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PEDIATRIC ORIGINAL

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Semi-recumbent position and body mass percentiles: effects on intra-abdominal pressure measurements in critically ill children

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Abstract *Purpose:* Patient position and body mass index (BMI) affect intra-abdominal pressure (IAP) measured by the intra-vesical method in adults. We sought to determine effects of patient position and BMI on IAP in children because accurate measurement and interpretation of IAP are important for patient management. *Methods:* Seventy-seven mechanically ventilated children (<18 years) admitted to a PICU were prospectively studied. IAP was taken with the head of the bed at 0° and 30° every 6 h over a 24-h period. Statistical methods included descriptives, univariate statistics to identify potential confounding variables and multivariable analysis to assess the impact of position on IAP after adjusting for the significant covariates. *Results:* Seventy-seven patients had 290-paired IAP measurements. Mean IAP at 30° was 10.6 ± 4.0 compared to 8.4 ± 4.0 at 0°, which was significantly higher ($p = 0.026$) even after adjusting for age, gender and length. There was no correlation between IAP and actual BMI or BMI percentiles. *Conclusion:* Patient position should be considered when interpreting IAP. BMI did not influence IAP measurements in children.

Keywords Semi-recumbent position · Body mass index · Intra-abdominal pressure · Children · Intra-vesical method

Introduction

The World Society of Abdominal Compartment Syndrome (WSACS) defines intra-abdominal hypertension (IAH) as a sustained or repeated pathologic elevation in intra-abdominal pressure (IAP) ≥12 mmHg and abdominal compartment syndrome (ACS) as a sustained IAP of >20 mmHg (with or without an abdominal perfusion pressure of less than 60 mmHg) that is associated with new organ dysfunction or failure [1, 2]. ACS is of concern because it is associated with multi-organ system failure and a high mortality rate [3–8]. Renal impairment has been described in adults at IAP thresholds between 10 and 15 mmHg, lower than the WSACS definition [9]. In children a concern is that multi-organ failure may occur at lower thresholds than that defined by the WSACS because children have lower mean arterial pressures (MAP). Thresholds of 12 and 15 mmHg have been used to define ACS in children [3, 5]. Accurately measuring and interpreting IAP values are important for prevention of ACS and clinical decision making that can impact management and affect outcomes.

Various techniques for measuring IAP have been described in the literature, but the intra-vesical technique is the gold standard for indirect measurement of IAP [10]. It involves the instillation of a pre-determined volume of normal saline in the bladder, allowing for equilibration of pressures and recording of the IAP using a pressure transducer. It is simple, accurate, non-invasive, safe, inexpensive and can easily be done at the bedside. However, IAP readings can be influenced by several factors, including patient position [11], agitation or tense abdominal muscles [12], volume of fluid instilled in the bladder for measurements [13–15], and body mass index (BMI) [16, 17]. Other factors that may affect IAP measurements by the intra-vesical method may include the temperature of fluid instilled in the bladder [18, 19], presence of air bubbles in the fluid column, position of the transducer [20], duration of the urethral catheter in the bladder and bladder compliance. Patient positioning is an important consideration as elevation of the head of the bed (HOB) in ventilated patients to avoid ventilator-associated pneumonia has become the standard of care in many countries. This routine patient care practice affects the accuracy of continuous IAP measurements in adult patients [11]. To our knowledge, there are no studies in children systematically evaluating the effects of patient positioning on IAP.

Childhood obesity is a growing epidemic with a prevalence of 16.3% (children 2–19 years) in the US (2003–2006) [21]. In adults, higher BMI has been correlated to higher IAP readings [16, 19, 22], and elevated IAP has been associated with increased morbidity and mortality in critically ill patients [3, 9]. Our study primarily sought to determine the influence of position on IAP and to determine the effect of BMI percentiles on IAP in critically ill children. We hypothesized that

1. Elevated positioning of the HOB increases IAP.
2. BMI percentiles that characterize children as at risk for being overweight or obese are associated with higher IAP.

Parts of this study have been partially presented in abstract form at an international conference [23].

Materials and methods

The Institutional Review Board of Loma Linda University approved this study. Seventy-seven children admitted to the Pediatric Intensive Care Unit (PICU) were enrolled after parental or guardian consent within the first 24 h of PICU admission.

Inclusion and exclusion criteria

Candidates for the study were patients ≤18 years old who were admitted to the PICU, mechanically ventilated and had urethral catheters in place. Patients with spinal precaution orders in effect were excluded.

Study design

This was a prospective observational study in a single PICU. The urethral catheter was connected to a pediatric AbViser™ device (WolfeTory Medical, Inc.™), an IAP monitoring kit. The transducer was zeroed at the level of the symphysis pubis in each patient before the readings were taken and as many times during the readings as was determined to be necessary by the research investigator. IAP measurements were taken using mean optimal volumes pre-determined for each individual as previously described [15]. Briefly, graduated volumes of normal saline were instilled in the bladder, and IAP was taken with each instillation. Pressure–volume curves were generated for each patient, and the mean optimal volume was determined from the plateau portion of the curve and used as the bladder instillation volume for the specific individual. At least 1 min was allowed for equilibration of IAP with each reading. Built in angle indicators on the patient's bed were used to position each patient. IAP measurements were taken with the HOB at 0° (baseline) and again at 30° every 6 h over a 24-h period or until the patient was extubated. The baseline position involved the patient laying flat with the face upwards, the dorsal side down and the HOB at 0° relative to the lower limbs. The 30° position had the HOB at 30° relative to the lower limbs. The measurements at 0° and 30° were done within 3 min of each other. The 77 patients studied had a total of 580 IAP measurements taken with the HOB at baseline and at 30°. Each patient had two to four paired measurements depending on the duration of mechanical ventilation. Two hundred ninety paired data points were used for statistical analysis. The mean difference between IAP readings at 0° and 30° was calculated for each patient. Age, gender, weight, height, admission diagnosis, BMI, Pediatric Risk of Mortality (PRISM) III score and peak end expiratory pressure (PEEP) were also recorded for each patient. These potential covariates were assessed as possible confounders on the effect of position on IAP difference between 0° and 30°.

Since BMI is imprecise as a measure of body fat in children, especially those less than 4 years old, and the CDC standard curves are the most readily available standards for American children [24, 25], we studied the relationship between IAP and BMI percentiles for age and gender in addition to actual BMI. The BMI was calculated using the following formula: weight (kg)/[height (m)]^2. The actual BMI was then plotted on the standardized CDC BMI-for-age growth charts to obtain a percentile ranking for each patient. The percentile indicates the relative ranking of the child's BMI among children of the same sex and age. BMI percentiles were categorized into four groups as follows: a patient was determined to have a healthy weight for height if the BMI percentile was 5–85, to be overweight or at risk for becoming overweight if their BMI percentile was 86–95, and was underweight if it was less than 5 [25, 26]. Patients with BMI percentiles of greater than 95 were defined as being obese [24]. The data were analyzed using these established BMI percentile categories for comparison.

Statistical analysis

Descriptive statistics using mean, medians and percentages were employed based on the variables assessed. Independent sample *t* tests were performed to assess gender differences in IAP. Kruskal–Wallis was performed to assess differences in IAP based on diagnosis and BMI percentiles. Correlation between IAP differences (0° vs. 30°) and mean optimal volume, age, weight, length, BMI, PRISM III score, and PEEP was assessed with Pearson or Spearman's rho correlation, depending on if assumptions were met. A general linear model using repeated measures ANOVA with one within-subject factor (IAP) and three covariates (age, length, and gender) was used to assess differences in IAP between 0° and 30° HOB position, after adjusting for the covariates.

Results

Demographics

Seventy-seven patients (38 females) with a median age of 28.3 months were enrolled. Table 1 shows patient characteristics. Eighty-one percent of the patients were admitted with a medical diagnosis, 13.0% with a surgical diagnosis and 5.2% were trauma patients. The median PRISM III score was 5 (0–36). The median BMI and BMI percentile was 16.4 kg/m^2 (6.5–80 kg/m^2) and 50 (1–100), respectively.

Intra-abdominal pressure

Baseline IAP ranged from 0–31 with 13.7% of baseline readings being 12 mmHg or greater, the threshold used for the definition of IAH and 3.8% being greater than 20 mmHg, the threshold used for the definition of ACS when associated with organ failure. At 30° HOB elevation, an even higher percentage of readings exceeded these thresholds (27.9% of readings were $\geq$12 mmHg, and 6.6% were >20 mmHg). The mean IAP at 0 and 30° was 8.39 and 10.59 mmHg, respectively.

Effect of positioning on IAP

The relationship between IAP at 0° and 30° is shown in Fig. 1. It demonstrates that as mean IAP at 0° increases, there is an apparent increase in mean IAP at 30°.

When we looked at the mean IAP difference at 0° compared to 30°, the factors that were found to significantly affect the IAP difference were age, gender, and length (Tables 2 and 3). Females had a higher mean IAP difference than males ($p = 0.020$). Older and taller patients tended to have higher IAP differences as well ($p = 0.020$ and 0.044 respectively). Diagnosis, BMI percentile, PEEP, PRISM III scores, and weight were not significant factors affecting IAP difference. After controlling for gender, age, and length, the difference between IAP at 0° and 30° elevation was still statistically significant ($p = 0.026$) (Table 4). The mean IAP with the HOB at 30° was 10.59 ± 4.02 compared to the baseline mean IAP of 8.39 ± 4.03 (Fig. 2).

Table 1 Patients characteristics, $N = 77$

	Descriptives *N* (%)
Gender	
Female	38 (49.4)
Male	39 (50.6)
BMI percentile	
Less than 5	8 (12.7)
5 to 85	34 (54.0)
86 to 95	10 (15.8)
96 and above	11 (17.5)
Diagnosis	
Medical	63 (81.8)
Surgical	10 (13.0)
Trauma	4 (5.2)
Age (months)	28.3 (0.5–221.4)[a]
Weight (kg)	13.0 (3.0–70.0)[a]
Length (cm)	87.1 ± 32.8[b]
BMI (kg/m^2)	16.4 (6.5–80.0)[a]
PRISM III score	5 (0–36)[a]
PEEP	5 (4–16)[a]
IAP at 0 degrees	8.39 ±4.03[b]
IAP at 30 degrees	10.59 ±4.02[b]
IAP difference between 0 and 30 degrees	2.21 ±1.66[b]

N (%) indicates number of participants and their percentage
BMI body mass index, *PRISM* Pediatric Risk of Mortality, *PEEP* peak end expiratory pressure, *IAP* intra-abdominal pressure
[a] Indicates median (range)
[b] Indicates mean with standard deviation

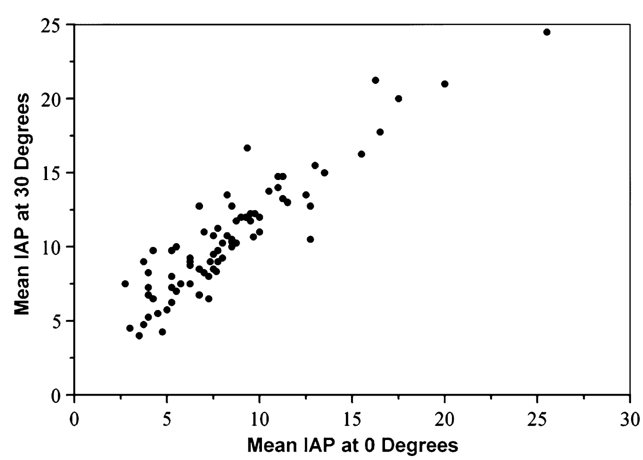

Fig. 1 Scatterplot of mean IAP at 0 and 30 degrees

Table 2 IAP difference among the patients

	Mean IAP difference from 0 to 30 degrees	*p* Value
Gender		
Female	2.65 ± 1.68[a]	0.020*
Male	1.78 ± 1.53[a]	
Diagnosis		
Medical	1.83 (−2.25–7.33)[b]	0.412
Surgical	3.13 (0.67–5.00)[b]	
Trauma	2.25 (1.50–4.75)[b]	
BMI percentile		
Less than 5	2.88 (−0.05–5.25)[b]	0.441
5 to 85	2.38 (−2.25–5.50)[b]	
86 to 95	1.38 (−0.75–7.33)[b]	
96 and above	2.00 (0.5–2.75)[b]	

IAP intra-abdominal pressure, *BMI* body mass index
[a] Indicates mean with standard deviation
[b] Indicates median (range)
* Significant at an alpha of 0.05

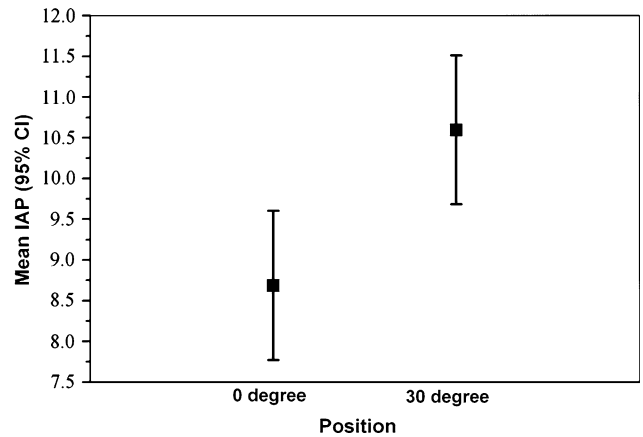

Fig. 2 Mean IAP at 0 and 30 degrees

Effect of BMI percentile on IAP

We had similar IAP readings among all four BMI percentile categories (Table 2), and the effect of BMI percentiles as a continuous variable on IAP was not significant ($p = 0.99$). Actual BMI also did not influence the IAP difference between 0° and 30° HOB positions.

Discussion

The WSACS consensus recommendation is that IAP should be measured with the patient in the supine position [1]. Our study is the first to examine the relationship between positioning and IAP in critically ill children, and suggests that elevation of the HOB increases the measured IAP significantly in this patient population. However, we did not find any relationship between IAP and BMI percentiles in our patients.

Patients receiving intensive care are rarely nursed in the supine position [27] and may need to be repositioned solely for IAP measurements. Mechanically ventilated patients are at a lower risk for ventilator-associated pneumonias by keeping the HOB elevated at 30° or more [27–29]. The semi-recumbent position is also associated with a decrease in gastroesophageal reflux, pulmonary aspiration, and abnormal oropharyngeal colonization [28, 30, 31]. In addition, it is associated with reducing intracranial and intra-ocular pressure [32–34]. In some cases, the patient's condition precludes positioning them supine solely for IAP measurement. Thus, understanding the role of positioning on IAP measurements is important so that the IAP values

Table 3 Spearman's correlation coefficients between IAP difference and several variables

	Mean optimal volume	Age (months)	Weight (kg)	Length (cm)	BMI (kg/m^2)	PRISM III score	PEEP
IAP difference (*p* value)	0.165 (0.155)	0.266 (0.020)*	0.144 (0.088)	0.255 (0.044)[a],*	−0.046 (0.720)	0.033 (0.777)	0.042 (0.725)

IAP intra-abdominal pressure, *BMI* body mass index, *PRISM* Pediatric Risk of Mortality, *PEEP* peak end expiratory pressure
[a] Pearson correlation (*p* value)
* Significant at an alpha of 0.05

Table 4 General linear model repeated measures analysis

	Type III sum of squares	Degrees of freedom	Mean square	*F* value	*p* Value
Position effect (0 degrees–30 degrees)	0.16	1	6.319	5.246	0.026*

* Significant at an alpha of 0.05 after adjusting for log transformed age, length, and gender

can be interpreted appropriately. Some authors have suggested determining corrective values to allow the interpretation of IAP taken in non-recumbent positions [19, 35]. We share this viewpoint and sought to determine the effects of patient positioning on IAP in children. Understanding this relationship may help in the derivation of corrective values in the future if necessary.

Our study showed that elevation of the HOB from 0° to 30° significantly increased the IAP reading in critically ill children. This is similar to findings in adult studies. Malbrain et al. [36] determined that mechanically ventilated adult ICU patients in a more upright position had higher IAP. In 45 adult trauma patients, measured IAP was higher as the HOB was raised in five different positions. In this study, the mean increase in IAP from 0°–30° was 3.37 (3.23–4.5) mmHg, slightly higher than the 2.21 $\pm$ 1.66 mmHg IAP difference we observed [11]. In 37 adults, McBeth et al. demonstrated a significant independent relationship between IAP and HOB increase with a greater correlation at higher elevations of 30° and 45°, and also showed that BMI, PEEP, and temperature affected the degree of IAP increase. The IAP increase reported in their study from 0° to 30° was 5.0 (CI 3.8, 6.1) [35]. There could be several reasons for the smaller IAP difference observed in our study when compared to these adult data. Larger instilled volumes have been demonstrated to increase IAP readings [13, 14]. We used mean optimal volumes determined for each patient for IAP measurements, and this specificity may have allowed us to use smaller volumes with greater accuracy in IAP measurements. However, determining the mean optimal volume for each patient is no longer necessary since recent data shows that a standard minimum volume of 3 ml can be used in children weighing up to 50 kg [15]. Another factor accounting for lower IAP difference in our patients may be the choice of the symphysis pubis as a reference point for placement of the transducer. It has been demonstrated to yield lower IAP readings when compared to readings at the mid-axillary line [20]. The length/height of patients may also have played a role. Our study showed that taller patients demonstrated a higher IAP difference. Since adults are generally taller than children, this factor may have influenced the reported results in previous adult studies. However, the effect of height on IAP has not yet been studied in adults.

Unlike the study by McBeth and colleagues, our study did not reveal that PEEP had an effect on IAP difference. However age, gender, and length were the factors that affected IAP in our patients (Table 3). It is unclear why age, gender, and height influenced IAP difference, as seen in our study. This specific research question will need to be addressed in future studies.

While the increase in IAP seen at 30° compared to 0° in our patients was statistically significant, the absolute magnitude of change was small. At first glance, an increase of 2.21 mmHg may not appear to be relevant. However, the number of IAP readings reaching or exceeding 12 mmHg, the threshold that defines IAH, doubled from 13.8% at 0° to 27.9% at 30°. Therefore, IAP measurements at 30° may meet the definition of IAH more frequently and subject patients to continuous IAP monitoring that may not be necessary or of greater concern receive potentially unnecessary treatment due to a falsely elevated IAP value. The number of readings >20 mmHg also increased from 3.4% at 0° to 6.6% at 30°. Of course, in the absence of new organ dysfunction, such patients would meet the definition of IAH and not ACS. Still IAP measurements at elevated HOB positions may lead to over classification of patients meeting IAH or ACS definitions. The increase in IAP seen at 30° may also impact the abdominal perfusion pressure (APP). Since APP is the difference between MAP and IAP [1], and children have lower MAP depending on age, even a slight increase in IAP could result in clinical changes or even organ damage. Our study did not evaluate the effect of positioning on APP.

It is also unclear from our data whether the pressures in the abdomen at higher bed elevations are erroneously high or truly elevated as a result of the position change. The properties of the abdomen have been described as a fluid model [37]. If the fluid model theory is applied, then the properties and behavior of the abdomen should follow Pascal's law ($P = \rho gh$), where P is pressure, g is gravity, and h is height of the fluid column. When the HOB is elevated, the height of the fluid column, in this case the abdomen, is increased, and the bladder at the base of that column will demonstrate a higher pressure, suggesting that it is a real elevation in pressure. However, this study was not designed to determine the validity of the fluid model in children. Nonetheless, our findings should serve to alert clinicians that elevating the HOB increases IAP and establish grounds for future studies into the effect of patient positioning on APP.

We did not find a correlation between BMI and IAP measurements in our patients. This is in contrast to studies involving adult patients, where higher BMI correlates with higher IAP readings [16, 23, 38, 39]. This increase is thought to be related to central obesity. The Lambert study showed a correlation between IAP and sagittal abdominal diameter, an index of degree of central obesity [38].

While some studies have reported a good correlation between BMI and measures of body fat in childhood [40], in infancy the relationship is poorer, and the utility of BMI in infancy and childhood is limited [24]. Age and growth affect BMI, and there are sex-specific effects on growth and fat distribution in children. BMI percentiles are therefore a more useful basis for comparison in children [24]. We did not find a significant difference in IAP readings in different BMI percentiles in our study. This differs from findings in adult studies and could be due to the differences in body fat distribution in growing children compared to adults. Statistical analysis was run with actual BMI and BMI percentiles as continuous variables as well, and neither affected IAP or IAP difference.

Our study had several limitations. All patients were sedated and in some cases chemically paralyzed, as is our practice with mechanically ventilated patients. However, because this was an observational study, the degree of sedation and chemical paralysis was determined by the bedside nurse and physicians, not the study investigators, and no sedation scoring system was used. The symphysis pubis was used as our reference point before the WSACS reached their consensus for IAP measurements using the mid-axillary line [20]. It was used at the onset of our study and maintained for consistency after the emergence of the consensus. We only measured IAP in two positions, 0° and 30°. Measuring the IAP at serial degrees up to the upright position and in the Trendelenberg position should be considered in future investigations. Correlating the effect of position on APP as well as IAP may be even more useful in children in view of lower MAP in this age. Also our patient population consisted of few patients with very elevated IAP. Future studies to validate the effect of HOB position on APP should include more patients with higher IAP and with evidence of ACS.

Conclusions

The IAP in critically ill children increases significantly when the HOB is elevated from 0° to 30°. Neither BMI values nor categorization into CDC BMI percentiles (including obese patients, patients at risk for being overweight, and underweight patients) showed any correlation with IAP.

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