How does Intra-abdominal Pressure Affect the Daily Management of My Patients?

I.E. De laet, J.J. De Waele, and M.L.N.G. Malbrain

Introduction

A compartment syndrome exists when increased pressure in a closed anatomic space threatens the viability of the enclosed tissue. When this occurs in the abdominal cavity the impact on end-organ function within and outside the cavity can be devastating. The abdominal compartment syndrome (ACS) is not a disease; as such it can have many causes and it can develop within many disease processes. Unlike many commonly encountered disease processes which remain within the purview of a given discipline, intra-abdominal hypertension (IAH) and the ACS readily cross the usual barriers and may occur in any patient population regardless of age, illness, or injury. In an attempt to bring together all physicians and other health care workers who are confronted on a regular basis with the adverse effects of IAH, the World Society of the Abdominal Compartment Syndrome (WSACS, www.wsacs.org) was founded.

Recent animal and human data suggest that the adverse effects of elevated intra-abdominal pressure (IAP) can already occur at lower levels than previously thought and even before the development of clinically overt ACS. Therefore, clinicians should be aware of all the different effects of IAH on organ function and incorporate the concept of IAH into their everyday clinical management. This chapter will give a brief overview of definitions, etiology, and epidemiology of IAH/ACS and focus on the influence of IAH on the general ICU management of the critically ill patient and how IAP can be used in daily practice irrespective of interventions specifically aimed at reducing IAP, which will not be discussed here.

Definitions

The results of the 2004 consensus conference of the WSACS held in Noosa, Australia were published in 2006 and contain a set of definitions related to IAH and ACS [1] (**Table 1**). These definitions are based on the best available scientific data today, but are likely to undergo some minor changes in the future.

IAH is defined by a sustained or repeated pathologic elevation of IAP ≥ 12 mmHg and ACS is defined as a sustained IAP ≥ 20 mmHg that is associated with new organ dysfunction/failure. ACS can be classified into primary, secondary, and recurrent ACS.

Table 1. Consensus definitions for intra-abdominal hypertension (IAH) and abdominal compartment syndrome (ACS) (adapted from [1])

Definition 1	IAP is the steady-state pressure concealed within the abdominal cavity.
Definition 2	APP = MAP – IAP
Definition 3	FG = GFP – PTP = MAP – 2 x IAP
Definition 4	IAP should be expressed in mmHg and measured at end-expiration in the complete supine position after ensuring that abdominal muscle contractions are absent and with the transducer zeroed at the level of the mid-axillary line.
Definition 5	The reference standard for intermittent IAP measurement is via the bladder with a maximal instillation volume of 25 ml of sterile saline.
Definition 6	Normal IAP is approximately 5–7 mmHg in critically ill adults.
Definition 7	IAH is defined by a sustained or repeated pathological elevation of IAP ≥ 12 mmHg.
Definition 8	IAH is graded as follows: • Grade I: IAP 12–15 mmHg • Grade II: IAP 16–20 mmHg • Grade III: IAP 21–25 mmHg • Grade IV: IAP > 25 mmHg
Definition 9	ACS is defined as a sustained IAP > 20 mmHg (with or without an APP < 60 mmHg) that is associated with new organ dysfunction/failure.
Definition 10	Primary ACS is a condition associated with injury or disease in the abdomino-pelvic region that frequently requires early surgical or interventional radiological intervention.
Definition 11	Secondary ACS refers to conditions that do not originate from the abdomino-pelvic region.
Definition 12	Recurrent ACS refers to the condition in which ACS redevelops following previous surgical or medical treatment of primary or secondary ACS.

APP: abdominal perfusion pressure; FG: filtration gradient; GFP: glomerular filtration pressure; IAP: intra-abdominal pressure; MAP: mean arterial pressure; PTP: proximal tubular pressure

Epidemiology and Etiology

IAP may increase most obviously because of increased intra-abdominal volume in the abdominal cavity (consisting of both the retroperitoneal space and the peritoneal cavity), but the compliance of the abdominal wall is equally important. Similar to the situation in the brain, there are essentially two parts to the abdominal pressure-volume curve. When the abdominal wall is very compliant and at low intra-abdominal volumes, relatively large increases in volume will lead to minor changes in IAP only [2]. However, at higher volumes the abdominal wall compliance may decrease and small volume changes can lead to important increases in IAP. This means that a small increase in intra-abdominal volume can lead to clinically important effects on organ function, but also that relatively small decreases in volume can lower IAP substantially, which offers options for treatment. This abdominal pressure-volume curve is shifted to the left in situations where the abdominal wall compliance is decreased due to hematoma, voluntary muscle activity, edema, or other factors. The occurrence of IAH is usually associated with a situation that causes increased abdominal volume or decreased abdominal compliance but often a combi-

nation of both these factors. The WSACS published a list of risk factors associated with these situations [1]. They are summarized in **Table 2**.

Techniques for IAP Measurement

Surveys among clinicians show that many of them use clinical examination for the diagnosis of ACS, a practice which has repeatedly been shown to be unreliable with a sensitivity and positive predictive value of around 40 – 60 % [3, 4]. The use of abdominal perimeter is equally inaccurate. Radiologic investigation, with plain radiography of the chest or abdomen, abdominal ultrasound, or computed tomography (CT)-scan are also insensitive to the presence of increased IAP. However, they can be indicated to illustrate the cause of IAH (e.g., bleeding, hematoma, ascites, abscess) and may offer clues for management (e.g., paracentesis, drainage of collections).

The most important tool in establishing the diagnosis of IAH or ACS is IAP measurement [2]. Since the abdominal contents are primarily non-compressive in nature and predominantly fluid-based, they can be assumed to behave according to Pascal's law. Therefore, the IAP measured at one point can be assumed to be the pressure throughout the abdominal cavity. IAP increases with inspiration (due to downward displacement of the diaphragm) and decreases with expiration (due to diaphragmatic relaxation).

'Normal' IAP is variable. In the strict sense it is less than 5 mmHg in adults under resting conditions. However, in obese persons, in pregnant women or in patients with chronic ascites, it can be higher, up to 10 or even 15 mmHg, without causing significant adverse effects, probably due to the chronic nature of the IAP increase with adaptation of the individual's physiology. In children, the normal IAP is generally lower. In general, IAP readings must be interpreted relative to the individual patient's physiologic state.

IAP can be measured directly or indirectly, intermittently or continuously.

Transvesical IAP Measurement

The bladder has been studied and used most extensively to measure IAP. The technique described by Kron et al. [5] has been adapted over the years by Cheatham and Safcsak [6] and served as a model for commercially available devices such as the Abvisor (WolfeTory Medical, Salt Lake City, USA) [2].

A manometer technique can also be used, which was first described by Harrahill in 1998 [7]. The patient's own urine is used as a transducing medium, and the height of the fluid column in the catheter reflects the IAP. Based on this technique, a commercially available device has been developed (FoleyManometer, Holtech Medical, Copenhagen, Denmark) [2]. Using this technique, an IAP can be obtained at regular intervals, but it remains labor intensive, especially when hourly IAP measurements are needed.

Continuous IAP measurement techniques have, therefore, been investigated. Balogh et al. [8, 9] introduced a method for continuous IAP measurement using a three way Foley catheter, which was found to perform excellently in ICU patients [2].

Transgastric IAP Measurement

Transgastric measurement of IAP has been reported, but is not used frequently in clinical practice. Collee et al. [10] used a fluid column in the nasogastric tube to measure IAP, but this technique has been replaced by the use of a balloon tipped catheter [2, 11], which can be used in a continuous or semi-continuous fashion. However, experience in critically ill patients is limited, and the influence of intestinal peristalsis and enteral nutrition, to name just two possible interfering factors, has not been studied so far.

Recommendations for IAP Measurement

Should I Measure IAP in all Patients?

Although the incidence of IAH in critically ill patients is considerable [12], routine IAP measurement in all patients admitted to the ICU is currently rarely performed, and probably not indicated. The WSACS has provided a list of risk factors associated with IAH and ACS (**Table 2**) [1]; in patients with two or more risk factors routine IAP monitoring is advised.

What Technique should I Use?

According to the WSACS consensus guidelines, IAP should be measured transvesically at end-expiration in the complete supine position after ensuring that abdominal muscle contractions are absent and with the transducer zeroed at the mid-axillary line at the level of the iliac crest. The technique used should be determined based on the indication and the condition of the patient, the available monitoring equipment, and the experience of the nursing staff with regards to possible pitfalls related to the technique used.

In some patients, a continuous technique may be preferable, e.g., when the abdominal perfusion pressure (APP) is used as a resuscitation endpoint, or in patients with impending ACS requiring urgent abdominal decompression. For most patients however, an intermittent technique may be adequate.

The manometer techniques can be used without the need for additional electronic equipment, which also allows for IAP measurement in the general ward when IAH or ACS is suspected.

Ideally, a protocol describing the preferred method of IAP measurement with details regarding the conditions in which it should be obtained should be available in every ICU.

What Frequency?

When an intermittent method is used, measurements should be obtained at least every 4 hours, and in patients with evolving organ dysfunction, this frequency should be increased up to hourly measurements.

When Should I Stop IAP Measurement?

IAP measurement can be discontinued when the patient has no signs of acute organ dysfunction, and IAP values have been below 10 mmHg for 24–48 hours. In case of recurrent organ dysfunction, IAP measurement should be reconsidered.

Table 2. Risk factors for the development of intra-abdominal hypertension (IAH) and abdominal compartment syndrome (ACS) [1]

A. Related to diminished abdominal wall compliance
- Mechanical ventilation, especially fighting with the ventilator and the use of accessory muscles
- Use of positive end-expiratory pressure (PEEP) or the presence of auto-PEEP
- Basal pleuropneumonia
- High body mass index
- Pneumoperitoneum
- Abdominal (vascular) surgery, especially with tight abdominal closures
- Pneumatic anti-shock garments
- Prone and other body positioning
- Abdominal wall bleeding or rectus sheath hematomas
- Correction of large hernias, gastroschisis or omphalocele
- Burns with abdominal eschars

B. Related to increased intra-abdominal contents
- Gastroparesis
- Gastric distension
- Ileus
- Volvulus
- Colonic pseudo-obstruction
- Abdominal tumor
- Retroperitoneal/abdominal wall hematoma
- Enteral feeding
- Intra-abdominal or retroperitoneal tumor
- Damage control laparotomy

C. Related to abdominal collections of fluid, air or blood
- Liver dysfunction with ascites
- Abdominal infection (pancreatitis, peritonitis, abscess,...)
- Hemoperitoneum
- Pneumoperitoneum
- Laparoscopy with excessive inflation pressures
- Major trauma
- Peritoneal dialysis

D. Related to capillary leak and fluid resuscitation
- Acidosis* (pH below 7.2)
- Hypothermia* (core temperature below 33 °C)
- Coagulopathy* (platelet count below 50000/mm^3 OR an activated partial thromboplastin time (aPTT) more than 2 times normal OR a prothrombin time (PT) below 50 % OR an international standardized ratio (INR) more than 1.5)
- Polytransfusion/trauma (> 10 units of packed red cells/24 hours)
- Sepsis (as defined by the American–European Consensus Conference definitions)
- Severe sepsis or bacteremia
- Septic shock
- Massive fluid resuscitation (> 5 l of colloid or > 10 l of crystalloid/24 hours with capillary leak and positive fluid balance)
- Major burns

* The combination of acidosis, hypothermia, and coagulopathy has been put forward in the literature as the deadly triad.

The Impact of IAH on Organ Function Management

ACS is diagnosed when the IAH is above 20 mmHg and there is evidence of new end-organ dysfunction [13]. IAH is diagnosed at lower levels of IAP when the patient is at risk, but there is no evidence of organ dysfunction, although subtle forms of organ dysfunction may be present at levels of IAP previously deemed to be safe [1]. There probably is a 'dose-dependent' association between IAP and organ dysfunction. Therefore, lowering IAP should have a beneficial effect on organ function and, indeed, decompressive laparotomy has been shown to improve organ function. However, at lower levels of IAH where decompressive laparotomy is not indicated, the increased IAP still has an impact on organ function, either as a causal agent or as an aggravating factor for other causes of organ dysfunction. IAH also has an impact on the parameters we use to monitor organ function as will be shown below. Therefore, whatever contribution IAH may have on organ dysfunction, IAP should be taken into account when assessing and managing IAH. We will provide an overview of the impact of IAH on monitoring and management of the different organ systems.

Effect on Cardiovascular Management

IAH is associated with a number of effects on the cardiovascular system that are caused by multiple factors [14]. First, due to the cranial movement of the diaphragm during IAH, the intrathoracic pressure will rise during IAH. Animal and human experiments have shown that 20–80 % of the IAP is transmitted to the thorax. This leads to compression of the heart and reduction of end-diastolic volume. Second, cardiac preload decreases due to decreased venous return from the abdomen and the systemic afterload is initially increased due to direct compression of vascular beds and activation of the renin-angiotensin-aldosterone pathway [15–18]. This leads to decreased cardiac output. Mean arterial blood pressure (MAP) may initially increase due to shunting of blood away from the abdominal cavity but, thereafter, normalizes or decreases [14, 19]. The cardiovascular effects are aggravated by hypovolemia and the application of positive end-expiratory pressure (PEEP) [20–24], whereas hypervolemia has a temporary protective effect [25].

IAH also has a marked effect on the reliability of hemodynamic monitoring. Preload estimation is most profoundly affected.

Preload estimation

Due to the abdomino-thoracic transmission of pressure, traditional filling pressures (central venous pressure [CVP] and pulmonary artery occlusion pressure [PAOP]) are falsely elevated in the presence of IAH, and do not reflect true cardiac filling. Due to the physiologic complexity of patients with IAH/ACS, resuscitation to arbitrary, absolute PAOP or CVP values should, therefore, be avoided as such a practice can lead to inappropriate therapeutic decisions, under-resuscitation, and organ failure. This must especially be kept in mind given the recent renewed interest in CVP as a resuscitation endpoint during early-goal directed therapy for severe sepsis and the propensity for sepsis and its treatment to result in subsequent IAH/ACS. Recognizing the impact of elevated IAP and intrathoracic pressure on the validity of intracardiac filling pressure measurements, some authors have suggested calculating the transmural PAOP ($PAOP_{tm}$) or CVP (CVP_{tm}) in an attempt to improve the accuracy of PAOP and CVP as resuscitation endpoints. Assuming proper placement of a pul-

monary artery catheter (PAC) and the absence of other confounding factors, $PAOP_{tm}$ may be calculated as end-expiratory PAOP ($PAOP_{ee}$) minus pleural pressure (Ppl) with CVP_{tm} calculated as CVP_{ee} – Ppl · Ppl is typically determined by measuring lower esophageal pressure using a balloon catheter. Kallet et al. calculated $PAOP_{tm}$ using esophageal pressure for Ppl, and reported that this improved the ability of $PAOP_{ee}$ alone to predict fluid responsiveness, i.e., preload recruitable increases in cardiac output [26]. Other authors have advocated the practice of measuring PAOP during disconnection of the patient's airway (the so-called "pop-off" PAOP) to minimize the effect of Ppl. Such a practice would not be valid in the patient with elevated IAP, however, as this does not reduce the contribution of IAP to the patient's Ppl. Moreover, such maneuvers may be harmful in that they result in temporary loss of PEEP and derecruitment, which is to be avoided in patients with acute respiratory distress syndrome (ARDS, which is often associated with ACS). We recently evaluated several equations for calculating $PAOP_{tm}$ in patients with IAH and PEEP levels from 0 to 20 cmH_2O [18]. Confirming the findings of previous authors, a significant correlation was found between IAP and Ppl with approximately 80 % of the IAP being transmitted to the intrathoracic compartment ($Ppl = 0.8 \times IAP + 1.6$ ($r^2 = 0.8$, $p < 0.0001$)). Of the four equations evaluated, all were equivalent in predicting preload-recruitable increases in cardiac output. As a result, we concluded that the simple calculation of subtracting half the IAP from $PAOP_{ee}$ or CVP_{ee} may provide a rapid bedside estimate of true transmural filling pressure. This finding has important implications. The Surviving Sepsis Campaign guidelines, targeting initial and ongoing resuscitation towards a CVP of 8 to 12 mmHg [27], and other studies, targeting a MAP of 65 mmHg [28], should be interpreted and adjusted according to these findings.

Due to the problems in using cardiac filling pressures in the presence of IAH, it may be more useful to use volumetric monitoring parameters such as right ventricular end diastolic volume index (RVEDVI) or global end-diastolic volume index (GEDVI). These parameters are particularly useful because of the changing ventricular compliance and elevated intrathoracic pressure [18, 29–32]. Cheatham et al. [33] and Chang et al. [34] independently compared PAOP, CVP, and RVEDVI as estimates of preload status in patients with elevated IAP before and after abdominal decompression. In both studies, cardiac index (CI) was noted to correlate significantly with RVEDVI and inversely with PAOP and CVP. While some have raised concern that mathematical coupling, the interdependence of two variables when one is used to calculate the other, may explain the significant correlation between RVEDVI and CI, three separate studies have confirmed the validity of RVEDVI as a predictor of preload recruitable increases in CI [18].

Brienza et al. [35] and Malbrain et al. [36] have both demonstrated that elevated intrathoracic pressure and IAP result in significant decreases in GEDVI despite paradoxical increases in measured PAOP and CVP. As with RVEDVI, GEDVI appears to be superior to PAOP and CVP in predicting preload status, especially in patients with elevated intrathoracic pressure or IAP where transmission of these pressures to the pulmonary capillaries can erroneously increase measured PAOP and CVP values.

Assessing fluid responsiveness

It is clear from the discussion above that preload measurement or estimation is a complex issue. This complexity is increased further by the fact that volume status alone does not completely predict the effect of volume administration on cardiovascular function. Fluid responsiveness, i.e., increase in CI after administration of fluids, is an even more elusive concept than preload as such. Apart from crude clinical

tests, such as the passive leg raising test or a limited fluid bolus test, fluid responsiveness has been shown to correlate best with stroke volume variation (SVV) and pulse pressure variation (PPV), parameters which can be derived from the arterial waveform, e.g., using the PiCCO device (Pulsion Medical Systems, Munich. Germany). However, there are some pitfalls [37]. SVV and PPV are only reliable predictors of fluid responsiveness in the absence of spontaneous breathing movements and in regular sinus rhythm, since stroke volume exhibits beat-to-beat variations in the presence of irregular cardiac rhythms or due to the pressure swings associated with spontaneous breathing. Furthermore, Duperret et al. showed in a pig model that SVV and PPV are increased when experimental IAH is induced [38]. However, since the pigs were not subjected to a fluid bolus, it is impossible to determine whether this was due to real hypovolemia induced by the decreased venous return in IAH, or a 'false' increase in SVV and PPV due to erroneous measurement.

Abdominal perfusion pressure

During the early evolution of IAH and ACS, attempts were made to identify a single 'critical' IAP that could be used to guide decision making in patients with IAH. This oversimplifies what is actually a highly complex and variable physiologic process. While IAP is a major determinant of patient outcome during critical illness, the IAP that defines both IAH and ACS clearly varies from patient to patient and even within the same patient as their disease process evolves. As a result, a single threshold value of IAP cannot be globally applied to decision making in all critically ill patients.

One approach to improving the sensitivity of IAP for decision making is to incorporate it into an assessment of abdominal perfusion as a resuscitation endpoint. Cheatham and colleagues first proposed the concept of APP as a predictor of survival in patients with IAH or ACS [39]. APP assesses not only the severity of IAH present, but also the adequacy of the patient's systemic perfusion. Analogous to the widely accepted and utilized concept of cerebral perfusion pressure (CPP), calculated as MAP minus intracranial pressure (ICP), APP, calculated as MAP minus IAP, has been proposed as a more accurate marker of critical illness and endpoint for resuscitation in patients with IAH [40].

APP provides an easily calculated measure that has been demonstrated to be superior to the clinical prediction of IAP alone. Cheatham et al. [39] in a retrospective trial of surgical/trauma patients with IAH (mean IAP 22 ± 8 mmHg) concluded that an APP ≥ 50 mmHg optimized survival. APP was also found to be statistically superior to arterial pH, base deficit, arterial lactate, and hourly urinary output in its ability to predict patient outcome. Malbrain [40] in three subsequent trials in mixed medical-surgical patients (mean IAP 10 ± 4 mmHg) suggested that an APP ≥ 60 mmHg represented an appropriate resuscitation goal. Persistence of IAH and failure to maintain an APP ≥ 60 mmHg by day 3 was found to discriminate between survivors and non-survivors.

As a resuscitation endpoint, APP has yet to be subjected to a prospective, randomized clinical trial (although such a study is currently being prepared by the WSACS). Further, the therapeutic threshold above which raising MAP to achieve a particular APP becomes futile or even detrimental remains unknown. Indiscriminate fluid administration places the patient at risk for secondary ACS and should be avoided. Target APP values may be achieved through a balance of judicious fluid resuscitation and application of vasoactive medications. Notwithstanding these concerns, maintaining an APP of 50–60 mmHg appears to predict improved survival from IAH/ACS that is not identified by IAP alone.

Effects of IAH on Respiratory Management

The transmission of IAP to the thorax also has an impact on the respiratory system. Patients with primary ACS will often develop secondary ARDS and may require a different ventilatory strategy and more specific treatment than a patient with primary ARDS [41, 42]. The major problem lies in the reduction of the functional residual capacity (FRC). Together with the alterations caused by secondary ARDS this will lead to the so-called 'baby-lung'. IAH decreases total respiratory system compliance by a decrease in chest wall compliance, while lung compliance remains virtually unchanged [43, 44]. Theoretically, the compliance of the thoracic and abdominal wall can be improved by the use of neuromuscular blockers. Several authors have looked at the effect of neuromuscular blockers on IAP and found that bolus injections do have a temporary lowering effect on the IAP [45]. Although there are no data on the effect on respiratory system compliance in the presence of IAH, it is safe to assume that the decreased IAP in itself has a beneficial effect. Therefore, the use of neuromuscular blockers can be considered, but the expected benefit has to be balanced against known complications of neuromuscular blockers such as increased incidence of dorsobasal atelectasis, ventilator-associated pneumonia (VAP), critical illness polyneuropathy, and ICU-related muscular weakness.

Quintel et al. [46] studied the effect of instillation of oleic acid into the lungs of dogs to induce acute lung injury (ALI), followed by an increase in IAP (by instillation of fluid into the abdominal cavity). This study demonstrated that the ALI and lung edema induced by oleic acid were aggravated in the presence of IAH.

Some recommendations can be made in terms of ventilation strategy for patients with IAH:

- Patients with IAH should be ventilated according to low tidal volume strategies as put forward in the ARDS Network Guidelines [47].
- Best PEEP should be set to counteract IAP while at the same time avoiding over-inflation of already well-aerated lung regions
  - Best PEEP = IAP
- During lung protective ventilation, the plateau pressures (Pplat) should be limited to transmural plateau pressures below 35 cmH_2O
  - $Pplat_{tm}$ = Pplat – IAP / 2
- Monitoring of extravascular lung water index (EVLWI) seems warranted in at risk patients since IAH is associated with increased risk of lung edema [46]
- In patients with decreased thoracic wall compliance, the use of neuromuscular blockers can be considered.

The Effect of IAH on Renal Function Management

Renal dysfunction is one of the most consistently described organ dysfunctions associated with IAH [48–52]. The etiology is multifactorial and offers a unique insight into the deleterious and sometimes cumulative effects of IAH on organ function.

The most important effect of IAH on the kidney is related to renal blood flow [53]. IAH has been shown to lead to renal venous compression and increased renal venous pressure. Renal arterial blood flow and microcirculatory flow in the renal cortex are also decreased. Direct compression of the renal cortex may be a contributing factor. The changes in renal blood flow lead to activation of the renin-angiotensin-aldosterone pathway and anti-diuretic hormone (ADH) secretion is also increased in IAH. The clinical importance of these changes is still unclear.

The management of renal function is one of the areas in which the presence of IAH markedly affects clinical management. Impairment of kidney function has been seen at relatively low levels of IAH previously deemed to be safe. In many instances, the first action taken when renal function starts to deteriorate is administration of fluids and, as explained before, fluid resuscitation indeed has a temporary protective effect from the deleterious effects of IAH in the early stages. However, fluid resuscitation will also lead to increased edema formation, third spacing and possibly to a vicious cycle of ongoing IAH. In fact, fluid loading is one of the major risk factors for the development of IAH and the major contributor to secondary ACS, the morbidity and mortality of which is even higher than for primary ACS. Therefore, although an initial fluid challenge at the first sign of kidney failure can be considered (especially at lower IAP values when the etiology of the kidney dysfunction is uncertain), we recommend that great care be taken to avoid fluid overload. In this light, colloid resuscitation may be preferable to crystalloids and mobilization of edema by administration of albumin (to increase colloid osmotic pressure) and diuretics can be attempted. As IAH-induced kidney function progresses, patients often do not respond to diuretic therapy. Fluid removal by means of ultrafiltration has been shown to have a beneficial effect on IAP and possibly on organ function [54]. The institution of renal replacement therapy with fluid removal, if hemodynamically tolerated, should not be delayed. There are no reliable data on the preferred method of renal replacement therapy.

The Effect of IAH on the Management of the Patient with Intracranial Hypertension

A direct relationship between IAP and ICP has been observed in animal and human studies [25, 55–59]. Several authors hypothesized that the increase in ICP secondary to IAH was caused by increased intrathoracic pressure, leading to increased CVP and decreased venous return from the brain and, thus, venous congestion and brain edema. This hypothesis gained acceptance when Bloomfield et al. [25] demonstrated that the association between IAP and ICP could be abolished by performing a sternotomy and bilateral pleuropericardiotomy in pigs. The reduced systemic blood pressure associated with decreased cardiac preload and the increase in ICP will lead to a decrease in CPP. Some authors have even demonstrated successful treatment of refractory intracranial hypertension with abdominal decompression or curarization [56, 59].

Some recommendations:

- IAP monitoring is essential for all trauma or non-trauma patients at risk of intracranial hypertension or IAH (according to the risk factors published by the WSACS)
- In all patients with intracranial hypertension, preventive measures should be undertaken to avoid increase in IAP
- Neurologic status should be frequently monitored in patients with IAH
- Avoid hypervolemia in patients with IAH to prevent further increase in ICP.
- Provide adequate treatment for IAH, especially if intracranial hypertension is also present
- Avoid laparoscopy in patients at risk for intracranial hypertension. The pneumoperitoneum used for laparoscopy creates a situation analogous to experimental settings of IAH and intracranial hypertension in which detrimental effects on ICP have been observed. This is especially important in trauma patients with associated brain and abdominal injuries.

The Influence of IAH on the Management of Specific Patient Groups

IAH and Patients with Severe Sepsis

Sepsis-induced IAH is probably due to a 'first hit', the systemic infection, followed by a 'second hit' characterized by a massive inflammatory reaction and capillary leak syndrome. In this acute phase, patients receive large amounts of fluids which leads to edema formation and IAH [60]. Where the digestive tract is concerned, IAH causes diminished perfusion, mucosal acidosis, and sets the stage for multiple organ failure. The pathological changes are more pronounced after sequential insults of ischemia-reperfusion and IAH. It appears that IAH and ACS may serve as the second insult in the two-hit phenomenon of the causation of multiple-organ dysfunction syndrome. Recent clinical studies have demonstrated a temporal relationship between ACS and subsequent multiple organ dysfunction syndrome.

Understanding this pathologic string of events, it is important to adjust sepsis treatment to the presence of IAH. In septic shock, fluid resuscitation is the first therapeutic action recommended in the Surviving Sepsis Campaign Guidelines [27]. Traditionally, fluid resuscitation protocols are aimed at correction of 'basic' physiological parameters such as blood pressure, CVP, and urine output. However, as we have described before, all these physiologic parameters can be affected by the presence of IAH. Abdominothoracic pressure transmission can lead to overestimation of the actual filling pressures and underresusctiation of the patient, while IAH-induced kidney injury can decrease urine output and lead to overresuscitation which is equally detrimental. There is increasing evidence that IAH may be the missing link between overresuscitation, multiple organ failure, and death.

Daugherty et al. recently conducted a prospective cohort study of 468 medical ICU patients [61]. Forty patients (8.5 %) had a net positive fluid balance of more than 5 l after 24 hours (all risk factors for primary ACS served as exclusion criteria). The incidence of IAH in this group was a staggering 85 % and 25 % developed secondary ACS. The study was not powered to detect differences in mortality and outcome parameters were not statistically different between patients with or without IAH and ACS. Nevertheless, there was a trend towards higher mortality in the IAH groups and mortality figures reached 80 % in the ACS group. Although epidemiologic research regarding this subject is virtually non-existent, the increase in reported series seems to indicate an increasing incidence of this highly lethal complication.

In light of this increasing body of evidence regarding the association between massive fluid resuscitation, IAH, organ dysfunction, and mortality, it seems wise to at least incorporate IAP as a parameter in all future studies regarding fluid management, and to put into question current clinical practice guidelines, not in terms of whether to administer fluids at all, but in terms of the parameters we use to guide our treatment.

IAH and the Burn Patient

Another population where fluid resuscitation has been a cornerstone of therapy for decades is burn patients. Undoubtedly, fluid resuscitation protocols have saved countless lives in burn patients. However, increasing numbers of reports in recent years have highlighted the association between administration of large amounts of fluids in the first 24 h after burn injury and the development of secondary ACS. This can be avoided by using adjusted fluid resuscitation protocols. Oda et al. [62]

reported a reduced risk of ACS (as well as lower fluid requirements during the first 24 hours and lower peak inspiratory pressures after 24 hours) when using hypertonic lactated saline for burn resuscitation, and O'Mara et al. [63] reported lower fluid requirements and lower IAP using colloids.

IAH and the Hematology Patient

Recent studies have alluded to the increased incidence and consequences of IAH in hematological patients [64]. The causes for this finding are multifactorial:

- Growth factor-induced capillary leak syndrome with concomitant large volume fluid resuscitation and third space sequestration
- Chemotherapy-induced ileus, colonic pseudo-obstruction (Ogilvie's syndrome), mucositis or gastroenteritis
- Sepsis and infectious complications aggravating intestinal and capillary permeability
- Extramedullary hematopoiesis as seen with chronic myeloid leukemia resulting in hepatosplenomegaly, chronic IAH, and chronic (irreversible) pulmonary hypertension
- The mechanisms of veno-occlusive disease seen after stem cell transplantation may be triggered by or related to increased IAP

Therefore, critically ill hematological patients should be managed according to the principles described above.

IAH in Morbidly Obese Patients

Recent studies show that obese patients have higher baseline IAP values [65]. As with IAH in the critically ill, elevated IAP in the morbidly obese patient can have far reaching effects on end organ function. Disease processes common in morbidly obese patients, such as obesity hypoventilation syndrome, pseudotumor cerebri, gastroesophageal reflux and stress urinary incontinence are now being recognized as being caused by the increased IAP occurring with an elevated body mass index [66–68]. Furthermore the increased incidence of poor fascial healing and higher incisional hernia rates have been related to IAH-induced reductions in rectus sheath and abdominal wall blood flow.

A New Concept: Acute Bowel Injury and Acute Intestinal Distress Syndrome

Although few epidemiologic data are available to confirm this observation, it is our impression that the incidence of primary IAH/ACS is decreasing due to increased awareness of the problem among surgeons, who are more likely to leave the abdomen open in high risk surgery cases. This observation was also mentioned by Kimball et al. [69] in a review of patients with ruptured aortic aneurysm.

The focus of attention is shifting to secondary ACS and rightfully so. This syndrome is highly prevalent in critically ill patients and leads to even higher mortality than primary IAH. As described by Kimball [70] and Kirkpatrick et al. [71], a variety of noxious stimuli (such as infection, trauma, burns, sepsis) can lead to activation of the innate immune system and neutrophil activation. This systemic immune

response causes release of cytokines into the circulation leading to systemic inflammatory response syndrome (SIRS) and capillary leak. Apart from a direct negative impact on cellular organ function, this syndrome also exerts its deleterious effect through accumulation of extravascular fluids in the tissues and local ischemia. This mechanism of injury is widely recognized and accepted in the lung, where it is classified as ALI or ARDS. However, the same pathological process occurs in the gut, but recognition of this concept is taking much slower to seep through into general ICU practice.

Why is this the case? It is undoubtedly true that bowel function is much harder to quantify than, e.g., lung function. PaO_2/FiO_2 ratios are very easy to calculate at the bedside and monitoring parameters such as EVLWI have been demonstrated to be accurate prognostic predictors. The same goes for the kidney. Urinary output and serum creatinine levels as crude indicators of kidney function are readily available and the acute kidney injury (AKI) RIFLE (Risk of kidney dysfunction, Injury to kidney, Failure of kidney function, Loss of kidney function, End-Stage kidney disease) classification has been linked with mortality. However, the role of the gut as the motor of organ dysfunction syndrome may be equally important and difficulties in assessing gut function should not deter us from recognizing that concept. In fact, in analogy to ALI and AKI, we propose the introduction of a concept named Acute Bowel Injury (ABI) which is manifest through bowel edema and the ensuing IAH. Even more than for other organ dysfunction syndromes, ABI has a negative impact on distant organ systems through the development of IAH, and can contribute to the development of AKI and ALI.

No specific markers of bowel function have been identified, apart from the very crude on/off parameter of enteral feeding tolerance. However, since capillary leak and bowel edema are cornerstones of this syndrome, ABI can probably best be defined, at least partially, in terms of IAP levels. Another plus for IAP is that it has already been linked to prognosis in several epidemiologic studies. One might argue then that the ABI concept is just another word for IAH. However, ABI reflects a more basic concept of complex bowel injury caused by a first hit (either directly, such as in abdominal sepsis or trauma, or indirectly such as in ischemia due to hypovolemic or distributive shock), followed by a second hit in the form of capillary leak, bowel edema, and local ischemia, of which (secondary) IAH is the result (**Fig. 1**). If the vicious cycle is not stopped this will eventually lead to acute intestinal distress syndrome and ACS. This definition set can evolve to a more intuitive understanding of the complexity of the pathologic process instead of a purely mechanical viewpoint of increased pressure in a confined anatomical space. Another viable option for definition of ABI and acute intestinal distress syndrome may be to use a gastrointestinal failure score based on both IAP values and enteral feeding tolerance such as proposed by Reintam et al. [72].

Conclusion

IAH and ACS occur frequently in ICU patients and are independently associated with mortality. The presence of IAH also has a profound effect on monitoring and support of almost all organ functions within the human body. Apart from specific strategies aimed at decreasing IAP and improving organ function, the IAP should be integrated in the supportive management of the various organ systems. This chapter has provided an overview of the different effects of IAH on organ function and its

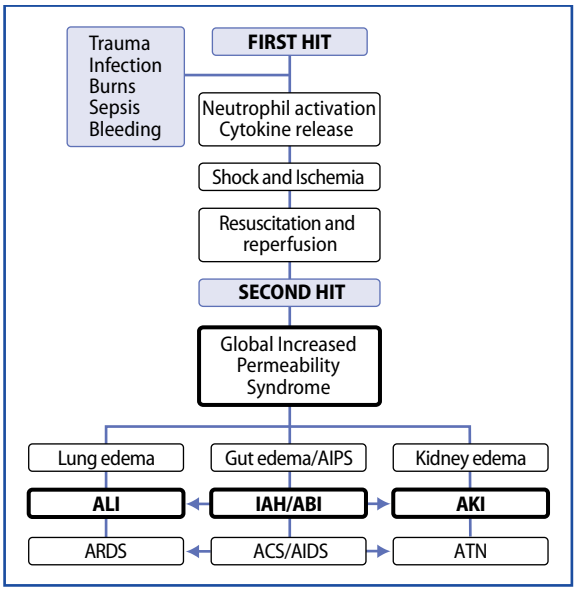

Fig. 1. The two hit model leading to intra-abdominal hypertension (adapted from [60] with permission). ABI: acute bowel injury; ACS: abdominal compartment syndrome; AIDS: acute intestinal distress syndrome; AIPS: acute intestinal permeability syndrome; AKI: acute kidney injury; ALI: acute lung injury; ARDS: acute respiratory distress syndrome; ATN: acute tubular necrosis; IAH: intra-abdominal hypertension

implications for management, and highlighted some patient populations in which these concepts are especially important.

References

1. Malbrain ML, Cheatham ML, Kirkpatrick A, et al (2006) Results from the International Conference of Experts on Intra-abdominal Hypertension and Abdominal Compartment Syndrome. I. Definitions. Intensive Care Med 32: 1722–1732
2. Malbrain ML (2004) Different techniques to measure intra-abdominal pressure (IAP): time for a critical re-appraisal. Intensive Care Med 30: 357–371
3. Kirkpatrick AW, Brenneman FD, McLean RF, Rapanos T, Boulanger BR (2000) Is clinical examination an accurate indicator of raised intra-abdominal pressure in critically injured patients? Can J Surg 43: 207–211
4. Sugrue M, Bauman A, Jones F, et al (2002) Clinical examination is an inaccurate predictor of intraabdominal pressure. World J Surg 26: 1428–1431
5. Kron IL, Harman PK, Nolan SP (1984) The measurement of intra-abdominal pressure as a criterion for abdominal re-exploration. Ann Surg 199: 28–30
6. Cheatham ML, Safcsak K (1998) Intraabdominal pressure: a revised method for measurement. J Am Coll Surg 186: 594–595
7. Harrahill M (1998) Intra-abdominal pressure monitoring. J Emerg Nurs 24: 465–466
8. Balogh Z, De Waele JJ, Malbrain ML (2007) Continuous intra-abdominal pressure monitoring. Acta Clin Belg Suppl 62: 26–32
9. Balogh Z, Jones F, D'Amours S, Parr M, Sugrue M (2004) Continuous intra-abdominal pressure measurement technique. Am J Surg 188: 679–684
10. Collee GG, Lomax DM, Ferguson C, Hanson GC (1993) Bedside measurement of intra-abdominal pressure (IAP) via an indwelling naso-gastric tube: clinical validation of the technique. Intensive Care Med 19: 478–480
11. Malbrain ML, De Laet I, Viaene D, Schoonheydt K, Dits H (2008) In vitro validation of a novel method for continuous intra-abdominal pressure monitoring. Intensive Care Med 34: 740–745
12. Malbrain ML, Chiumello D, Pelosi P, et al (2005) Incidence and prognosis of intraabdominal

hypertension in a mixed population of critically ill patients: A multiple-center epidemiological study. Crit Care Med 33: 315 – 322
13. Malbrain ML, Deeren D, De Potter TJ (2005) Intra-abdominal hypertension in the critically ill: it is time to pay attention. Curr Opin Crit Care 11: 156 – 171
14. Cheatham M, Malbrain M (2006) Cardiovascular implications of elevated intra-abdominal pressure. In: Ivatury R, Cheatham M, Malbrain M, Sugrue M (eds) Abdominal compartment syndrome. Landes Bioscience, Georgetown, pp 89 – 104.
15. Kashtan J, Green JF, Parsons EQ, Holcroft JW (1981) Hemodynamic effect of increased abdominal pressure. J Surg Res 30: 249 – 255
16. Ridings PC, Bloomfield GL, Blocher CR, Sugerman HJ (1995) Cardiopulmonary effects of raised intra-abdominal pressure before and after intravascular volume expansion. J Trauma 39: 1071 – 1075
17. Richardson JD, Trinkle JK (1976) Hemodynamic and respiratory alterations with increased intra-abdominal pressure. J Surg Res 20: 401 – 404
18. Malbrain ML, Cheatham ML (2004) Cardiovascular effects and optimal preload markers in intra-abdominal hypertension. In: Vincent JL (ed) Yearbook of Intensive Care and Emergency Medicine. Springer-Verlag, Heidelberg, pp 519 – 543
19. Cheatham M, Malbrain M (2006) Abdominal perfusion pressure. In: Ivatury R, Cheatham M, Malbrain M, Sugrue M (eds) Abdominal Compartment Syndrome. Landes Bioscience, Georgetown 69 – 81
20. Simon RJ, Friedlander MH, Ivatury RR, DiRaimo R, Machiedo GW (1997) Hemorrhage lowers the threshold for intra-abdominal hypertension-induced pulmonary dysfunction. J Trauma 42: 398 – 403
21. Burchard KW, Ciombor DM, McLeod MK, Slothman GJ, Gann DS (1985) Positive end expiratory pressure with increased intra-abdominal pressure. Surg Gynecol Obstet 161: 313 – 318
22. Pelosi P, Ravagnan I, Giurati G, et al (1999) Positive end-expiratory pressure improves respiratory function in obese but not in normal subjects during anesthesia and paralysis. Anesthesiology 91: 1221 – 1231
23. Sugrue M, D'Amours S (2001) The problems with positive end expiratory pressure (PEEP) in association with abdominal compartment syndrome (ACS). J Trauma 51: 419 – 420
24. Sussman AM, Boyd CR, Williams JS, DiBenedetto RJ (1991) Effect of positive end-expiratory pressure on intra-abdominal pressure. South Med J 84: 697 – 700
25. Bloomfield GL, Ridings PC, Blocher CR, Marmarou A, Sugerman HJ (1997) A proposed relationship between increased intra-abdominal, intrathoracic, and intracranial pressure. Crit Care Med 25: 496 – 503
26. Kallet RH, Katz JA, Pittet JF, et al (2000) Measuring intra-esophageal pressure to assess transmural pulmonary arterial occlusion pressure in patients with acute lung injury: a case series and review. Respir Care 45: 1072 – 1084
27. Dellinger RP, Carlet JM, Masur H, et al (2004) Surviving Sepsis Campaign guidelines for management of severe sepsis and septic shock. Intensive Care Med 30: 536 – 555
28. Rivers E, Nguyen B, Havstad S, et al (2001) Early goal-directed therapy in the treatment of severe sepsis and septic shock. N Engl J Med 345: 1368 – 1377
29. Cheatham ML, Block EF, Nelson LD, Safcsak K (1998) Superior predictor of the hemodynamic response to fluid challenge in critically ill patients. Chest 114: 1226 – 1227
30. Cheatham ML, Nelson LD, Chang MC, Safcsak K (1998) Right ventricular end-diastolic volume index as a predictor of preload status in patients on positive end-expiratory pressure. Crit Care Med 26: 1801 – 1806
31. Schachtrupp A, Graf J, Tons C, Hoer J, Fackeldey V, Schumpelick V (2003) Intravascular volume depletion in a 24-hour porcine model of intra-abdominal hypertension. J Trauma 55: 734 – 740
32. Michard F, Alaya S, Zarka V, Bahloul M, Richard C, Teboul JL (2003) Global end-diastolic volume as an indicator of cardiac preload in patients with septic shock. Chest 124: 1900 – 1908
33. Cheatham ML, Safcsak K, Block EF, Nelson LD (1999) Preload assessment in patients with an open abdomen. J Trauma 46: 16 – 22
34. Chang MC, Miller PR, D'Agostino R Jr, Meredith JW (1998) Effects of abdominal decompression on cardiopulmonary function and visceral perfusion in patients with intra-abdominal hypertension. J Trauma 44: 440 – 445

35. Brienza N, Dambrosio M, Cinnella G, Conte M, Puntillo N, Bruno F (1996) [Effects of PEEP on intrathoracic and extrathoracic blood volumes evaluated with the COLD system in patients with acute respiratory failure. Preliminary study]. Minerva Anestesiol 62: 235–242
36. Malbrain M, Debaveye Y, Bertieaux S (2000) Effect of abdominal compression and decompression on cardiorespiratory function and regional perfusion. Intensive Care Med 26:S264 (abst)
37. Malbrain ML, De Laet I (2008) Functional haemodynamics during intra-abdominal hypertension: what to use and what not. Acta Anaesthesiol Scand 52: 576–577
38. Duperret S, Lhuillier F, Piriou V, et al (2007) Increased intra-abdominal pressure affects respiratory variations in arterial pressure in normovolaemic and hypovolaemic mechanically ventilated healthy pigs. Intensive Care Med 33: 163–171
39. Cheatham ML, White MW, Sagraves SG, Johnson JL, Block EF (2000) Abdominal perfusion pressure: a superior parameter in the assessment of intra-abdominal hypertension. J Trauma 49: 621–626
40. Malbrain ML (2002) Abdominal perfusion pressure as a prognostic marker in intra-abdominal hypertension. In: Vincent JL (ed) Yearbook of Intensive Care and Emergency Medicine. Springer-Verlag, Heidelberg, pp 792–814
41. Ranieri VM, Brienza N, Santostasi S, et al (1997) Impairment of lung and chest wall mechanics in patients with acute respiratory distress syndrome: role of abdominal distension. Am J Respir Crit Care Med 156: 1082–1091
42. Gattinoni L, Pelosi P, Suter PM, Pedoto A, Vercesi P, Lissoni A (1998) Acute respiratory distress syndrome caused by pulmonary and extrapulmonary disease. Different syndromes? Am J Respir Crit Care Med 158: 3–11
43. Mutoh T, Lamm WJ, Embree LJ, Hildebrandt J, Albert RK (1991) Abdominal distension alters regional pleural pressures and chest wall mechanics in pigs in vivo. J Appl Physiol 70: 2611–2618
44. Mutoh T, Lamm WJ, Embree LJ, Hildebrandt J, Albert RK (1992) Volume infusion produces abdominal distension, lung compression, and chest wall stiffening in pigs. J Appl Physiol 72: 575–582
45. De laet I, Malbrain ML (2007) ICU management of the patient with intra-abdominal hypertension: what to do, when and to whom? Acta Clin Belg Suppl 62: 190–199
46. Quintel M, Pelosi P, Caironi P, et al (2004) An increase of abdominal pressure increases pulmonary edema in oleic acid-induced lung injury. Am J Respir Crit Care Med 169: 534–541
47. Slutsky AS, Ranieri VM (2000) Mechanical ventilation: lessons from the ARDSNet trial. Respir Res 1: 73–77
48. Biancofiore G, Bindi L, Romanelli AM, et al (2002) Renal failure and abdominal hypertension after liver transplantation: determination of critical intra-abdominal pressure. Liver Transpl 8: 1175–1181
49. Biancofiore G, Bindi ML, Romanelli AM, et al (2003) Postoperative intra-abdominal pressure and renal function after liver transplantation. Arch Surg 138: 703–706
50. Sugrue M, Buist MD, Hourihan F, Deane S, Bauman A, Hillman K (1995) Prospective study of intra-abdominal hypertension and renal function after laparotomy. Br J Surg 82: 235–238
51. Sugrue M, Hallal A, D'Amours S (2006) Intra-abdominal pressure hypertension and the kidney. In: Ivatury R, Cheatham M, Malbrain M, Sugrue M (eds) Abdominal Compartment Syndrome. Landes Bioscience, Georgetown, pp 119–128
52. Sugrue M, Jones F, Deane SA, Bishop G, Bauman A, Hillman K (1999) Intra-abdominal hypertension is an independent cause of postoperative renal impairment. Arch Surg 134: 1082–1085
53. De laet I, Malbrain ML, Jadoul JL, Rogiers P, Sugrue M (2007) Renal implications of increased intra-abdominal pressure: are the kidneys the canary for abdominal hypertension? Acta Clin Belg Suppl 62: 119–130
54. Kula R, Szturz P, Sklienka P, Neiser J, Jahoda J (2004) A role for negative fluid balance in septic patients with abdominal compartment syndrome? Intensive Care Med 30: 2138–2139
55. De laet I, Citerio G, Malbrain ML (2007) The influence of intraabdominal hypertension on the central nervous system: current insights and clinical recommendations, is it all in the head? Acta Clin Belg Suppl 62: 89–97
56. Josephs LG, Este-McDonald JR, Birkett DH, Hirsch EF (1994) Diagnostic laparoscopy increases intracranial pressure. J Trauma 36: 815–818

57. Bloomfield GL, Ridings PC, Blocher CR, Marmarou A, Sugerman HJ (1996) Effects of increased intra-abdominal pressure upon intracranial and cerebral perfusion pressure before and after volume expansion. J Trauma 40: 936–941
58. Citerio G, Vascotto E, Villa F, Celotti S, Pesenti A (2001) Induced abdominal compartment syndrome increases intracranial pressure in neurotrauma patients: a prospective study. Crit Care Med 29: 1466–1471
59. Deeren D, Dits H, Malbrain MLNG (2005) Correlation between intra-abdominal and intracranial pressure in nontraumatic brain injury. Intensive Care Med 31: 1577–1581
60. Malbrain ML, De laet I (2008) AIDS is coming to your ICU: be prepared for acute bowel injury and acute intestinal distress syndrome. Intensive Care Med 34: 1565–1569
61. Daugherty EL, Hongyan L, Taichman D, Hansen-Flaschen J, Fuchs BD (2007) Abdominal compartment syndrome is common in medical intensive care unit patients receiving large-volume resuscitation. J Intensive Care Med 22: 294–299
62. Oda J, Ueyama M, Yamashita K, et al (2006) Hypertonic lactated saline resuscitation reduces the risk of abdominal compartment syndrome in severely burned patients. J Trauma 60: 64–71
63. O'Mara MS, Slater H, Goldfarb IW, Caushaj PF (2005) A prospective, randomized evaluation of intra-abdominal pressures with crystalloid and colloid resuscitation in burn patients. J Trauma 58: 1011–1018
64. Ziakas PD, Voulgarelis M, Felekouras E, Anagnostou D, Tzelepis GE (2005) Myelofibrosis-associated massive splenomegaly: a cause of increased intra-abdominal pressure, pulmonary hypertension, and positional dyspnea. Am J Hematol 80: 128–132
65. Hamad GG, Peitzman AB (2006) Morbid obesity and chronic intra-abdominal hypertension. In: Ivatury R, Cheatham M, Malbrain M, Sugrue M (eds) Abdominal Compartment Syndrome. Landes Bioscience, Georgetown, pp 187–194
66. Sugerman HJ (2001) Effects of increased intra-abdominal pressure in severe obesity. Surg Clin North Am 81: 1063–1075
67. Sugerman HJ (1998) Increased intra-abdominal pressure in obesity. Int J Obes Relat Metab Disord 22:1138
68. Sugerman HJ, DeMaria EJ, Felton WL III, Nakatsuka M, Sismanis A (1997) Increased intra-abdominal pressure and cardiac filling pressures in obesity-associated pseudotumor cerebri. Neurology 49: 507–511
69. Kimball EJ, Kinikini DV, Mone MC, et al (2006) Delayed abdominal closure in the management of ruptured abdominal aortic aneurysm. Crit Care Med 33 (suppl 12):A38 (abst)
70. Kimball EJ (2006) Intra-abdominal hypertension and the abdominal compartment syndrome: 'ARDS' of the gut. Int J Intensive Care Spring:1–7
71. Kirkpatrick AW, Balogh Z, Ball CG, et al (2006) The secondary abdominal compartment syndrome: iatrogenic or unavoidable? J Am Coll Surg 202: 668–679
72. Reintam A, Parm P, Kitus R, Starkopf J, Kern H (2008) Gastrointestinal Failure Score in critically ill patients: a prospective observational study. Crit Care 12:R90