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Comparison of Intra-Abdominal Pressure Measurements in Critically Ill Patients Using Intravesical Normal Saline at 15°C, 25°C, and 35°C

Authors' Contribution:
Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
Funds Collection G

ABD 1 **Jianfeng Zou***
EG 2 **Lili Zheng***
DE 1 **Weizheng Shuai**
CD 1 **Qi Li**
BE 1 **Qian Wang**
DE 1 **Zhicheng Zhang**
BD 1 **Dawei Li**

1 Department of Critical Care Medicine, Sixth Medical Center of People's Liberation Army (PLA) General Hospital, Beijin, PR China
2 Yeehong Business School, Shenyang Pharmaceutical University, Beijing, PR China

* Jianfeng Zou and Lili Zheng contributed equally to this manuscript

Corresponding Author: Jianfeng Zou, e-mail: doczou@sohu.com

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Background: The incidence of intra-abdominal hypertension (IAH) and abdominal compartment syndrome (ACS) in intensive care units is high. Dynamic monitoring of intra-abdominal pressure (IAP) is important to treat patients with these conditions. The World Society of Abdominal Compartment Syndrome revised IAP measurement and treatment guidelines in 2013. IAP is measured by instilling ≤25 mL of sterile saline into the bladder, but there is no requirement for the saline to be at a specific temperature. Many doctors presume that using cold saline will trigger bladder muscle spasms, resulting in measurement error. In the present study, we investigated the effect of body-temperature saline on IAP measurements.

Material/Methods: A single-center study was conducted in 12 patients with IAH over a 2-year period. IAP was measured via the bladder with instillation of sterile saline at temperatures of 35°C, 25°C, and 15°C. We analyzed the data using R software, version 4.1.0. Paired *t* tests were used for comparisons between groups. A Spearman rank correlation analysis was performed to compare groups. Analysis results were plotted using the R packages ggplot2, ggpubr, and BlandAltmanLeh. $P<0.05$ was considered statistically significant.

Results: There was a significant difference in IAP measurement between the 15°C and 35°C groups ($t=-2.55$, $P=0.027$). There was no significant difference between the 25°C and 35°C groups ($t=0.73$, $P=0.48$). Bland-Altman analysis showed that IAP was consistent in the 25°C and 35°C groups.

Conclusions: Although it is preferable to measure IAP with saline at body temperature (35°C), a temperature >25°C is associated with accurate results. Using saline at <15°C should be avoided.

Keywords: **Compartment Syndromes • Intra-Abdominal Hypertension • Muscular Diseases**

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Background

Intra-abdominal pressure (IAP) is approximately 5 to 7 mmHg in critically ill adults. A persistent increase in IAP in critically ill patients in the Intensive Care Unit (ICU) – resulting from acute respiratory failure, gastrointestinal dysfunction, abdominal and pelvic hemorrhage, effusion, intensive fluid resuscitation, and/or septic shock – can lead to intra-abdominal hypertension (IAH) or abdominal compartment syndrome (ACS) [1]. IAH is defined as a sustained or repeated pathological increase in IAP to ≥12 mmHg. ACS is defined as a sustained IAP >20 mmHg (with or without an abdominal perfusion pressure <60 mmHg) that is associated with new organ dysfunction/failure. IAH severity is defined as follows: grade I, 12 to 15 mmHg; grade II, 16 to 20 mmHg; grade III, 21 to 25 mmHg; and grade IV, >25 mmHg [2].

Attention increasingly is being paid to the incidence of IAH [3]. It reportedly occurs in 30% to 50% of critically ill patients and 8% to 15% subsequently develop ACS [4,5]. IAH can cause dysfunction in pulmonary, cardiovascular, renal, and gastrointestinal systems, which leads to a vicious cycle. If not effectively treated in a timely manner, IAH can cause multiple-organ dysfunction or death; diagnosing it is heavily dependent upon dynamic measurement of IAP. Early treatment can prevent deterioration, improve patient outcomes, and reduce mortality.

IAP monitoring has received increasing attention in patients who are at high risk and critically ill [5]. The World Society of the Abdominal Compartment Syndrome (WSACS) is dedicated to research about ACS. The organization revised its guidelines for ACS measurement and treatment in 2013, based on published clinical studies [6]. The current guidelines recommend placing the patient in the supine position, inserting a urethral catheter and emptying the bladder, connecting the catheter to the piezometer, injecting ≤25 mL of sterile saline into the urethral catheter, and setting the 0 point at the midaxillary line. IAP is the pressure measured at the end of expiration. The standard unit of measure is mmHg. However, there is no specific requirement for saline temperature. A common current practice is to measure bladder pressure using ≤25 mL of saline. In this context, we presumed that sufficient accuracy could be achieved using room-temperature saline. Measurement of IAP is fundamental to the diagnosis and treatment of IAH and ACS; therefore, we evaluated the effects of saline temperature on IAP measurement.

Material and Methods

Patient Population

The present study was conducted in the Critical Care Medicine Department of the Sixth Medical Center, a tertiary hospital in Beijing, China. Our ICU has 14 beds and approximately 300 hospitalizations per year. Patients treated in the ICU in the past 2 years who were at high risk of IAH because of factors such as major abdominal surgery, severe trauma, and acute severe pancreatitis were included in the study. Patients were excluded if they had bladder lesions, contracture, trauma, neurogenic bladder, and other bladder-related issues. All patients enrolled in the study provided written informed consent. The protocol was approved by our institution's Ethics Committee before the start of the study (approval number: HZKY-PJ-2021-16).

Study Design

Sterile normal saline was prepared and kept at constant temperatures of 35°C, 25°C, and 15°C using a heating bath (Model DK-8D, Qianjun, Shanghai, China). IAP was measured using the intravesical pressure method, as described by the WSACS [6]. First, the patient's bladder was emptied. IAP measurements were recorded after installation of 25 mL of sterile saline into the bladder and with the patient in the supine position at end expiration and the transducer zeroed at the level of the midaxillary line. First, 35°C was used, then 25°C, and finally 15°C. It took about 10 s to infuse 25 mL of saline into the bladder and close the catheter. The IAP was read 10 s after the instillation. After each measurement, the patient's bladder was emptied again [7]. Two colleagues read the IAP measurements independently and their readings were averaged and recorded as the final value. Before the study, these clinicians were well trained by the author in how to measure IAP.

Statistical Analysis

All analyses were conducted with R software, version 4.1.0 (R Foundation for Statistical Computing, Vienna, Austria). Paired *t* tests were used for comparison between groups. Analysis results were plotted using the R packages ggplot2, ggpubr, and BlandAltmanLeh. $P<0.05$ was considered statistically significant. A Spearman rank correlation was performed to compare groups.

Results

Clinical Characteristics and IAP Measurements

Twelve patients at high risk of IAH (8 men and 4 women; median age 66.4±18.9 years) who were admitted to our department from June 2017 to September 2019 were included in the present study. Their baseline clinical characteristics are shown in **Table 1**. Of the patients, 2 had severe pancreatitis, 4 had septic shock, 2 had postoperative abdominal infections, 1 had a metastatic tumor in the gastrointestinal tract, 1 had thrombotic intestinal necrosis, 1 had obstetric pathology, and 1 had trauma and multiple injuries with gastrointestinal perforation.

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Table 1. Patient characteristics.

Patient no.	Sex (Male/Female)	Age (y)	Primary disease	SOFA score*	Outcome (death or survival)
1	M	78	Sepsis	13	D
2	F	29	Postpartum hemorrhage	6	S
3	F	62	Severe pancreatitis	11	D
4	M	65	After surgery for gastrointestinal perforation	8	S
5	F	74	Sepsis	7	S
6	M	32	Trauma, multiple injuries	15	D
7	F	76	Thrombotic intestinal necrosis	13	D
8	M	67	Multiple metastasis of gastric cancer	8	D
9	M	54	Severe pancreatitis	4	S
10	M	85	Sepsis	10	D
11	F	91	Sepsis	11	D
12	M	84	After radical gastrectomy	12	D

* Sequential Organ Failure Assessment (SOFA) score was used to assess the severity of disease in patients included in the study.
D – death; F – Female; M – Male; S – survival.

Analysis of IAP Using Saline at Different Temperatures

The results of the Spearman correlation analysis for IAP measurement with saline infusion between 15°C and 35°C were *P*<2.2e-16 and rho=0.958042. For the measurements made with the 25°C and 35°C infusions, the results were *P*<2.2e-16 and rho=0.986014. Both analyses showed a positive correlation between the saline temperatures and the IAP measurements (**Figure 1A, 1B**).

Figure 2A shows IAP measurements using saline at 35°C, 25°C, and 15°C. There was a significant difference between measurements using the 15°C and 35°C infusions (*t*=-2.55, *P*=0.027). **Figure 2B** shows that there was no significant difference between the 25°C and 35°C infusions (t=0.73, *P*=0.48).

Bland-Altman analysis showed a considerable difference between the groups with the 15°C and 35°C infusions (mean difference±SD, 0.625±1.661; **Figure 3A**). In contrast, there was a minimal difference between the 25°C and 35°C groups (mean difference±SD, 0.067±0.622; **Figure 3B**). These findings indicate that IAP measurements using saline at 25°C and 35°C are consistent, which suggests that either temperature is acceptable for clinical IAP measurement. However, the results differed when using saline at 15°C, which suggests that lower temperatures should be avoided.

Discussion

ACS is a severe complication that results from an acute and sustained increase in IAP, and thus causes significant morbidity and mortality [8]. Recently, there has been an increasing focus on the clinical significance of IAP in critically ill patients, [9] which can greatly affect circulation, respiration, and abdominal organ function [10-12]. The ACS concept was introduced by Kron in 1984 to describe dysfunction involving the cardiovascular, pulmonary, renal, gastrointestinal, and cranial organ systems caused by severe increases in IAP [13].

A recent multicenter study performed by Reintam Blaser et al revealed a high incidence of IAH in patients in the ICU (34% on the first day of ICU admission). In that study, incidence of IAH throughout the observation period was 47.5% for grade I, 36.6% for grade II, 11.7% for grade III, and 4.2% for grade IV. The severity of IAH within 2 weeks after ICU admission was an independent predictor of mortality on days 28 and 90 [14,15].

Patients with IAH have a significantly longer duration of mechanical ventilation, as well as longer stays in the ICU and hospital. However, the impacts of IAH and its severity on mortality are controversial [15]. Emerging evidence supports the need for greater attention to diagnosis and treatment of diseases related to increased IAP, such as IAH and ACS [8,16].

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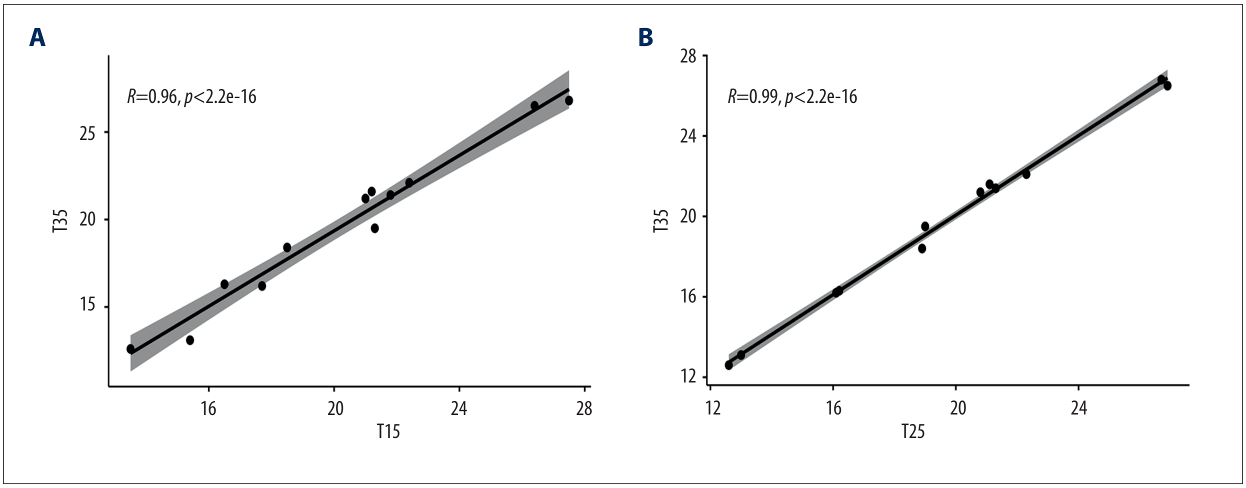

Figure 1. (**A**) Scatter plot of Spearman correlation between the 15°C and 35°C groups. *P*<2.2e-16, rho=0.958042. (**B**) Scatter plot for Spearman correlation between the 25°C (T25) and 35°C (T35) groups. *P*<2.2e-16, rho=0.986014. R – rho.

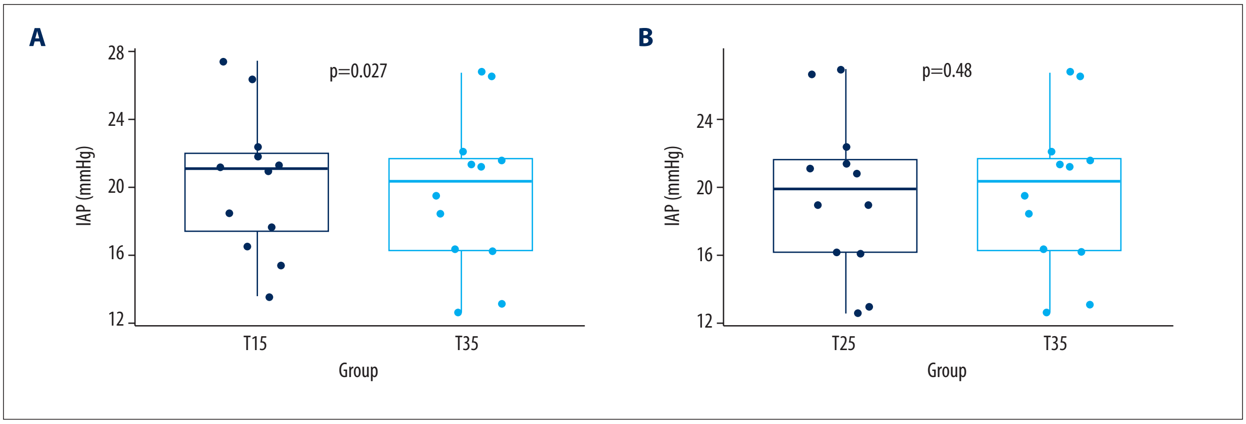

Figure 2. (**A**) Comparison of IAP measurements using saline at 15°C (T15) and 35°C (T35). A paired *t* test analysis showed a significant difference (t=-2.55, *P*=0.027). IAP – intra-abdominal pressure. (**B**) Comparison of IAP measurements using saline at 25°C (T25) and 35°C (T35). A paired *t* test analysis showed no significant difference (*t*=0.73, *P*=0.48). IAP – intra-abdominal pressure.

IAP measurement can be performed directly and indirectly. With the direct method, a piezometer or pressure sensor connected to a paracentesis needle or abdominal drainage tube is used. During laparoscopic surgery, a pneumoperitoneal device can be used. Brooks et al directly and accurately measured IAP using an abdominal probe connected to a pressure monitor [17]. However, all of these methods are complicated and invasive; therefore, they have not been widely adopted. Checking pressure in the inferior vena cava, stomach, rectum, or urinary bladder can be used as a surrogate for IAP. The urinary bladder has good compliance and its use in pressure measurement is both uncomplicated and cost-effective; therefore, bladder pressure is widely used to evaluate IAP.

In 2006, the WSACS introduced standard definitions for IAP, IAH, and ACS [1]. The reference standard for intermittent IAP measurements is achieved by instilling 50 mL of sterile saline into the bladder. In 2013, the WSACS revised the IAH and ACS definitions and standardized the method for IAP measurement. IAP is measured at end expiration with the patient in the supine position, after absence of abdominal muscle contractions has been confirmed and with the transducer zeroed at the level of the midaxillary line. Notably, ACS can be complicated by new dysfunction or failure in organs in the cardiovascular, pulmonary, renal, gastrointestinal, and cranial systems. It also occurs in patients with extra-abdominal septic shock, in whom it leads to a higher mortality rate [18]. The definitions and methods recommended by the WSACS have led to standards for diagnosis and measurement of IAP, improved the consistency of IAH and ACS research, and enabled timely identification and treatment of these conditions to improve patient outcomes [8,19]. The WSACS, however, did not specify what temperature saline to use for IAP measurement.

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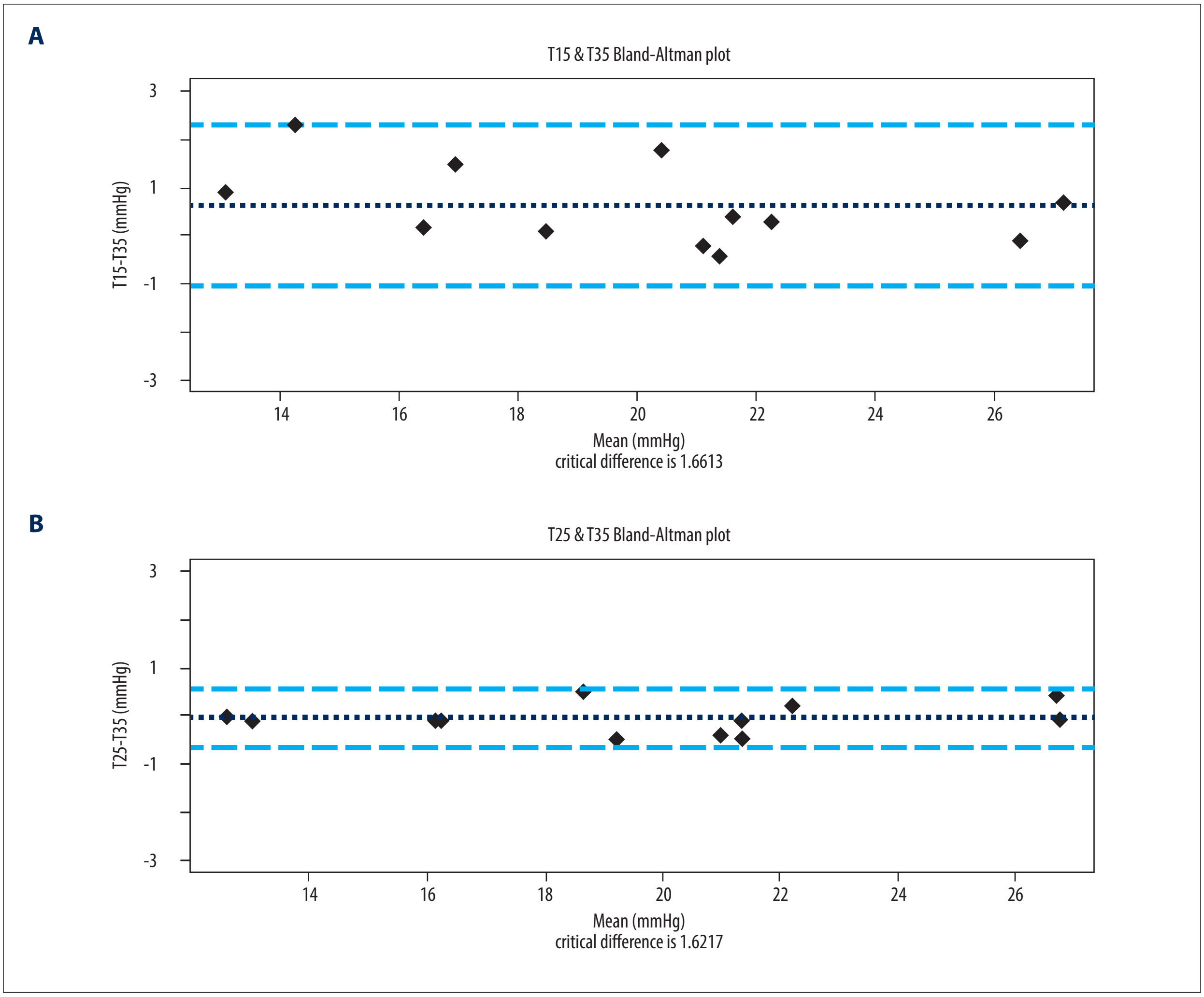

Figure 3. (**A**) Bland-Altman plot of IAP measurements using saline at 15°C (T15) and 35°C (T35). The upper line indicates 2.286, the mean of the middle line indicates 0.625, lower line indicates -1.036, and the mean difference±SD is 0.625±1.661. IAP – intra-abdominal pressure. (**B**) Bland-Altman plot of IAP measurements using saline at 25°C (T25) and 35°C (T35). The upper line indicates 0.555, the mean of the middle line indicates 0.067, the lower line indicates -0.688, and the mean difference±SD is 0.067±0.622. IAP – intra-abdominal pressure.

Saline is typically stored at 10°C to 30°C in in our institution's pharmacy warehouse. Temperatures in the operating room and ICU are required to be maintained at 2°C to 26°C and the humidity is 45% to 65% year-round. After being moved from storage to a ward, the temperature of saline increases to 25°C and 35°C, or around body temperature. Therefore, we chose to use saline at 3 temperatures – 15°C, 25°C, and 35°C and with 10-degree increments – to measure IAP and assess measurement consistency. Spearman correlation analysis showed good correlations between saline at 15°C to 35°C and 25°C to 35°C and IAP measurements, which was consistent with our supposition.

Chiumello showed that there were no significant differences in IAP measured at room temperature (18°C to 0°C) versus body temperature (35°C to 37°C) using saline volumes of 50 mL, 100 mL, and 150 mL, but it was significantly higher when saline volume was increased to 200 mL [7]. IAP commonly is measured using <25 mL of saline [6]. In our study, we focused on the effect of temperature on IAP measurement. We evaluated the consistency of measurements using a paired *t* test and a Bland-Altman plot. The Bland-Altman plot was first introduced by Bland and Altman in 1986 to display information in a graphical manner. The plot combines statistical and clinical standards to compare consistency between 2 test methods [20].

We theorized that because 35°C was close to body temperature, saline at that temperature was unlikely to stimulate the bladder muscle wall. Therefore, our first measurement was with 35°C saline and that temperature was used as the reference

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standard for comparison with measurements performed using saline at 15°C and 25°C. Our study showed a statistically significant difference between IAP measurements with 15°C and 35°C saline; the lower temperature may have led to greater bladder muscle stimulation. In contrast, measurements of IAP with 25°C saline were consistent with the results obtained using 35°C saline. Dynamic monitoring of IAP is required for patients with IAH, generally at intervals of 4 to 6 h (or maximum intervals of 8 h) to maintain IAP <15 mmHg [8,21]. ICUs typically are constructed to maintain room temperature at 24°C to 26°C. Therefore, saline stored there for an extended period can be used as-is to produce accurate IAP measurements, thereby reducing the workloads of nurses and intensivists. If the saline temperature is below 24°C, it should be heated to approximately 25°C to 35°C.

Limitations

In the present study, modifying saline temperature by 10°C was too large an increment and smaller ranges may lead to more accurate IAP measurements. In a future study, we plan to assess IAP measurement using saline at 20°C and 30°C, and to include a larger group of patients, if possible.

Conclusions

Timely trans-bladder measurement of IAP is important for critically ill patients. Our study revealed that room-temperature saline (>25°C) can be used directly to measure IAP, without heating it to body temperature. Use of saline at temperatures <15°C should be avoid and it should be heated to 25°C to 35°C before infusion into the bladder.

Conflict of Interest

None declared.

Declaration of Figures Authenticity

All figures submitted have been created by the authors who confirm that the images are original with no duplication and have not been previously published in whole or in part.

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