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CONTINUOUS INTRA-ABDOMINAL PRESSURE MONITORING

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Key words: intra-abdominal hypertension, abdominal compartment syndrome, continuous intra-abdominal pressure monitoring, abdominal perfusion pressure, IAP, IAH, ACS

ABSTRACT

Background: Intra-abdominal hypertension (IAH) and abdominal compartment syndrome (ACS) can develop within 12 hours of ICU admission in high-risk patients. Until recently the intermittent intra-abdominal pressure (IAP) measurement via the urinary catheter was the clinical standard. This is a relatively labour intensive technique and its intermittent nature could prevent timely recogni-

tion of significant changes in IAP. The historical continuous IAP (CIAP) measurements were poorly reproducible (gastric route) or invasive/impractical (direct measurement). The aim of this paper is to review the current evidence on CIAP monitoring.

Methods: A broad Medline search of the English literature was performed using the terms of "intra abdominal pressure" and "continuous". This result was analysed based on the title and abstract. Only original clinical studies with continuous IAP measurement were considered in this review. New techniques of CIAP monitoring evaluated in large animal models are discussed as potential future directions.

Results: There is a growing evidence of measuring (monitoring) CIAP using several techniques (gastric, direct abdominal, inferior vena cava, and urinary bladder. The strongest evidence supports the direct abdominal, the gastric and the bladder route. From these three techniques the CIAP monitoring via the bladder has excellent agreement with the current standard of intermittent bladder pressure measurement. While the direct measurement could be very accurate it is an invasive method and feasible in patient who underwent laparotomy or laparoscopy.

Conclusions: Until a better technique is available the CIAP monitoring via the bladder or stomach should be considered as the standard for continuous monitoring of the IAP. It is a less labour intensive, safe, less invasive and reliable method.

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BACKGROUND

Intra-abdominal hypertension (IAH) and abdominal compartment syndrome (ACS) are consistently reported to have significant morbidity and mortality (1-3). The present definition of IAH and ACS (World Society of Abdominal Compartment Syndrome, WSACS) is based on the determination of the intra-abdominal pressure (IAP). IAH is defined as a sustained elevated IAP (>12 mmHg) without organ dysfunction and ACS is defined as IAH with new organ dysfunction such as respiratory, cardiac or renal (4).

Although there are several possibilities, the most widely accepted and feasible way to measure IAP is via the draining port of a standard urinary catheter, originally described by Kron et al (5), which was validated and modified by many authors. The technique is simple and since the critically ill patients who benefit from IAP measurement already have urinary catheters in situ, no further invasive interventions are necessary. It is an intermittent measurement requiring clamping of the catheter and instilling 20 to 25 ml of normal saline into the bladder at every separate measurement.

Although IAP measured via the urinary catheter is the current standard of care to screen patients for IAH/ACS and it has excellent correlation with directly measured IAP, its intermittent nature is its major limitation. The description of the IAP trend in a given patient depends on the interval between separate intermittent measurements, which varies from 4 to 12 hours in most intensive care unit protocols. Recent research highlights that post-injury ACS most frequently occurs within 6-8 hours after ICU admission (2), suggesting, that significant changes in the IAP can happen in the timeframe between the presently used separate measurements. When IAP is greater than 20 mmHg, the abdomen is on the steep portion of its compliance curve and a small increase in volume of abdominal contents can result in a large increase in IAP that may be detected too late by intermittent IAP measurements to avoid full blown ACS (6).

The aim of this paper is to review the current evidence on continuous IAP monitoring.

METHODS

A broad Medline search of the English literature was performed using the terms of "intra abdominal pressure" and "continuous". The results were then analysed based on the title and abstract. Only original clinical studies

with continuous IAP measurement were considered in this review. New techniques of CIAP monitoring evaluated in large animal models are discussed as potential future directions.

RESULTS

Continuous gastric pressure measurement

Sugrue et al compared the intermittent bladder pressure measurement (recommended standard of the WSACS) with the gastric semi-continuous IAP measurement performed via the gastric tonometer (7). The mean difference or bias was 0.35 mmHg (and the limits of agreement ranged from -3.1 to 3.8 mmHg). Thus the gastric balloon technique tends to give a reading that was up to 3 mmHg below or 4 mmHg above that of the urinary catheter technique. These limits of agreement, although "statistically" acceptable can be clinically relevant. The other potential disadvantage of intragastric recording is the effect of the migrating motor complexes, which are the normal cyclic motor fronts that can be identified as periods of regular contraction lasting up to two minutes over a 90 min period and proven to be preserved even after severe trauma (8). The technique of IAP monitoring via gastric tonometry allows a semi-continuous recording of IAP over time, while the standard intravesical method only allows a "snapshot" discontinuous recording. However intra-abdominal pressure monitoring using tonometry is 10 times more expensive compared to the intravesical method, and realistically would be used only when the patient has a tonometer in place for measuring intramucosal pH. Other disadvantages are that the air in the tonometer balloon gets resorbed after 4 to 6 hours so that the trend is lost and the balloon needs to be recalibrated, and that simultaneous intestinal pH and IAP measurements are not (yet) possible with the tonometer. Malbrain et al modified this technique and referred to it as a "semi-continuous method" because of the limitations stated above (9). Afterwards Malbrain validated a continuous transgastric IAP measurement technique in 22 sedated mechanically ventilated ICU patients (submitted ICM). The IAP was estimated using 2 different methods: via the bladder (IBP) and via a balloon-tipped gastric catheter (IGP) connected to an IAP monitor (Spiegelberg, Hamburg, Germany). In total 2029 IGP and 705 IBP measurements were performed. Correlation between IGP and IBP was studied in the 705 paired samples. The mean values for IAP (mmHg) were

9.7±3.3 (IGP) versus 9.9±3.2 (IBP). There was a good correlation between both measurement techniques: $IBP = 0.86 \times IGP + 1.6$ ($R^2=0.81$, $p<0.0001$). Bland and Altman analysis showed good agreement: IGP was almost identical to IBP with a mean bias of -0.2 ± 1.5 (SD) mmHg (95%CI -0.3 to 0); the limits of agreement were -3.1 to 2.8 mmHg and confirmed the good agreement. Agreement was best in the complete supine position. However these preliminary results need to be confirmed in a multi centre trial. De Waele et al found both water and air as a suitable medium for IAP measurement via a balloon tipped compliance catheter with certain precautions specific to the air and water filling: to avoid over-distension (air) and aspiration/refilling (water) of the balloon, which both can cause false measurements (10).

Continuous bladder pressure measurement

Balogh et al described the CIAP technique via the bladder (11). This method involves a minimal addition to the currently recommended intermittent bladder pressure measurement but offers a continuous monitoring tool. The authors compared the Intermittent IAP and the new continuous IAP measurements in 25 trauma and general surgical patients. These patients had a three-way catheter placed previously into their bladder. Size 18 Fr standard three-way catheters (Lubri-Sil™ All-Silicone Foley catheter, C.R. Bard, Inc. Covington, GA, U.S.A.) were used in the study patients. The continuous IAP measurement (CIAP) was performed via the irrigation port of the three-way catheter, in which continuous normal saline perfusion (4 ml/hr) was maintained and connected through a two-way stopcock and normal saline filled tubing to a pressure transducer placed in-line with the iliac crest at the mid axillary line. The transducer was zeroed and the CIAP measurement recorded on the bedside monitor. The continuous measurement was compared in each patient with three separate consecutive interrupted measurements (IIAP) as three measurement pairs. The IIAP measurements were performed immediately after the CIAP was recorded. This method was performed through the drainage port of the three-way catheter and involved the clamping of the tube leading to the collection bag and filling the bladder with 50 mL of sterile normal saline. Pressures were measured via a T-piece inserted into the catheter drainage tubing with the same re-zeroed transducer and tubing used for the CIAP measurement and

displayed on the bedside patient monitor. The CIAP was 14.2 ± 0.66 (range 2 - 24) mmHg and the IIAP was 14.0 ± 0.68 (range 3 - 24) mmHg. In 75% of measurements the measured pairs were exactly the same, in 21% there was a 1 mmHg difference and in 4% the difference was 2 mmHg. There was no measurement difference greater than 2 mmHg. The mean difference between the CIAP and IIAP was 0.019 ± 0.05 mmHg. The Bland-Altman scatter plot (12) did not follow any patterns of typical systematic bias. However these preliminary results need to be validated in a multicentre trial.

Continuous direct peritoneal pressure measurement

Brooks et al compared the Stryker intracompartmental pressure monitor measurement with the laparoscopic insufflator pressure figures in 15 laparoscopic patients (13). The mean difference between the techniques was 0.04 ± 3.8 mmHg. Unfortunately they have not compared the new method with the clinically used intermittent bladder pressure. The method was used only in the operating room and the catheter was removed at the end of the laparoscopic surgery. The complication rate of the peritoneal catheter insertion outside the operating room without laparoscopy or laparotomy is unknown. No data exist on the potential complications if the catheter is used for monitoring the IAP for several days on ICU setting. Although this method appears to be accurate, it requires further validation and at the moment it is not feasible for non-operatively managed patients.

Risin et al compared the intermittent bladder pressure measurement with the intra-abdominal pressure measurement via intraperitoneal surgical drains placed during laparotomy (14). They found very good correlation ($r=0.962$) between the two techniques but unfortunately did not perform Bland and Altman analysis. Good correlation means that the measured pressures are related but not necessarily the same and it does not reveal systemic measurement biases like Sugrue et al described with the gastric method. Certainly it is a very simple technique in laparotomy patients who have drains but the current surgical practice less likely to use peritoneal drains and many patients require IAP monitoring who did not have laparotomy.

Davis et al (15) and Suominen et al (16) also used direct peritoneal monitoring via peritoneal dialysis catheter in paediatric populations. They connected the peritoneal dialysis catheter to the pressure transducer

and monitored IAP continuously (this technique was they standard) to evaluate the effect of bladder filling volume on IAP measurement of children with body weight range of 1.5 – 42 kg.

Future continuous abdominal pressure monitoring

Continuous IAP monitoring via the inferior vena cava could be a valuable tool in high risk patients on the ICU. The animal studies and some anecdotal clinical evidence show good correlation (17).

Some new promising direct and indirect measurement techniques were described and validated in animal laboratories. Schachtrupp et al validated for continuous direct IAP measurement a piezoresistive probe, a modified piezoresistive probe technique, a water-capsule technique and an air-capsule (ACM) pressure measurement probe (18,19). All these techniques had excellent accuracy and the authors conclude that probably the modified piezoresistive and the ACM (Spiegelberg) technique had the greatest feasibility for the human practice.

Meier et al evaluated rectus abdominis compartment pressure monitoring as a tool for continuous IAP monitoring in a rat model (20). The rectus sheath compartment pressured showed an excellent agreement over the 12 mmHg pressure threshold, which is the clinically relevant IAP.

DISCUSSION

The need for continuous monitoring of the IAP has been brought up by different groups of investigators in the past. Various methods have been tested and recommended for clinical use but none of them have become the standard of care for IAP monitoring. The more invasive methods are excellent in laboratory settings but are less feasible in clinical scenarios. The direct measurement of IAP via the gas insufflator during laparoscopy was only used in controlled elective surgical settings for testing other routes of IAP measurements and was never clinically validated. The validity of the measurement during insufflation is also questionable and the method is not feasible for use in the ICU.

Gastric pressure

Simple techniques utilizing nasogastric tubes and gastric tonometers to measure IAP have been used by several authors. Concern has been expressed about simple perfusion techniques using a nasogastric tube, and Lacey in an animal study found that the use of gastric pressure measurement though the irrigation port of the nasogastric tube was not reproducible (17). Collee et al used an unperfused nasogastric tube for measuring IAP and found that gastric pressure may be 2.5cm of water above or below intra-vesical pressure (21). Sugrue et al validated the methodology of IAP measurement via a nasogastric tube with a tonometer and found that the gastric balloon technique tends to give a reading of up to 3 mmHg below or 4 mmHg above that of the urinary catheter technique (7). Obeid et al compared IAP measurement using four techniques in 26 patients. These included an intra-gastric route via a simple nasogastric tube, a laparoscopic insufflator, rectal pressure via a modified oesophageal stethoscope and a standard intra-vesical method using a urinary catheter (6). Obeid found that with a standard 6mmHg rise in IAP, as measured by the insufflator, was best correlated with the intravesical measurements and a rise of 5.7mmHg. The gastric and rectal pressures were less reliable with the following changes recorded: -0.7 ± 9.8 mmHg and 3.3 ± 8.8 mmHg, respectively. He found that the rectal and gastric pressures were more position dependent and less reliable than the intravesical approach. Additionally the content of the stomach and rectum could influence the measurements. The other potential disadvantage of intragastric recording is the effect of the migrating motor complexes (8). The technique of IAP monitoring via gastric tonometry allows a semi-continuous recording of IAP over time, while the standard intravesical method requires a discontinuous recording. Intra-abdominal pressure monitoring using tonometry is more expensive compared to the intravesical method. But simultaneous intestinal pH and IAP measurements are not possible with the tonometer. The gastric route of CIAP monitoring is a bit more cumbersome (proper positioning of the compliance catheter) and might have a higher risk of infectious complications in the paranasal sinuses. The effect of gastric nutrition on gastric CIAP monitoring is largely unknown. While most ICU patients who are high-risk for IAH/ACS have a urinary catheter, the insertion of an oro-/nasogastric tube often means an additional procedure.

New techniques as with the Spiegelberg (Spiegelberg, Hamburg, Germany) or CIMON (Pulsion Medical

Systems, Munich, Germany) that are fully automated will allow a real continuous IAP trend that is user independent. The Spiegelberg technique has been validated in vitro recently (22) as well as in pigs (19) and the human data (23) are submitted for publication while the preliminary results of the in vitro and in vivo (pigs) validation of the CiMON device will be presented at the third WCACS. The clinical relevance of the limits of agreement when comparing these techniques with bladder pressure need to be seen within the context of body position and zero reference and further studies need to be done before final conclusions can be drawn.

Direct peritoneal pressure

The direct abdominal pressure measurement could be a feasible option for patients requiring laparotomy or laparoscopy. There is no published evidence available regarding the use of this technique in non-operatively managed patients. Considering that the incidence of secondary ACS is up to 50% of all ACS patients at the moment, direct monitoring does not provide a safe option for them.

Inferior vena cava pressure

The measurement of the pressure in the inferior vena cava via a femoral vein catheter is reported in animal models (17) but its routine use may not be warranted because of possible infectious and thrombo-embolic complications. Additionally, in patients who already have a temporary abdominal closure on ICU admission, interventions such as aseptic catheter insertion in the groin area may not be optimal to perform.

Bladder pressure

The gold standard for IAP measurement recommended by the WSACS is the intravesical intermittent technique (4) originally described by Kron (5). This technique is used virtually in all clinical reports on IAH and ACS. The critically ill or injured patients who benefit from IAP monitoring already have urinary catheters in situ so the method does not require further invasive intervention. It is cheap and easily reproducible.

The intravesical measurement of IAP while reliable is time consuming and requires instillation of saline into the bladder and clamping of the urinary catheter. The major limitation of vesical IAP measurement however is its intermittent nature. One vesical IAP measurement takes 5 to 7 minutes including the clamping and filling up of the bladder with 20-25 mL of normal saline. This labour and time requirement prevents its performance to any more frequently than 4 to 8 hourly interval in most ICU protocols (11). This timeframe is not adequate for the timely recognition of IAH and ACS after severe traumatic shock with consequent aggressive resuscitation (2).

The preliminary validation of the technique of continuous IAP monitoring via bladder revealed that this new method has a good agreement with the present "gold standard" of intermittent intra-vesical IAP measurements. The Bland and Altman's methodology statistically confirmed this.

The intra-vesical CIAP does not require a major change in the present practice apart from the use of three-way urinary catheters. This method abandons the cumbersome steps of draining, clamping of the catheter and filling with 20-25 mL of normal saline. The monitoring is continuous and does not interfere with the urinary flow through the drainage port of the catheter, however the creation of a urine column from bladder to collection bag could create a negative suction force that might underestimate real IAP. The continuous IAP monitoring is less labour and time consuming compared to the standard intermittent measuring technique.

Advantages of continuous IAP

The continuous IAP measurement has several potential advantages to exploit in the future. The continuous measurement of the IAP makes it possible to monitor the abdominal perfusion pressure (mean arterial pressure minus IAP) similar to the analogy of the cerebral perfusion pressure. This new measure theoretically may be a superior parameter to monitor over the IAP since it includes the patients hemodynamics in some extent. This idea is further supported by the clinical observation that not all patients develop ACS at IAP higher than 25 mmHg but some patients develop ACS with IAP below 25 mmHg. The concept of abdominal perfusion pressure is not a totally new concept. Cheatham et al found it superior to IAP and mean arterial pressure alone in a retrospective prediction

model (24). The main criticism of the study was the retrospective nature, and the intermittent measurements of the IAP. It is difficult to imagine how could be calculated the abdominal perfusion pressure from a continuously measured mean arterial pressure and the 4 hourly intermittently measured IAP in a retrospective fashion. But despite all the criticism the abdominal perfusion pressure approach to the describing and predicting IAH/ACS is more realistic and physiologic than the arbitrary IAP thresholds. The abdominal perfusion pressure had relatively high (0.76) area under the receiver operating characteristic curve (ROC) in their model. Post-injury ACS can be predicted by much better accuracy (even with excluding IAP from the model) ROC = 0.88 at the time of emergency department discharge and ROC = 0.99 after one hour post-ICU admission (2). But for this more abundant monitoring is required such as gastric tonometry and preferably pulmonary artery catheter. The continuous IAP monitoring can provide the 24 hours abdominal perfusion pressure trends of the patients and this possible meaningful parameter needs to be validated prospectively.

IAP is difficult to monitor during the laparotomy, when eventually the decision should be made whether to close the fascia or apply temporary abdominal closure. The continuous IAP monitoring can be coupled to the anaesthetic monitor and appreciate the pressure changes during the attempted closure.

So far, the only obvious downside of continuous IAP monitoring besides the multicentric validation is the price difference for the three-way Foley catheter (which is less than €15) or the dedicated nasogastric tube (estimated cost €50 - €75). Given the magnitude of the cost of the care of critically ill and injured ICU patients, the acquired additional and more accurate information and the decreased workload on the healthcare personnel, this extra expenditure is negligible.

CONCLUSION

Given the accuracy and feasibility of continuous IAP measurement via the bladder or the stomach we recommend its routine clinical use in patients with IAH > 15 mmHg with other risk factors: general/vascular surgical patients after major abdominal surgery; severe acute pancreatitis; >15% total body surface area burns, trauma patients with severe traumatic shock and resuscitation or undergoing damage control laparotomy, and ICU patients with more than 1 new organ failure. The possible role of abdominal perfusion pressure

monitoring and continuous IAP monitoring in the operating room during abdominal closure needs to be evaluated.

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