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Take-home message:

Automated IAP measurement allows for reliable analysis of trends in IAP with reduced workload for ICU nurses.

Statements and Declarations:

Competing interests:

All authors declare that they have no conflicts of interest.

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No funding in cash was received for this study.

Potrero Medical (Hayward, CA, USA) provided the catheters and Accuryn Monitoring Systems for use in this study and were not involved in study design, data interpretation and writing of this manuscript.

Ethics approval:

All methods were carried out in accordance with relevant guidelines and regulations. The medical ethical committee of our hospital approved the study and waived the need for patient informed consent on the basis that this study is not clinical research with human subjects as meant in the Medical Research Involving Human Subjects Act (WMO) and it does not fall within the scope of Medical Device Regulation (MDR)(METc 2022/327). The study was not prospectively registered in a trial registry, because it was classified as non-WMO research by the ethics committee.

Patient informed consent:

Not applicable.

Availability of data and material:

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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Abstract

Objectives

The 2013 World Society of the Abdominal Compartment (WSACS) Guidelines state that intra-abdominal pressure (IAP) should be measured in the supine position. Since patients in the intensive care are preferably nursed in an elevated head of bed position, measuring IAP in more upright positions is more practical. However, measured IAP increases in more upright positions. This study aimed to evaluate automated IAP measurement in different HOB elevations in postoperative cardiothoracic surgery patients.

Design

Single-center observational study.

Setting

ICU of a university hospital.

Participants

37 postoperative cardiothoracic surgery patients admitted to the ICU.

Interventions

IAP was measured by the Accuryn Monitoring System in 0°, 15°, 30°, 45° and 60° HOB elevation.

Measurements and Main Results

IAP measurements in 37 patients were analyzed. Mean IAP at 0° was 9.3 (SD 2.2). Mean IAP increased to 17.9 mmHg (SD 2.9) at 60°. A repeated measures ANOVA was conducted with a pairwise comparison for post-hoc analysis.

Mean difference in IAP per 15° HOB elevation was: +1.8mmHg (95% CI 1.4-2.2) for 0°-15° , +2.4mmHg (2.0-2.8) for 15°-30°, +2.2mmHg (1.9-2.5) for 30°-45°, and +2.1mmHg (1.8-2.4) for 45°-60°.

Conclusions

This pilot study demonstrates the increase of IAP by approximately 2 mmHg per 15 degree increase in HOB elevation in automated measurements in postoperative cardiothoracic patients. This finding may facilitate more routine measurements of IAP and thereby earlier signalling of increases in IAP. Future studies should focus on validating these results in larger ICU populations.

Key words: intra-abdominal pressure, supine position, head-of-bed elevation, HOB elevation

Introduction

Intra-abdominal hypertension (IAH) is prevalent among critically ill patients, affecting up to half of the patients during the course of their stay in the Intensive Care Unit (ICU) and is associated with increased morbidity and mortality (1,2). It is a condition defined by a sustained increase in intra-abdominal pressure (IAP) of ≥12 mmHg (3). IAH can progress to abdominal compartment syndrome (ACS), a serious condition defined as a sustained IAP exceeding 20 mmHg in the presence of new-onset organ failure (3, 4). Monitoring IAP is essential to detect IAH and to identify progression to ACS (5). Furthermore, IAP may be used to calculate abdominal perfusion pressure (APP), which is calculated as the mean arterial pressure (MAP) minus IAP. APP has been suggested as the abdominal analogue to cerebral perfusion pressure and a potential end point for resuscitation (3).
Measuring and monitoring IAP comes with challenges. The 2013 World Society of the Abdominal Compartment (WSACS) guidelines state that IAP should be measured in the supine position (3). However, most patients in the ICU are in 30^0 head-of-bed (HOB) elevation to prevent ventilator-associated pneumonia (6). This makes regular IAP monitoring complex and time consuming for nursing staff.

Frequent measurement of IAP requires considerable time as it involves connecting a carefully calibrated pressure sensor to the urinary catheter and instillation of saline into the bladder. Consequently, current clinical practice involves sporadic 'on-spot' measurements with major time intervals between measurements. Changing a patient into the supine position each time before measuring IAP is impractical from the perspective of both the nurse and the patient. This makes capturing increased IAP and observing a sustained increase in IAP over time challenging. Additionally, IAP measurements may suffer from imprecision, for example through inter-individual variation in executing the IAP measurement procedure (10). Previous research has found that HOB elevation is associated with increased IAP (7,8). However, the increase in IAP in different HOB elevations varied in these studies. Frequent or continuous measurement of IAP, also in non-supine positions would improve patient care. (4). Furthermore, measurement in non-supine positions would reduce the workload for nursing staff. Based on De Keulenaer et al. (7), our group has previously proposed a correction reference table stating that 0°-20° HOB elevation has no effect on IAP, 20°-40° HOB elevation increases IAP by 4 mmHg, and above 40° HOB elevation, IAP rises by 9 mmHg (9). However, this equation has not been validated in a clinical study.

A novel monitoring tool has been developed. It measures IAP via a semi-flaccid balloon and a computer chip at the tip of a urinary catheter. This system (Accuryn Monitoring System, Potrero Medical, Hayward, CA, USA) offers the possibility to easily, automatically and accurately measure IAP (11-13).

The primary objective of this study was to examine automated IAP measurements in different HOB elevations. The study was performed in postoperative cardiothoracic surgery patients since these constitute a rather homogenous group of critically ill patients, exposed to a distinct pathophysiological 'hit' during surgery, where IAH is common (11).

Methods

Study-design and setting

This is a single-center observational pilot study in the Department of Critical Care for adults at the University Medical Center Groningen (UMCG) in the Netherlands. Patients aged 18 years or older undergoing cardiothoracic surgery with subsequent admission to the ICU were eligible for the study. Exclusion criteria were a medical history of prostate disease, the presence of a suprapubic urinary catheter and the inability of the patient to give oral consent to the anesthesiologist. Since this study was an observational pilot study, an a priori sample size calculation was not feasible. Oral informed consent was obtained by the anesthesiologist.

Device

The Accuryn Monitoring System is FDA-approved, and CE-marked. This monitoring system measures bladder pressure at 100 Hz through a semi-flaccid balloon containing a pressure sensor at the tip of a urinary catheter. Active drain line clearance of the urinary catheter with 2 one-way valves ensures an empty bladder and calibration is not necessary. IAP is displayed on the monitor screen upon touching a button.

Patients included received an Accuryn Monitoring System. The catheter was inserted in the operating theatre. The system was used during the time an indwelling catheter was indicated.

Outcome

The main outcome was IAP in mmHg in the 0° (supine, reference position), 15°, 30°, 45° and 60° HOB positions, measured within 24 hours after ICU admission. IAP was measured twice in each position and averaged to reduce random error of measurement.

Data

We collected general patient characteristics (age, gender, length, weight, body mass index (BMI), type of surgery). Furthermore, we recorded sedation, presence of muscle relaxants and mechanical ventilation as they potentially affect IAP. Sedation was defined as the administration of continuous intravenous propofol during IAP measurements. The presence of muscle relaxants was defined as a last bolus of rocuronium less than two hours before IAP measurement. In patients with impaired renal function (serum creatinine >110umol/L in males and >90umol/L in females) it was defined as a bolus of rocuronium less than four hours before IAP measurement. IAP was measured in two series of five HOB positions: first in 0°(supine position) followed by 15°, 30°, 45° and 60° HOB and second at 60° followed by 45°, 30°, 15° and 0° (supine position) HOB. The angle of the HOB elevation was measured using the scale on the side of the ICU bed. In case of hemodynamic instability or actions that had priority, measurements were paused and completed later.

Statistics

Statistical analysis was performed using IBM SPSS Statistics Version 29. Results are expressed in means with standard deviation (SD), medians with interquartile range (IQR) or in numbers (N) and percentages, depending on the distribution. The Interclass Correlation Coefficient (ICC) was calculated to compare the first and the second measurement per HOB position. The two-way mixed model was used to assess absolute agreement.

A repeated measures ANOVA was conducted to analyze the differences in IAP per repeated measurement group. A Greenhouse-Geisser correction was performed. For post hoc analysis a Bonferroni correction was performed. A pairwise comparison was performed to determine the significance between the five HOB elevations. $P < 0.05$ was considered significant.

We also assessed the relation between HOB position and IAP with linear regression.

Ethical considerations

All methods were carried out in accordance with relevant guidelines and regulations. The medical ethical committee of our hospital approved the study and waived the need for patient informed consent on the basis that this study is not clinical research with human subjects as meant in the Medical Research Involving Human Subjects Act (WMO) and it does not fall within the scope of Medical Device Regulation (MDR)(METc 2022/327). The study was not prospectively registered in a trial registry, because it was classified as non-WMO research by the ethics committee.

Results

Thirty-seven patients were included in the study. There were some missing IAP values in three patients caused by hemodynamic instability in 45° and 60° HOB positioning (N=2) and reflux esophagitis as a contra-indication for supine positioning (N=1). Therefore the repeated measures ANOVA was performed in 34 patients.

The majority of this cohort was male with 26 patients (70%) (Table 1). The median BMI was 27.8kg/m² (IQR 24.4-31.4). Seventeen patients underwent coronary artery bypass graft (CABG) surgery (46%) and nine valve surgery (24%). The median time between end of surgery and first IAP measurement was 85 minutes (IQR 67-115). There were two outliers of 15 and 16 hours. At the time of IAP measurement 35 patients (95%) were mechanically ventilated and sedated and 5 patients (14%) were under the influence of muscle relaxants.

The ICC was 0.97 (95% CI 0.94-0.98, p <0.001) for measurements performed in supine positions. ICC for measurements in 15° HOB elevation was 0.98 (95% CI 0.96-0.99), for 30° HOB 0.98 (95% CI 0.95-0.99), for 45° HOB and for 60° HOB was 0.99 (95% CI 0.98-0.99) respectively. IAP in 0°, 15°, 30°, 45° and 60° were normally distributed with a total mean of 13.6 mmHg (SD 4.0). The mean IAP in supine position was 9.3 (SD 2.2), at 15° 11.1 mmHg (SD 2.5), at 30° 13.5 mmHg (SD 2.6), at 45° 15.8mmHg (SD 2.6) and at 60° 17.9 mmHg (SD 2.9) (Table 2). IAH was found in 14% of patients in supine position and this increased to 78% in 30° and 100% in 60° (Figure 1).

The assumptions of a repeated measures ANOVA were met, except for the assumption of sphericity, for which the Greenhouse Geisser correction was used. A significant difference between the mean IAP at various HOB elevations was found [F (1.85, 60.88) =771.70, p <0.01]. The pairwise comparison showed a significant increase of 1.8mmHg (95% CI 1.4-2.2, p <0.01) in the 15° position compared to supine, 2.4mmHg (95% CI 2.0-2.8, p

<0.01) increase in 30° compared to 15°, 2.2mmHg (95% CI 1.9-2.5, p <0.01) in 45° compared to 30° and 2.1mmHg (95% CI 1.8-2.4, p <0.01) increase in 60° compared to 45° (Figure 1).

Discussion

This observational pilot study assessed the impact of HOB elevation on IAP in 37 postoperative cardiothoracic surgery patients who were mostly sedated and mechanically ventilated. We found that HOB elevation has a significant effect on IAP. The results suggest a linear increase of approximately 2 mmHg in IAP per 15° increase in HOB elevation in this study population.

The significant influence of HOB elevation on IAP demonstrated in this study is in line with previous research (7, 8, 14-17). Two studies had different findings on the increase of IAP in HOB elevation. McBeth et al. found a mean difference of 5.0 mmHg from the supine position to 30° and 7.4 mmHg for 45° in a general ICU population (8). This is higher than the results in our study. A recent prospective cohort study measured 76 patients via an intra-vesical measurement method with manometry, in supine, 15° and 30° with a mean difference between 0° and 15° of 1.1mmHg and a difference between 0° and 30° of 2.7 mmHg (14). IAP differences were smaller in this study. None of these studies used an automated IAP measurement technique to measure IAP, hence the IAP difference may be explained by the use of a different measuring technique (10). Furthermore, in previous studies, all patients admitted to the ICU were included with a large variety of diagnoses. In contrast, we included a clearly defined patient population and measured IAP in a well defined postoperative period where most patients were sedated and mechanically ventilated. Our results imply that correcting IAP in different HOB elevations is necessary to avoid an overestimation of IAP, and hence a higher prevalence of IAH. As Figure 1 indicates, 14% of patients had IAH (IAP ≥ 12 mmHg) at 0º, 78% had IAP at 30 º and 100% of patients had IAH at 60º HOB elevation. Khanna et al. found IAH in 93% of postoperative cardiothoracic surgery patients by measuring IAP continuously via the same monitoring system that was used in our study, for 48 hours (11). This is considerably higher than in previous studies estimating a prevalence of 32-46% (18-20). The interpretation of these results is limited by the fact that patient positioning was not documented, but it is likely that HOB elevation affected these results.

This is one of the first studies that examines IAP using the Accuryn Monitoring System, which may measure IAP more precisely than previous hydrostatic measurement tools. Previous measurement tools were susceptible to deviations in measurements among different nurses or techniques (10). The high ICC shown in this study confirms an excellent reproducibility of the repeated measurements, which may also facilitate continuous measurements with the potential of trend analysis. Another strength is that the homogenous character of cardiothoracic surgery patients allows better examination of the relation between HOB and IAP than a heterogeneous cohort.

Our study has several limitations. This study is a single-center pilot study with a limited sample size. Timing of data collection and ventilatory settings were not standardized and factors such as intra-thoracic pressure and fluid balance that could influence IAP are not reported. The high F-statistic and narrow confidence intervals should be interpreted cautiously given the sample size. Convenience sampling was used for inclusion. This method increases the risk of selection bias and therefore this study population might not be fully representative. Our study population does not include patients with IAPs higher than 16mmHg measured in supine position. IAP correction for HOB elevation might differ in this population.

Future research should focus on the potential of continuous IAP and APP measurement in all HOB positions and larger patient cohorts, as well as in different patient populations. Moreover, future research should evaluate other patient positions, such as prone positioning.

The primary aim of the first WSACS guidelines in 2006 was to achieve consensus on the definitions of IAH and ACS, to “facilitate future research and improve patient care” (4). As we enter a new era of continuous IAP monitoring, there is again a need for standardizing our clinical practice. With this study we demonstrate that automated measurements of IAP in various HOB positions are possible and reliable.

Conclusion

This pilot study demonstrates the increase of IAP by approximately 2 mmHg per 15 degree increase in HOB elevation in automated measurements in postoperative cardiothoracic patients. This finding may facilitate more routine measurements of IAP and thereby earlier signalling of increases in

IAP. Future studies should focus on validating these results in larger ICU populations.

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Authors contributions :

FG: Performance of measurements, data analysis, data interpretation, writing of the manuscript

GJ: Selection of patients, performance of measurements, and revision of the manuscript

FB: Revision of manuscript

LY: Selection of patients and revision of the manuscript

MN: Conceptualization, study design, data analysis, data interpretation and revision of the manuscript

MvM: Study design, data interpretation, revision of manuscript

JK: Conceptualization, study design, data analysis, data interpretation and revision of manuscript

MS: Conceptualization, study design, performance of measurements, data analysis, data interpretation and revision of manuscript

Tables

Table 1. Baseline characteristics of patients (N=37)

Variable	
Age (years) (median (IQR))	66 (50-74)
Female	11 (30%)
BMI (kg/m²) (median (IQR))	27.8 (24.4-31.4)

Time between end surgery and measurement (min) (median (IQR))	85 (67-115)
Sedated during measurement	35 (95%)
Muscle relaxation	5 (14%)
Mechanical ventilation	35 (95%)
Type of operation	
CABG	17 (46%)
On-pump	11 (30%)
Off-pump	6 (16%)
Valve surgery	9 (24%)
CABG + valve	2 (5%)
Aortic surgery	4 (11%)
Heart transplantation	1 (3%)
Re-operation	3 (8%)
Other	1 (2%)

IQR: Interquartile Range, CABG: coronary artery bypass graft

Table 2. Mean IAP per HOB position (N=37)

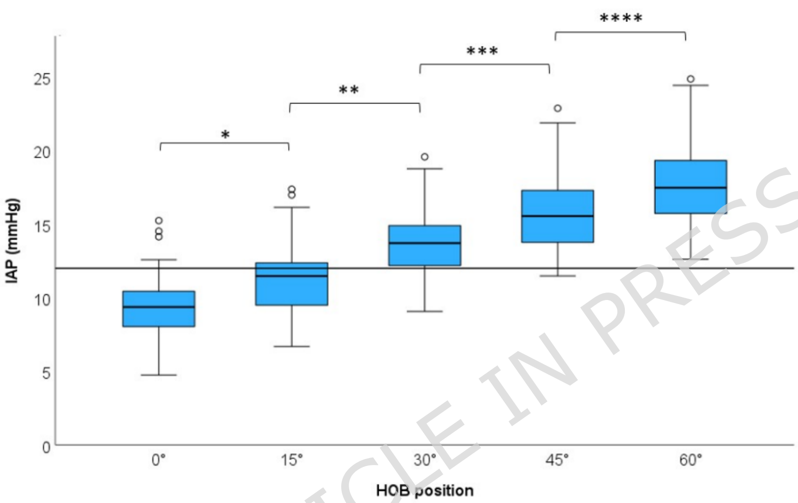
HOB position	0°	15°	30°	45°	60°

IAP, Mean (SD)	9.3 (2.2)	11.1 (2.5)	13.5 (2.6)	15.8 (2.6)	17.9 (2.9)

HOB: head-of-bed, IAP: Intra-abdominal pressure, SD: standard deviation

Figures

Figure 1. Boxplot of IAP per HOB position (N=34)



IAP: intra-abdominal pressure, HOB: head-of-bed

The reference line at IAP = 12mmHg illustrates that patient positioning in increasing HOB positions significantly increases diagnosis of intra-abdominal hypertension (IAP ≥ 12mmHg)

*: mean difference 1.8mmHg (95%CI 1.4-2.2), p<0.001

**: mean difference 2.4mmHg (95%CI 2.0-2.8), p<0.001

***: mean difference 2.2mmHg (95%CI 1.9-2.5), p<0.001

****: mean difference 2.1mmHg (95%CI 1.8-2.4), p<0.001