

A user's guide to intra-abdominal pressure measurement

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Abstract

The intra-abdominal pressure (IAP) measurement is a key to diagnosing and managing critically ill medical and surgical patients. There are an increasing number of techniques that allow us to measure the IAP at the bedside. This paper reviews these techniques. IAP should be measured at end-expiration, with the patient in the supine position and ensuring that there is no abdominal muscle activity. The intravesicular IAP measurement is convenient and considered the gold standard. The level where the mid-axillary line crosses the iliac crest is the recommended zero reference for the transvesicular IAP measurement; moreover, marking this level on the patient increases reproducibility. Protocols for IAP measurement should be developed for each ICU based on the locally available tools and equipment. IAP measurement techniques are safe, reproducible and accurate and do not increase the risk of urinary tract infection. Continuous IAP measurement may offer benefits in specific situations in the future. In conclusion, the IAP measurement is a reliable and essential adjunct to the management of patients at risk of intra-abdominal hypertension.

Key words: intra-abdominal pressure, measurement, bladder pressure, intravesicular pressure, gastric pressure, rectal pressure, femoral venous pressure, continuous, abdominal perfusion pressure

The intra-abdominal pressure (IAP) measurement is fundamental for the evaluation of critically ill patients at risk of intra-abdominal hypertension (IAH), in particular following emergency trauma and acute care surgery [1]. While it is almost 140 years since Wendt first described the association between raised IAP and organ dysfunction, it is really only in the last 20 years that we have come to understand the importance of the relationship between IAP and intra-abdominal organ perfusion [2, 3]. As such, a number of different techniques have evolved concurrently over the last 20 years to measure and accurately quantify IAP.

The World Society of the Abdominal Compartment Syndrome (WSACS, www.wsacs.org), founded in 2004, has outlined definitions and recommendations relating to the measurement of IAP in 2006/2007 [4, 5], which were subsequently updated in 2013 [6]. Within these documents, an underlying and fundamental message remains that to understand the role of elevated IAP in the evolution from

IAH to full-blown abdominal compartment syndrome (ACS) we need to measure IAP. The WSACS recommends that IAP be measured every 4 to 6 hours in critically ill patients who demonstrate one or more risk factors for the development of IAH or ACS. Starkopf et al. recently reviewed whether we should measure IAP in all patients in an ICU as identifying high-risk patients is not always successful [7]. They concluded that the risk of developing IAH is minimal in mechanically ventilated patients with a positive end-expiratory pressure (PEEP) < 10 cm H₂O, PaO₂/F_iO₂ > 300, and a BMI < 30 kg m⁻² and without pancreatitis, hepatic failure/cirrhosis with ascites, gastrointestinal bleeding or laparotomy and the use of vaso-pressors/inotropes on admission. In these patients, omitting IAP measurements might be considered. Table 1 lists the risk factors for IAH, when 2 or more risk factors are present a baseline IAP measurement should be obtained. Suggested practice guidelines relating to IAP have been in place for over a decade and may help in identifying patients at risk [8].

Table 1. Risk factors for IAH/ACS

Diminished abdominal wall compliance
Acute respiratory failure, especially with elevated intrathoracic pressure
Abdominal surgery with primary fascial or tight closure
Major trauma/burns
Prone positioning, head of bed > 30°
High body mass index (BMI), central obesity
Increased intra-luminal contents
Gastroparesis
Ileus
Colonic pseudo-obstruction (Ogilvie)
Increased abdominal contents
Hemoperitoneum/pneumoperitoneum
Ascites/liver dysfunction
Capillary leak/fluid resuscitation
Acidosis (pH < 7.2)
Hypotension
Hypothermia (core temperature < 33° C)
Massive transfusion (> 10 units of blood/24 hrs)
Coagulopathy platelets < 55 G L ⁻¹ or PT > 15 sec /PTT > 2 times normal/INR > 1.5)
Massive fluid resuscitation (> 5 L/24 hours)
Pancreatitis
Oliguria
Sepsis
Major trauma/burns
Damage control laparotomy

Through the work of the WSACS and other advances in medical care there has been an obvious improvement in the care of critically ill patients and their outcomes [9]. Moreover, the measurement of IAP has been pivotal in this paradigm shift in care. The purpose of this article was to review the physiology of IAP and existing and emerging methods to measure direct and surrogate values of IAP. We focus on new concepts in IAP measurement, while considering the influence of patient body position, mechanical ventilation, and body habitus on IAP values.

METHODS

A MEDLINE and PubMed search was performed using the search terms “abdominal pressure” or “bladder pressure” or “vesicular pressure” and “measurement” or “monitoring” or “technique”. Titles and abstracts identified by this search were screened and selected on the basis of relevance, methodology and scientific merit. Full text articles of the selected abstracts were used to supplement the authors’ expert opinion and experience. The references of the selected

Table 2. Current Recommendations for Grading IAH

IAH grading	
Grade I	12–15 mm Hg
Grade II	16–20 mm Hg
Grade III	21–25 mm Hg
Grade IV	≥ 25 mm Hg

papers were also checked for other citations of interest. The resulting references were included in the current review, which will outline the new concepts in IAP measurement, recapitulate on normal pressure values, focus on different techniques to measure pressure, looking at the effect of body position, ventilation and body habitus on IAP values.

DEFINITIONS AND PHYSIOLOGY

IAP is the pressure concealed within the abdominal cavity as defined superiorly by the diaphragm, anteriorly and posteriorly by the abdominal wall, and inferiorly by the pelvic floor. Although normal IAP values are considered to be around 5 to 7 mm Hg can vary tremendously depending on physical activity, in general they fluctuate gradually in patients [10]. In critically ill patients baseline IAP is around 10 mm Hg. Different grades of IAH have been defined by the WSACS (Table 2). IAP may also be used to calculate abdominal perfusion pressure (APP), which is calculated by subtracting the IAP from the mean arterial pressure (MAP): $APP = MAP - IAP$ [2].

In general, the abdominal compartment transduces pressure evenly throughout the cavity [11]. Exceptions occur in the presence of pelvic haematoma following trauma or retroperitoneal haemorrhage [12]. In addition, isolated organs may undergo individual organ hypertension through the limitations of their fascial envelopment. This can occur in the kidney, where Gerota’s fascia can itself create a functionally isolated organ compartment. Isolated liver compartments can occasionally occur in liver haematoma, caused by the restriction of Glisson’s capsule.

Cresswell examined the influence of body position and compartment pressure following liver transplantation and found a clinically significant variation in inter-compartmental pressure following liver transplantation [13]. They suggested that there could be regional perfusion differences and that IAP should be interpreted with caution.

FACTORS AFFECTING IAP MEASUREMENT

IAP needs to be measured in mm Hg and at the end of expiration with the patient in the supine position and the transducer placed at the mid-axillary line where it crosses the iliac crest. Intermittent IAP measurements provide a somewhat artificial measurement of IAP that does not

Table 3. Current IAP Measurement techniques

1. Bladder	
Intermittent	
Modified Kron	
Harrahill	
Foley Manometer (Holtech Medical, Charlottenlund, Denmark)	
Unometer abdopressure (ConvaTec, Skillman, NJ, USA)	
AbViser valve (ConvaTec, Skillman, NJ, USA)	
Continuous	
3 way Foley catheter	
T-Doc air charged catheter (Laborie International, Mississauga, Ontario, Canada)	
2. Gastric	
Intermittent	
Nasogastric tube	
GastroManometer (Holtech Medical, Charlottenlund, Denmark)	
Continuous	
CiMon (Pulsion Medical Systems, Munich, Germany)	
Spiegelberg (Spiegelberg, Hamburg, Germany)	
3. Rectal	
4. Vaginal	
5. Inferior Vena Cava	
6. Direct Peritoneal Pressure	
Continuous via central venous line or peritoneal drain	
Compass™ Vascular Access Pressure Transducer (Mirador Biomedical, Seattle, WA, USA)	

truly reflect the day-to-day activities of an ICU or critically ill patient. However, it allows one to attain the reproducibility of results and is cost-effective and easy to perform, costing between 20 and 80 Euros per patient and taking 10 minutes to initiate and 5 minutes to perform [11]. We know from the work of Yi, and others, that body position can affect IAP [14,

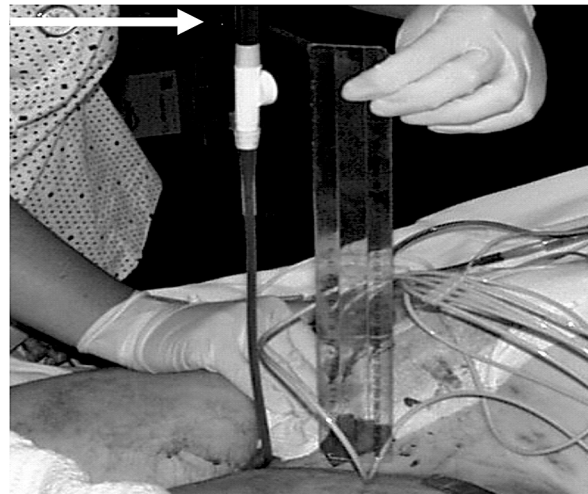


Figure 1. Harrahill technique of IAP measurement. The arrow indicates the height of the urine column and this correlates to IAP

15]. Cheatham et al., in a multicentre analysis of different body positions found that mean IAP values at each head of bed position were significantly different [15]. The bias between IAP supine and IAP at HOB 15° was 1.5 mm Hg (1.3–1.7). The bias between IAP supine and IAP at HOB 30° was 3.7 mm Hg (3.4–4.0). Cheatham et al. concluded that consistent body positioning from one IAP measurement to the next is necessary to allow one to observe the consistent trending of IAP for accurate clinical decision-making. De Waele et al., in another multicentre study on the effect of transducer position found the bias between the IAP transducer located in the mid-axillary line (IAPmidax) and the IAP transducer at the level of the pubis symphysis was 3.8 mm Hg (95% CI 3.5–4.1) and 2.3 mm Hg (95% CI 1.9–2.6) between the IAPmidax and the transducer located at the mid-chest level [16]. Both of these studies emphasise the importance of a standardised approach to IAP measurement to ensure

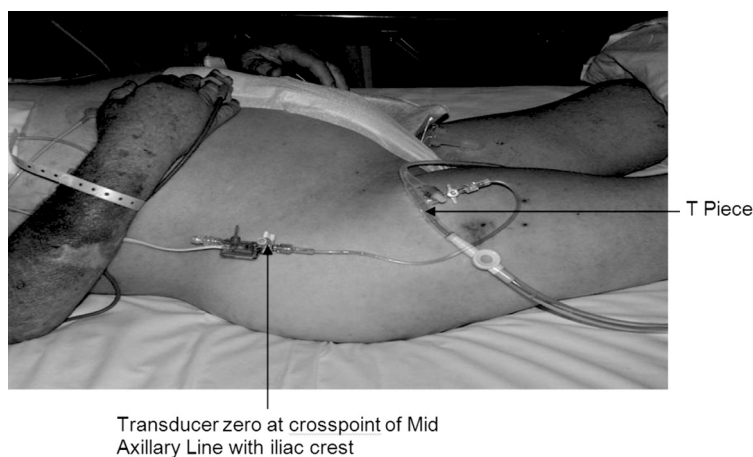


Figure 2. Modified intravesicular pressure measurement technique. Picture of modified Kron technique IAP measurement showing transducer, T Piece and Urinary Catheter

Table 4. Conditions for a reproducible IAP measurement

1. Expressed in mm Hg (1 mm Hg = 1.36 cm H₂O)
2. Measured at end-expiration
3. Performed in the supine position
4. Zeroed at the iliac crest in the mid-axillary line
5. Priming volume < 25 mL of saline (1 mL kg⁻¹ for children up to 20 kg)
6. Measured 30–60 sec after instillation to allow for bladder detrusor muscle
7. Measured in the absence of active abdominal muscle contractions

the reproducibility of results. More recently, Soler Morejon et al. identified the importance of the zero reference level and its impact on IAP measurement in surgical patients after abdominal surgery [17].

A clinical examination is not a reliable indicator of IAP [18, 19]. The abdominal perimeter also correlates poorly with IAP [20]. As such, determination of the level of IAP requires measurement via a catheter or device, which may be either self-made or proprietary. IAP can be measured directly from catheters placed in the peritoneal cavity or indirectly classically through the bladder or alternatively via the rectum, vagina or stomach [11]. Measurements can be intermittent or continuous [21, 22]. A list of current available IAP techniques is displayed in Table 3.

BLADDER PRESSURE MEASUREMENT

While simple, the Harrahill technique where the urinary catheter is elevated at 90 degrees, is not reproducible (Fig. 1) [23]. The gold standard for IAP measurement is the intravesical technique [24, 25]. This method, originally developed by Kron, has subsequently been modified over the last 10 years by Iberti, Sugrue, Malbrain and others [11, 26–28].

To measure intra-vesicular pressure at defined intervals, the bladder should be filled with a maximum of 25 mL of saline in line with the WSACS guidelines and an intermittent measurement can be made. Table 4 lists the conditions for a reproducible bladder pressure measurement. De laet et al. has recently confirmed that low volume instillation is acceptable [29–31]. Transduction of intra-vesicular pressure can then be performed using a number of bladder techniques. These include the use of an interposition T-piece, direct cannulation of the urinary catheter using a transducer based needle, or the insertion of a continuous transduction method using a 3-way Foley catheter (Figs 2, 3). Over the years different variations on the original Kron's technique have been suggested (Fig. 4). Another simple method includes the bedside Foley manometer U-Tube (Figs 5, 6). In addition, a number of variations in these techniques have been described. Bladder pressure measurements can also be performed continuously [21, 32], as presented in Figure 7. However, only recently have bedside ICU monitors (Philips,

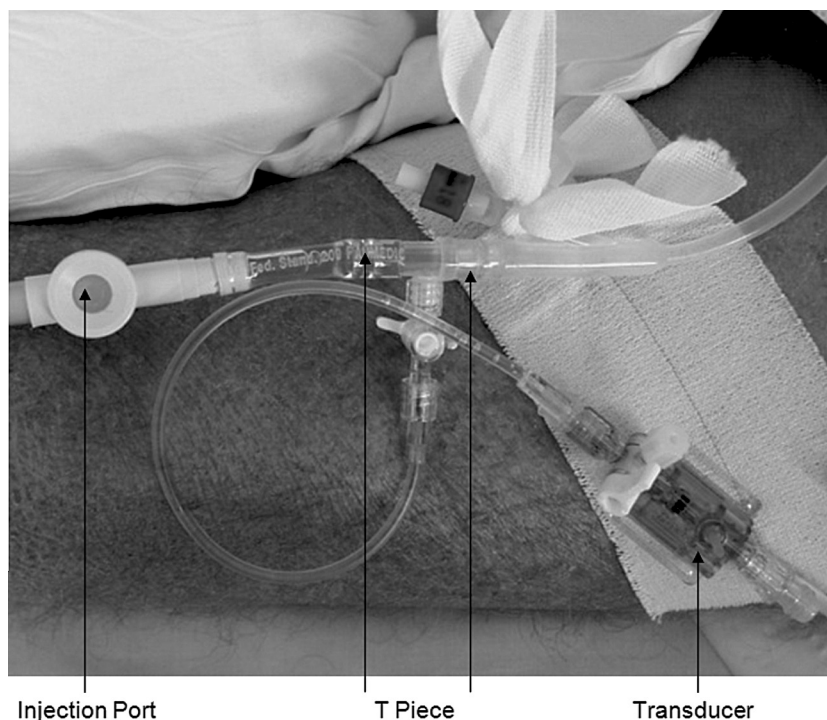


Figure 3. Closer look at the T piece in place connected to the transducer

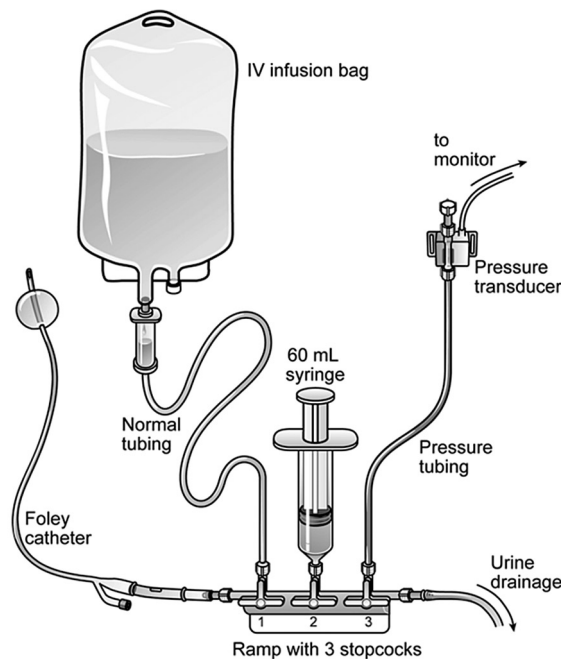


Figure 4. Modified method for intravesicular pressure monitoring as described by Malbrain (adapted from Desie et al. [28] with permission)

Set-Up:

- Wash hands and follow universal antiseptic precautions
- A Foley catheter is sterile placed and the urinary drainage system connected.
- Using a sterile field and gloves, the drainage tubing is cut (with sterile scissors) 40cm after the culture aspiration port after disinfection.
- A ramp with 3 stopcocks (e.g. Manifold set, Pvb Medizintechnik GmbH, a SIMS Trademark, 85614 Kirchseeon, Germany, REF: 888-103-MA-11; or any other manifold set or even 3 stopcocks connected together will do the job) is connected to a conical connection piece (e.g. Conical Connector with female or male lock fitting, B Braun, Melsungen, Germany, REF: 4896629 or 4438450) at each side with a male/male adaptor (e.g. Male to Male connector piece, Vygon, Ecouen, France, REF: 893.00 or 874.10).
- The ramp is then inserted in the drainage tubing.
- A standard intravenous (IV) infusion set is connected to a bag of 500mL of normal saline or D5W and attached to the first stopcock.
- A 60-mL syringe is connected to the second stopcock and the third stopcock is connected to a pressure transducer via rigid pressure tubing.
- The system is flushed with normal saline
- The pressure transducer is fixed at the symphysis or the thigh.
- Connect the transducer to the monitor via the special pressure module and ensure a normal waveform on the scope.
- Select a scale from 0 to 20 or 40 mmHg

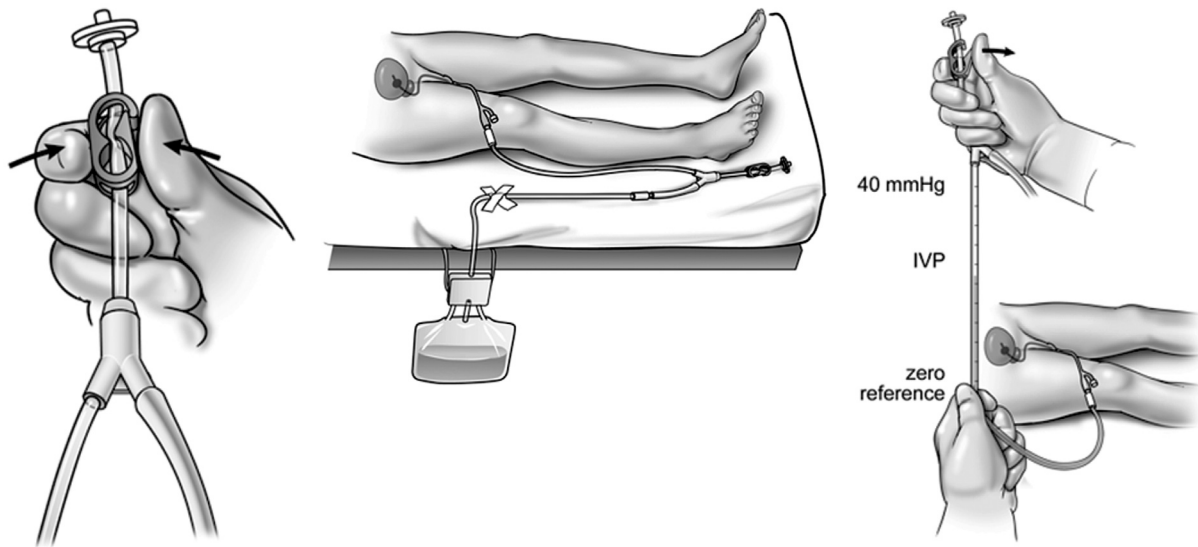
Method of measurement:

- If the patient is awake, explain the procedure.
- If the patient is sedated, ensure good sedation.
- Place the patient in a complete supine position.
- Zero the pressure module at the midaxillary line of the patient at the level of the iliac crest (mark for future reference) by turning the proximal stopcock on to the air and the transducer
- At rest the 3 stopcocks are turned "off" to the IV bag, the syringe and transducer giving an open way for urine to flow into the urometer or drainage bag, said otherwise the 3 stopcocks are turned "on" to the patient.
- To measure IVP, the urinary drainage tubing is clamped distal to the ramp-device and the third stopcock is turned "on" to the transducer and the patient and "off" to the drainage system.
- The third stopcock also acts as a clamp.
- The first stopcock is turned "off" to the patient and "on" to the IV infusion bag, the second stopcock is turned "on" to the IV bag and the 60-mL syringe.
- Aspirate 20-25ml of normal saline from the IV bag into the syringe.
- The first stopcock is turned "on" to the patient and "off" to the IV bag and the 20-25ml of normal saline is instilled in the bladder through the urinary catheter.
- The first and second stopcock are then turned "on" to the patient, and thus turned "off" to IV tubing and the syringe.
- The third stopcock already being turned "on" to the transducer and patient allows then immediate IVP reading on the monitor.

Eindhoven, The Netherlands) provided a channel for labelled IAP recording.

Some have expressed concerns regarding the possibility of inducing urinary tract infection due to the manipulation

of the closed circuit of the urinary catheter and collection system. However, according to Cheatham et al. [33] and Desie et al. [28] this fear is unwarranted.

**PANEL A, Initial set-up:**

- Open the FoleyManometer LV (Holtech Medical, Charlottenlund, Denmark, www.holtech-medical.com) pouch and close the tube clamp
- Place the urine collection device under the patient's bladder and tape the drainage tube to the bed sheet.
- Insert the FoleyManometer between catheter and drainage device.
- Prime the FoleyManometer with 20ml of sterile saline through its needle-free injection/sampling port.
- Prime only once i.e. at initial set-up, or subsequently to remove any air in the manometer tube.

PANEL B, Urine drainage

- Let the urine drain in between IVP measurements
- Urine sampling from the needle-free port is facilitated by temporarily opening the red clamp. Remember to close clamp afterwards.
- Avoid a U-bend of the large urimeter drainage tube (which will impede urine drainage).
- Replace the FoleyManometer whenever the Foley catheter or the urine collection device is replaced, or at least every 7 days.

PANEL C, Intravesicular pressure Monitoring:

- Place the "0 mmHg" mark of the manometer tube at the midaxillary line at the level of the iliac crest (mark for future reference) and elevate the filter vertically above the patient.
- Open the bio-filter clamp, and read IVP (end-expiration value) when the meniscus has stabilized after about 10 seconds.
- Close clamp after IVP measurement and place the FoleyManometer in its drainage position.

Figure 5. Intravesicular pressure monitoring with the FoleyManometerLV (adapted from Desie et al. [28] with permission). This technique that uses the patient's own urine as pressure transmitting medium is a surprisingly simple, reliable, and cost-effective clinical tool. Based on a modified version of the IAP monitoring technique described by Kron et al. [3], the disposable FoleyManometer provides a closed sterile circuit which connects between the patient's Foley catheter and the urine collection device. Each IAP determination takes about 10 seconds, and no subsequent correction of urine output is required. The technique uses a low bladder infusion volume, has a needle-free sampling port and can measure IAP in a range from 0 - 40 mmHg. Therefore it is an ideal technique to screen critically ill patients for IAH

OTHER INDIRECT IAP MEASUREMENT TECHNIQUES

The gastric route can also be used to measure IAP and provides one of the easiest ways of measuring continuous IAP [11, 27, 34–36]. Recently, a novel transgastric technique has been described using a GastroManometer [37]. Continuous intra-gastric pressure measurements are possible using a balloon-tipped nasogastric probe, which provides a continuous trace [11, 35]. The Spiegelberg continuous intra-gastric pressure monitor using an air-filled pouch to the tip also allows one to perform continuous monitoring [11, 38, 39].

Inferior vena cava pressures also indirectly reflect IAP and can be measured via trans-femoral cannulation [40]. Variations exist between pressures using different techniques. De Keulenaer et al. identified that morbidly obese patients have higher baseline pressures in an overview of IAP measurement techniques

in patients with different body mass indexes [40]. Femoral vein pressure cannot be used as a surrogate measure of IAP unless the IAP is above 20 mm Hg. For two IAP techniques to be considered interchangeable, the WSACS recommends a bias of less than 1 mm Hg with a precision of 2 mm Hg and limits of agreement between -4 and 4 mm Hg. De Keulenaer et al., in one of the largest human trials comparing bladder pressure with femoral vein pressure, found that, while there was a good correlation and a reasonable bias, the limits of agreement were too large to consider both techniques equivalent. However, femoral vein pressure and bladder pressure can be interchanged when the IAP is above 20 mm Hg [40].

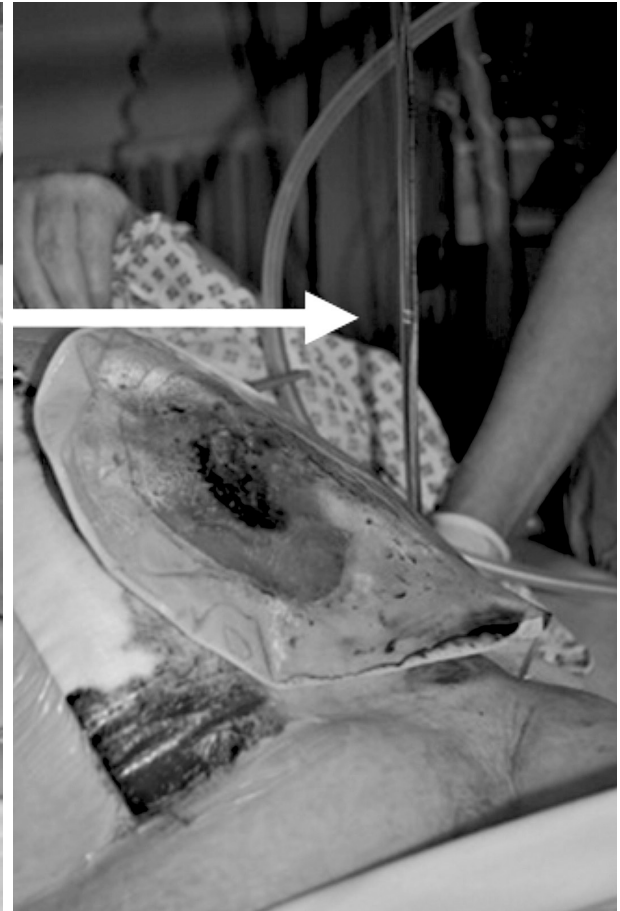
At present, rectal and transvaginal measurement of IAP are less practical and more experimental. Remote indirect



Panel A. Patient set-up



Panel B. Elevation of urine drainage tubing

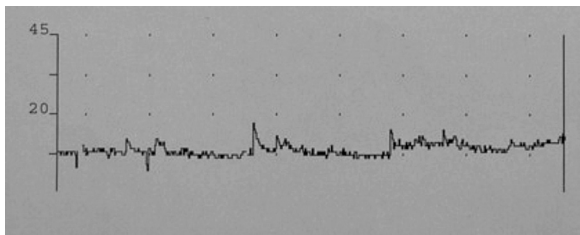


Panel C. Measurement of IAP at end-expiration. The column of urine is measured in from the top of the line as shown by the arrow

Figure 6. The positioning and set up for FoleyManometer measurement of IAP in a patient



Panel A. Showing the set up for continuous IAP with a 3-way Foley catheter and the irrigation channels is connected to arterial line transducer perfused at 4 mL h⁻¹



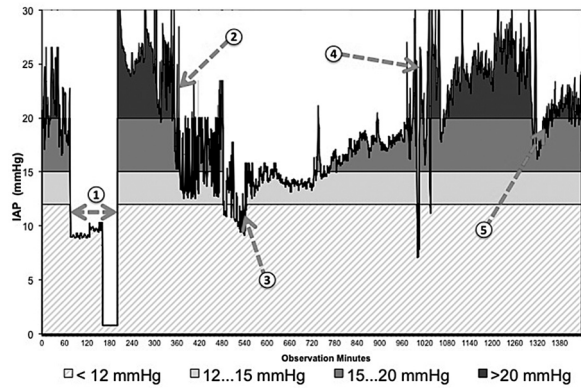
Panel B. Continuous tracing of IAP as obtained via 3-way Foley

Figure 7. Continuous bladder pressure measurement

IAP measurement can also be performed using intravaginal transmitters in a wireless fashion in women [41].

Newer techniques are being continuously developed including wireless transducers for monitoring IAP [42, 43]. Recently, Chiumello developed a new polyfunctional nasogastric tube that allows recordings of pressure in both the oesophagus and stomach [44]. Special balloon-tipped bladder catheters have also become available for continuous IAP monitoring [45]. Other techniques include the use of an external digital transducer connected to a peritoneal drain [46].

In general, IAP measurements are simple to perform, reproducible and should be undertaken in high-risk patients in the ICU. Identification and management of IAH will improve outcomes and aid in decision-making in decompression and abdominal closure [47].



Panel A. Tracing obtained with CiMon monitor in a 52 year old patient with abdominal sepsis. (1) indicates the transport to CT and disconnection to monitoring; (2) indicates the start of paracentesis while (3) indicates the end after evacuation of 3280 mL ascites. (4) indicates a progressive increase in IAP related to a hematoma formation around the spleen as shown on ultrasound. (5) indicates start of surgery with hematoma removal. Light grey indicates IAP range between 12 and 15 mm Hg, darker grey IAP between 15 and 20 mm Hg and the darkest grey IAP > 20 mm Hg. The light shaded area indicates normal IAP < 12 mm Hg

Patient 1				
Begin:	14/03/2010	8:00	0	
End:	15/03/2010	7:59	1439	
Duration:	1440 min			
Area:	27204,44 min*mmHg			
Mean (SD):	18,89	6,51	Observation Minute	
Min:	0,78	mmHg	@	162
Max:	43,85	mmHg	@	479
IAP-Range	Accumulated time min		Accumulated area min*mmHg	
<12	166,00	11,53%	16534,47	60,78%
12...15	239,00	16,60%	3555,97	13,07%
15...20	423,00	29,38%	4128,79	15,18%
>20	612,00	42,50%	2985,21	10,97%

Panel B. The table shows the automatic calculation of the time above a certain threshold (TAT) as well as the area under the curve (AUC) for a certain threshold

Figure 8. Automated a nalysis of 24 hour IAP trend

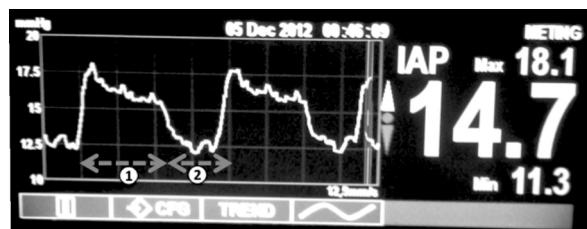


Figure 9. Continuous IAP tracing in patient with COPD and forced expiration, note the end-expiratory increase in IAP caused by accessory abdominal muscle contractions, wheezing and auto-PEEP. The IAP at end-expiration is erroneously increased and is 18.1 mm Hg while the value at endinspiration is only 11.3 mm Hg and more correct in this setting. (1) indicates the expiration period while (2) shows inspiration

IMPORTANCE OF CONTINUOUS IAP MONITORING

A continuous trend of 24-h IAP recordings can be obtained with a balloon-tipped IAP catheter placed in the stomach or a 3-way Foley catheter. If IAP is only measured intermittently, i.e. 2 to 4 times a day, the daily fluctuations and peak pressures may be missed. Therefore, continuous IAP monitoring allows better to assess the effects of medical management. Moreover, during continuous IAP monitoring respiratory variations can be more easily identified: the IAP increases at end-inspiration (IAP_{ei}) and decreases at end-expiration (IAP_{ee}). Hence, the delta IAP or ΔIAP can be calculated as IAP_{ei} minus IAP_{ee} . In mechanically ventilated patients the ΔIAP is related to the compliance of the abdominal wall (C_{ab}), as suggested by Sturini et al. [48]. Another surrogate parameter for C_{ab} is the abdominal pressure variation (APV), calculated as ΔIAP divided by the mean IAP (MIAP). In mechanically ventilated patients MIAP may better reflect the true impact of sustained IAH as compared to IAP_{ee} [49]. Continuous IAP monitoring also allows one to obtain a continuous APP tracing that can be used as a resuscitation endpoint [2]. Future options may include the automatic analysis of 24-hour IAP trends with a calculation of the area under the curve (AUC) above a certain threshold and the time above a threshold (TAT), as illustrated in Figure 8. Continuous IAP monitoring can also be helpful to identify the transmission from one compartment to another (e.g. the abdomino-thoracic index of transmission is on average 50%) and to better understand polycompartmental interactions. In patients with chronic obstructive pulmonary disease (COPD), continuous IAP monitoring allows one to assess patient-ventilator interactions, dyssynchrony and work-of-breathing (Fig. 9) [50].

SUMMARY KEY POINTS

- IAP should be measured at end-expiration, with the patient in the supine position and ensuring that there is no abdominal muscle activity.
- The intravesicular IAP measurement is convenient and considered the gold standard.
- The level where the mid-axillary line crosses the iliac crest is the recommended zero reference for transvesicular IAP measurement; moreover, marking this level on the patient increases reproducibility.
- When the head of the bed is elevated above 30°, IAP is increased.
- Protocols for IAP measurement should be developed for each ICU based on the locally available tools and equipment.
- IAP measurement techniques are safe, reproducible and accurate.
- IAP measurement techniques have greatly improved over the years, with multiple assembled kits commercially available.

- The intravesicular IAP measurement does not increase the risk of urinary tract infection
- A continuous IAP measurement may offer benefits in specific situations in the future.

CONCLUSIONS

Over the years different direct and indirect techniques of measuring IAP have been described. Each technique needs to be assessed on its own merits; most importantly the intensivist should pick one technique and measure IAP in a standardized reproducible fashion. In the future, new techniques may become available using cost-effective solid-state pressure transducers, inserted via the bladder or stomach or by the ingestion of wireless capsules, allowing the continuous monitoring of IAP.

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