oximetry, and noninvasive blood pressure measurement, was performed on each patient. Initial values of HR, blood pressure (BP), and peripheral oxygen saturation (SpO_2) were assessed. For preoxygenation, patients were given 100% oxygen with a mask for three minutes. Anesthetic induction was performed with intravenous injections of 7 mg/kg thiopental (Pentothal®; Abbott Laboratories, Irving, TX, USA), 2 µg/kg fentanyl citrate (Fentanyl®; Hospira, IL, USA), and 0.6 mg/kg rocuronium (Esmeron®; N.V. Organon, Oss, Holland). Anesthesia was maintained with 1% sevoflurane (Sevoflurane Baxter®; Baxter Healthcare Corporation, Deerfield, IL, USA) in an anesthetic mixture of 40% O_2 and 60% N_2O. Mechanical ventilation was conducted at a rate of 12 breaths/min, with an inspiration/expiration ratio of 1:2 and a tidal volume of 8 ml/kg.

Radial artery cannulation was performed in each patient using a 20G intravenous cannula. At the 20th minute after general anesthesia, when the patients were still in the lithotomy position, arterial blood gas, HR, BP (systolic and diastolic), SpO_2, PIP, PPlt, and $ETCO_2$ were recorded, which were accepted as the first measurements of the study. After placing the patients in the prone position at 20 minutes, arterial blood gas and the other parameters were measured and accepted as the second measurements of the study. The VD/VT ratio and P(A-a) O_2 values were calculated for both positions. During surgery, the additional analgesic requirement was met with 1 µg/kg fentanyl when the sudden increase in HR and BP values did not respond to the 50% increase in inhalation agent concentration. The BP, HR, and SpO_2 levels were measured and recorded throughout general anesthesia.

The drugs used in anesthetic maintenance were stopped after the surgical procedure was completed while the patient was in the supine position, and ventilation was initiated with 100% O_2. After the initiation of spontaneous breathing, 0.01 mg/kg atropine sulfate (Atropine®; Pfizer, USA) and 0.04 mg/kg neostigmine methylsulfate (Neostigmine®; AstraZeneca, Sweden) were administered. When spontaneous breathing was sufficient, the endotracheal tube was removed.

Statistical analysis

Data analysis was performed using the Number Cruncher Statistical System (NCSS, 2007) and Power Analysis and Sample Size Statistical Software (PASS, 2008, Utah, USA). Descriptives were presented using descriptive statistical methods (mean, standard deviation, median, frequency, and ratio). In group comparisons of parameters showing normal distribution, the repeated measures test was used in triplicate measurements and the Bonferroni test was used in paired comparisons. A paired sample *t*-test was used for the evaluation of duplicate parameters. A Wilcoxon signed-rank test was used to evaluate the P(A-a)O_2 parameter as it did not show a normal distribution. All results were evaluated at a 95% confidence interval (CI) and a *p*-value of <0.05 and <0.01.

RESULTS

The mean age of patients was 44.18±10.81 years. Sixty-five percent of the patients had an ASA score of I and 35% of them had an ASA score of II **(Table 1)**. Arterial blood gas measurements are shown in **Table 2**. There was a significant difference between lithotomy and prone positions with regard to pH and HCO_3 values measured at 20 minutes (7.40±0.03 vs. 7.39±0.04, p=0.024; and 23.03±1.19 vs. 22.53±1.42, p=0.024 and p<0.001, respectively).

Measurements of ventilation and hemodynamic parameters are shown in **Table 3**. There was a significant difference between lithotomy and prone positions with regard to $EtCO_2$, PIP, PPlt, and HR measured at 20 minutes (p=0.017, p<0.001, p<0.001, and p=0.039, respectively).

DISCUSSION

We compared both positions based on the hypothesis that there may be significant changes with regard to hemodynamic parameters, respiratory mechanics, and arterial oxygenation in lithotomy and prone positions during PNL,

Table 1. Demographic characteristics and ASA scores of the patients

Age, (years) mean±SD	44.18±10.81
Gender	
Male, n (%)	22 (55%)
Female, n (%)	18 (45%)
Weight, (kg) mean±SD	75.85±14.46
BMI, mean±SD	27.90±5.49
ASA score	
ASA I, n (%)	26 (65%)
ASA II, n (%)	14 (35%)

SD: standard deviation; BMI: body mass index

Table 2. Arterial blood gas measurements

Parameters	20th minute in lithotomy position mean ± SD	20th minute in prone position mean ± SD	*p*
pH	7.40±0.03	7.39±0.04	0.024*
PaO_2 (mmHg)	171.95 ±35.15	174.83±31.79	0.384
$PaCO_2$ (mmHg)	37.52±3.75	37.35±3.85	0.633
HCO_3 (mmol/L)	23.03±1.19	22.53±1.42	<0.001*
SaO_2 (%)	98.95±0.57	98.92±0.48	0.736
pAO_2 (mmHg)	238.48±4.88	238.29±4.86	0.767
P(A-a)O_2 (mmHg)	66.43±34.13	62.97±34.12	0.245

PaO_2: partial arterial oxygen pressure; $PaCO_2$: partial arterial carbon dioxide pressure; SaO_2: arterial oxygen saturation; pAO_2: alveolar oxygen partial pressure; *Wilcoxon signed-rank test: There was a significant difference with regard to pH and HCO_3

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Table 3. Ventilation and hemodynamic parameters

Parameters	20th minute in lithotomy position	20th minute in prone position	*p*
$EtCO_2$ (mmHg)	31.25±2.67	30.58±2.47	0.017*
VD/VT	0.16±0.06	0.17±0.07	0.208
PIP (cmH_2O)	18.33±3.67	22.18±4.25	<0.001**
PPlt (cmH_2O)	17.50±3.34	20.90±3.89	<0.001**
MAP (mmHg)	91.18±13.66	94.17±16.54	0.839
HR	80.47±14.19	78.53±13.55	0.039**

$EtCO_2$: end-tidal carbon dioxide; VD: dead space volume; VT: tidal volume; PIP: peak inspiratory pressure; PPlt: inspiratory plateau airway pressure; MAP: mean arterial pressure; HR: heart rate; **Wilcoxon signed rank test: There was a significant difference with regard to $EtCO_2$, PIP, PPlt, and HR

and we found that there were significant changes between the two positions with regard to PH, HCO_3, $EtCO_2$, PIP, PPlt, and HR.

For diagnostic and therapeutic applications in anesthesia, surgery, and intensive care, knowing the effect of surgical positions and general anesthesia on arterial blood gas and respiratory parameters is highly important. Position changes can affect the pulmonary blood circulation due to the effect of gravity.[7] It has been shown that while gravity is more effective in the lateral position, it has less effect in the prone position.[8] West et al. attributed a mechanism governing the distribution of pulmonary flow to gravity-induced differences in hydrostatic pressures that affect regional vascular resistance and blood flow.[9] Additionally, Glenny et al. found that vascular anatomy was the most important determinant of regional pulmonary blood flow and that gravity was an important but secondary determinant.[10] On the other hand, Wieslander et al. claimed that the effect of gravity on body position changes was related to gravity-related changes in pulmonary vein distension rather than pulmonary artery distension.[7]

Prone position therapy is a complementary strategy for the treatment of acute respiratory distress syndrome (ARDS) with lung-protective ventilation. Compared to the supine position, the prone position provides more homogeneous ventilation and perfusion.[11,12] Guérin et al. showed a significant improvement in oxygenation in patients with an average PaO_2/FiO_2 value of 100 mmHg.[13] In addition to the positive effects of the prone position on oxygenation in patients with lung damage, many studies have shown that there will be no change in oxygenation with the prone position in individuals with healthy lungs.[14-16] Similarly, our study also consisted of ASA I-II patients and found no significant difference between the two positions with regard to PaO_2. However, in patients operated on under general anesthesia, the prone position is considered to be associated with an increased incidence of many complications, particularly airway-related complications.[17]

During the prone position, $PaCO_2$ may remain unchanged, increase, or even decrease. The changes in $PaCO_2$ depend on the behavior of alveolar ventilation and its ratio to the total ventilated lung volume.[18] A decrease in $PaCO_2$ means a decrease in dead space. The decrease in $PaCO_2$ has been clearly demonstrated after the reduction of dead space in ARDS patients.[19] In a study conducted on patients who underwent cervical spine surgery in the prone position, it was shown that $PaCO_2$ and $EtCO_2$ decreased significantly without considerable hemodynamic changes.[20] Since the patients included in our study did not have lung problems, no significant decrease was found in $PaCO_2$ values. Intagliata et al. and Zhang et al. also showed that there was no significant difference in $PaCO_2$ levels in both supine and prone positions.[21,22]

It has been shown that the cardiac output measured 15 minutes after placing a patient in the prone position is lower than the values measured in the supine position.[23] The lower measurement of $EtCO_2$ value in the prone position shown in our study was attributed to low cardiac output. The relationship between $EtCO_2$ value and cardiac output is known. It is considered that decreased cardiac output in the prone position may be due to a decreased HR rather than a decreased preload or increased afterload.[24] On the other hand, Ragheb et al. reported that there was no significant difference between the supine and prone positions regarding $EtCO_2$.[25]

Musti et al. reported that there was no significant change in MAP and HR values after the patients were placed in the prone position.[26] On the other hand, Lee et al. reported that HR decreased and MAP values did not change in the study groups after being placed in the prone position.[23] Similarly, in our study, the MAP values did not change, and the HR values decreased significantly in our patients. Idem et al. evaluated patients who underwent PNL under general anesthesia and attributed the significant decrease in HR to the depth of perioperative anesthesia and the reduction of surgical stress.[27]

It has been shown that airway pressures increase and compliance decreases when patients whose minute ventilation is kept constant under general anesthesia are placed in the prone position.[28,29] In our study, the PIP and PPlt values increased significantly when the patients were placed in the prone position, which could be attributed to the restriction of the expansion of the rib cage and the decrease in the elasticity of the chest wall in the prone position.

Hassani et al. reported that there was no significant difference in the VD/VT ratio between the two positions in patients who underwent spinal surgery.[30] Idem et al. showed that there was no significant change in the VD/VT ratio in patients who underwent PNL under general anesthesia.[27] Likewise, in our study, there was no statistical difference between the two positions with regard to the VD/VT ratio. In the study by Idem et al., the authors also noted that there was no significant difference in pH, $PaCO_2$, $EtCO_2$, PIP, and PaO_2 in the prone position at different time points.[30] In our study, there were significant changes in HCO_3 and pH values. Metabolic acidosis is common in major surgeries. Lawton et al. detected perioperative metabolic acidosis in 78% of their patients who underwent general anesthesia. The authors indicated that this was inevitable and claimed that there was evidence that acidosis developed due to the effect of volume loading and surgical stress and that the mean HCO_3 values decreased by 0.9 mmol/L during the time between anesthesia induction and incision.[31] Our results and experiences also suggest that this claim is true.

Position changes in patients with normal preoperative pulmonary function may not have any clinical consequences.[32] However, changes in hemodynamics and respiratory parameters that may occur in patients with comorbidities may make the position change meaningful. The prone position may have a negative effect on hemodynamic parameters in risky patients.[33] On the contrary, there is no harm in performing the operative treatment in the prone position under general anesthesia in patients with stable hemodynamics and no major risk factors such as additional cardiovascular and respiratory tract diseases.[33]

Most inhaled anesthetics and many intravenous anesthetics cause vasodilation. Due to this effect of anesthetic agents, the body's natural adaptation mechanisms may not be activated, and patients may become more vulnerable to position changes. This may result in an exaggerated hemodynamic response and differential mechanical ventilator dynamics. Sevoflurane, which we use, reduces respiratory system resistance by 15% in patients. Inhaled anesthetics can increase viscoelastic and elastic pressures in the lung by decreasing pulmonary compliance. Since the same drugs are used in similar doses in two different positions in patients, we think that the anesthetic substances used did not have a different effect on the two groups in the parameters evaluated in our study.[33]

Our study has some limitations. The major limitations of the study were the inclusion of low-risk patients and the exclusion of patients with risky heart or lung diseases and morbidly obese patients. Another significant limitation was that only a single group of patients was analyzed. Additional studies are needed to compare the effects of surgical position on hemodynamic and respiratory parameters in patients with non-compensated heart failure and morbid obesity.

Despite these limitations, the present study's strengths are the lack of a one-to-one similar study and the demonstration that, while there are some changes caused by the prone position in non-risky patients, they do not affect hemodynamics.

CONCLUSIONS

It was observed that the prone position decreased dynamic and static compliance and increased the PIP and PPLT values in patients undergoing PNL. However, these changes did not have a negative effect on hemodynamic parameters.

Main points

- The changes and problems arising from the positions in the operations should have been prevented earlier and will be managed immediately.
- In PNL surgery, the prone position can change some parameters, such as decreased dynamic and static compliance and increased PIP and PPLT values.
- In patients who have ASA I or II score, these changes do not adversely affect hemodynamics.

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Competing Interests

The authors have declared that no competing interests exist.

Author contributions

S.Y.: design, drafting, acquisition of data, manuscript writing, and critical revision; A.B.K.: design, drafting, acquisition of data, and interpretation of data; A.E.: design, drafting, interpretation of data, and manuscript writing; E.O.: design, drafting, interpretation of data, and critical revision

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Влияние литотомии и положения лёжа на гемодинамические параметры, механику дыхания и артериальную оксигенацию при чрескожной нефролитотомии, выполненной под общей анестезией

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Резюме

Цель: Положение тела во время операции может повлиять на функции организма пациента, особенно на гемодинамические параметры. Мы стремились провести сравнительный анализ влияния литотомии и положения лёжа на дыхательную механику, артериальную оксигенацию и гемодинамические параметры у пациентов, перенёсших чрескожную нефролитотомию (PCNL).

Материалы и методы: В исследование было включено 40 пациентов в возрасте 16-63 лет, перенёсших операцию по поводу мочекаменной болезни. У пациентов не было диабета или сердечно-лёгочных заболеваний в анамнезе, и они имели I–II балл по шкале Американского общества анестезиологов (ASA). pH, парциальное давление кислорода в артериальной крови, парциальное давление углекислого газа в артериальной крови, HCO_3, сатурация артериальной крови кислородом, углекислый газ в конце выдоха ($EtCO_2$), парциальное давление кислорода в альвеолах, отношение объёма мёртвого пространства к дыхательному объёму, $P(A-a)O_2$, пиковое давление вдоха (PIP), давление плато в дыхательных путях (PPlt), систолическое артериальное давление, диастолическое артериальное давление, среднее артериальное давление и значения частоты сердечных сокращений (HR) оценивались одновременно на протяжении всей операции и подвергались сравнительному анализу как для литотомии, так и для положения лёжа.

Результаты: Наблюдалась значительная разница между литотомией и положением лёжа в отношении значений pH и HCO3, которые относятся к параметрам газов артериальной крови, измеренным на двадцатой минуте ($p<0.05$ и $p<0.001$ соответственно). Существовала значительная разница между литотомией и положением лёжа в отношении $EtCO_2$, PIP, PPlt и HR, измеренных на двадцатой минуте ($p<0.05$, $p<0.001$, $p<0.001$ и $p<0.05$ соответственно).

Заключение: Положение лёжа снижало динамическую и статическую податливость и увеличивало значения PIP и PPlt у пациентов, перенёсших PCNL. Однако эти изменения не оказывают негативного влияния на показатели гемодинамики у пациентов низкого риска.

Ключевые слова

нефролитотомия, чрескожная, положение лёжа, механика дыхания, дыхательный объём