# Incidence and clinical effects of intra-abdominal hypertension in critically ill patients

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***Objective:*** **The objective of this study was to determine the epidemiology and outcomes of intra-abdominal hypertension in a heterogeneous intensive care unit population.**

***Design:*** **This was a prospective cohort study.**

***Setting:*** **This study was conducted at a medical–surgical intensive care unit in a university hospital.**

***Patients:*** **Study patients included all those consecutively admitted during 9 months, staying >24 hrs, and requiring bladder catheterization.**

***Measurements and Main Results:*** **On admission, epidemiologic data and risk factors for intra-abdominal hypertension were studied; then, daily maximal and mean intra-abdominal pressures ($IAP_{max}$ and $IAP_{mean}$), abdominal perfusion pressure, fluid balances, filtration gradient, and sequential organ failure assessment score, were registered. IAPs were recorded through a bladder catheter every 6 hrs until death, discharge, or along 7 days. Intra-abdominal hypertension was defined as IAP ≥12 mm Hg. Abdominal compartment syndrome was defined as IAP ≥20 mm Hg plus ≥1 new organ failure. Main outcome measure was hospital mortality. Of 83 patients, considering $IAP_{max}$, 31% had intra-abdominal hypertension on admission and another 33% developed it after (23% and 31% with $IAP_{mean}$). Main risk factors were mechanical ventilation, acute respiratory distress syndrome, and fluid resuscitation (relative risk, 5.26, 3.19, and 2.50, respectively). Patients with intra-abdominal hypertension were sicker, had higher mortality (53% vs. 27%, $p = .02$), and consistently showed higher total and renal sequential organ failure assessment score, daily and cumulative fluid balances, and lower filtration gradient. Nonsurvivors had higher $IAP_{max}$, $IAP_{mean}$, and fluid balances and lower abdominal perfusion pressure. Abdominal compartment syndrome developed in 12%; 20% survived. Logistic regression identified $IAP_{max}$ as an independent predictor of mortality (odds ratio, 1.17; 95% confidence interval, 1.05–1.30; $p = .003$) after adjusting with Acute Physiology and Chronic Health Evaluation II and comorbidities (odds ratio, 1.15; 95% confidence interval, 1.06–1.25; $p = .001$; and odds ratio, 2.68; 95% confidence interval, 1.27–5.67; $p = .013$, respectively). Models with $IAP_{mean}$ and abdominal perfusion pressure also performed well. Areas under receiver operating characteristic curves were .81 and .83.**

***Conclusions:*** **Intra-abdominal hypertension, diagnosed either with $IAP_{max}$ or $IAP_{mean}$, was frequent and showed an independent association with mortality. Intra-abdominal hypertension was significantly associated with more severe organ failures, particularly renal and respiratory, and a prolonged intensive care unit stay. (Crit Care Med 2008; 36:1823–1831)**

**Key Words: Intra-abdominal pressure; intra-abdominal hypertension; abdominal perfusion pressure; abdominal compartment syndrome; multiple organ dysfunction syndrome; renal dysfunction; filtration gradient**

Recently, there has a been growing interest in the concept of intra-abdominal pressure (IAP) (1, 2), its determinants (3–5), and in the impact of intra-abdominal hypertension (IAH) on organ dysfunction in the critically ill (7, 8). One extreme of IAH, the abdominal compartment syndrome (ACS), was described more than a century ago in the surgical literature (9), and diagnostic criteria and different therapeutic approaches have now been settled for it (4). It is possible, indeed, that IAH might be a very frequent event in critically ill patients, even in those admitted for clinical reasons, as a consequence of intense fluid resuscitation (10). Some researchers have even suggested that the measurement of IAP might be considered in severity scores (1) given that IAH has been found associated with a worse outcome in some critically ill subpopulations, as trauma and hepatic transplantation (7, 11). As a matter of fact, knowledge about the magnitude of the problem of IAH in the intensive care unit (ICU) setting is beginning to expand, especially after the publication of the final report of the 2004 International Conference of Experts on Intra-abdominal Hypertension and Abdominal Compartment Syndrome, endorsed by the World Society of the ACS (4, 6). Yet, there is some paucity of information regarding epidemiologic and prognostic issues.

Therefore, we decided to carry out a prospective cohort study to answer the following questions. First, what is the incidence of IAH in a general, mixed medical–surgical ICU population? Second, what is the association of IAH to patients' outcomes? Third, are there any differences in the prognostic ability of maximal ($IAP_{max}$) and mean ($IAP_{mean}$) IAP? Fourth, which are the effects of IAH on organ dysfunctions and on other physiological variables?

## METHODS

*Setting.* This study was conducted at a medical–surgical ICU located in a university hospital.

*Patients.* All consecutive patients admitted to the ICU between November 1, 2004, and July 31, 2005, and expected to stay for more

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than 24 hrs were included in the protocol, provided they needed an indwelling bladder catheter during the ICU stay. Exclusion criteria were pregnancy, bladder surgery, and age <18 yrs. All data were collected prospectively.

*Data Collection.* On admission, age, gender, clinical/surgical status, diagnoses, antecedent of trauma, Acute Physiology and Chronic Health Evaluation (APACHE) II score, and expected mortality were recorded. Severity of underlying diseases was stratified with McCabe score as nonfatal (score of 1), ultimately fatal (2), or rapidly fatal (3) (12). Predisposing conditions for the occurrence of IAH were registered as previous abdominal surgery, abdominal infection (pancreatitis, abscess, other), massive fluid resuscitation, hypotension, gastroparesis/ileus, acidosis, multiple transfusions, mechanical ventilation, pneumonia, bacteremia, or acute respiratory distress syndrome (6).

Fluid balance, cumulative fluid balance, total Sequential Organ Failure Assessment (SOFA) score, and renal SOFA subscore score were recorded daily (13) (Appendix).

Use and length of mechanical ventilation, and of ICU stay, were calculated. Difficult-to-wean patients were defined as those undergoing a gradual weaning process (either requiring prolonged ventilation >72 hrs or a failed trial of spontaneous breathing after >24 hrs of ventilation) (14).

Hospital mortality was the main outcome variable.

*Measurement of Intra-abdominal Pressure.* Intra-abdominal pressure was measured in millimeters of mercury through a Foley bladder catheter. The aspiration port was attached to a short 18-G catheter with three stopcocks connected to an intravenous infusion set, a syringe for flushing and draining the tubing system, and a pressure transducer. After clamping the tube leading to the collection bag, 50 mL of saline was injected into the bladder and IAP was measured at end expiration in complete supine position and with the transducer zeroed at the level of pubic symphysis (2, 15). This volume was used to minimize the risk of IAP overestimation (16). The procedure was repeated after 3 mins, and the mean of the two measurements was used for calculations.

IAP was recorded every 6 hrs (6:00 a.m., 12:00 p.m., 6:00 p.m., and 12:00 a.m.) until death, discharge, or along 7 days, whichever came first. Mean arterial pressure was recorded simultaneously or otherwise calculated. All measurements were performed by two of the researchers (MGV and JRW).

*Definitions.* IAH was defined as a sustained (at least three consecutive values) pathologic elevation of IAP ≥12 mm Hg (4–6). $IAP_{max}$ (the highest daily value) was considered for main analysis (2, 4). $IAP_{mean}$ (mean of the four daily values) was also calculated. IAH was considered as primary or secondary (of abdominal or extra-abdominal cause, respectively).

One-day point prevalence (on admission) and incidence (new cases developing during ICU stay) were calculated for both $IAP_{max}$ and $IAP_{mean}$.

For definitions of abdominal perfusion pressure (APP) (4), filtration gradient (FG) (4), and ACS, see the Appendix.

*Statistical Analysis.* Data are expressed as percentages (%), mean ± SD, or median and 25% to 75% interquartile range, as appropriate. Comparisons across the groups with IAP <12 and IAP ≥12 and across survivors and nonsurvivors were performed.

Continuous, normally distributed variables were compared with *t*-test, and for nonnormally distributed, Mann-Whitney *U*-test was used. Categorical variables were compared by means of chi-square test. A $p$ value <.05 was considered statistically significant.

An associative multiple logistic regression analysis, with hospital mortality as the dependent variable, was constructed. Variables associated with mortality in univariate analysis ($p < .2$) were tested. $IAP_{max}$, $IAP_{mean}$, and APP were evaluated in different models. Odds ratios and 95% confidence intervals were calculated. Receiver operating characteristic (ROC) curves were constructed with the final models, and their areas (AUROC) estimated. Calibration of the models was assessed by the Hosmer-Lemeshow goodness-of-fit test. A $p$ value >.05 indicated a good agreement between observed and predicted mortality. Discrimination was assessed using AUROC to evaluate how well the models set off patients who lived from those who died.

Kaplan-Meier curves for survival at hospital discharge were constructed for patients with and without IAH for $IAP_{max}$.

In addition, ROC curves were constructed to find out sensitivity and specificity for mortality at different IAP and APP thresholds.

Statistical analysis was performed with STATA 9.0 software (College Station, TX).

The Institutional Review Board approved the protocol and waived the need for an informed consent, because patients did not require additional interventions over the usual care.

## RESULTS

During the study period, 153 patients were admitted to the ICU and 60 were excluded from the protocol for the following reasons: 36 had ICU stay <24 hrs, nine were <18 yrs, seven were pregnant, two had nephrostomies, and two did not require urinary catheterization. Ninety-three patients fulfilled the inclusion criteria for IAP measurement. The entire protocol of IAP measurements was completed in 83 patients (89%).

When considering $IAP_{max}$, 26 patients (31%) had IAH on admission and the remaining 27 (33%) developed it during their ICU stay (incidence). With $IAP_{mean}$, figures were 19 (23%) and 26 (31%), respectively. Figure 1 shows day-by-day cumulative incidence.

The occurrence of IAH for the whole group was 64% when defined with a $IAP_{max}$ ≥12 mm Hg at some time and of 54% if defined as $IAP_{mean}$ ≥12 mm Hg. Characterization of the whole cohort and comparisons between the subgroups of IAP ≥ and <12 mm Hg are displayed in Table 1. Risk factors for development of IAH are shown in Table 2.

Hospital mortality was 43%. Patients with IAH were significantly more acutely ill, admitted with more organ failures, underwent mechanical ventilation more often, showed a tendency to more frequent difficulties in the weaning process ($p = .07$) (Table 1), and, above all, had significantly higher hospital mortality rates and longer ICU stays. In 32% of patients, IAH was the result of a primary (abdominal) cause.

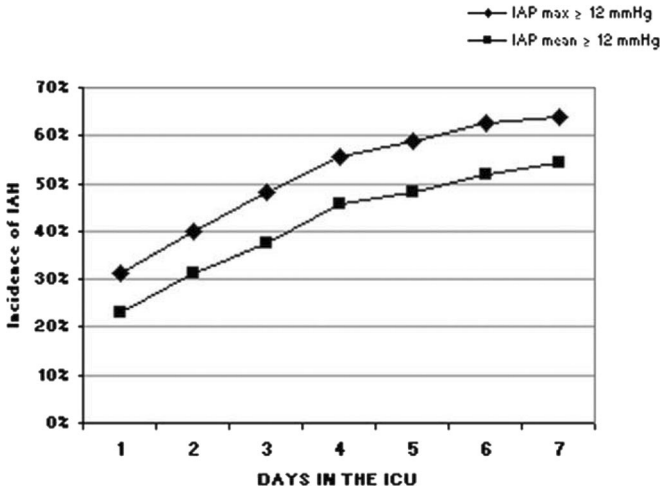


**Figure 1.** Evolution of the incidence of intra-abdominal hypertension along the study period, either defined by maximum intra-abdominal pressure ($IAP_{max}$) or a mean intra-abdominal pressure ($IAP_{mean}$) ≥12 mm Hg. Incidence plateaus at the fifth day.

In addition, patients with IAH had significantly more severe organ dysfunctions throughout the first 3 days. Renal compromise, expressed by SOFA renal subscore, was significantly higher during days 1 and 2, and FG remained significantly lower along the whole week. Daily and cumulative fluid balances were significantly higher during days 2 to 3, during days 3 to 5, and during day 7, respectively (Fig. 2).

Figure 3 shows the evolution of different variables in survivors and nonsurvivors. Briefly, IAH (whether defined with $IAP_{max}$ or $IAP_{mean}$), APP, and daily and cumulative fluid balances differed significantly between both groups.

Twelve percent of patients ($n = 10$) developed ACS. Data of this extremely sick subpopulation, with a median SOFA of 10 points (6–11), is displayed on Table 3. Only two (20%) survived, both with primary ACS. All received the usual medical treatments: nasogastric suctioning and rectal decompression, diuretics, deep sedation, and neuromuscular blockade. None underwent surgical decompression.

Kaplan-Meier survival analysis for $IAP_{max}$ is shown in Figure 4.

ROC curves determining threshold points of IAP for mortality and of APP for survival were constructed and their areas were calculated (Fig. 5). The "best" cutoff values, which are those maximizing sensitivity and specificity, and that most correctly classified the outcome in patients, were: an $IAP_{max}$ ≥14 mm Hg (sensitivity: 74%; specificity: 59%; correctly classified 65%); an $IAP_{mean}$ ≥10 mm Hg (85% and 51%, respectively; correctly classified 65%), and an APP ≥75 mm Hg (77% and 56%; correctly classified 68%).

Variables that differed significantly between survivors and nonsurvivors in univariate analysis and that were entered into multiple logistic regression analysis were: $IAP_{max}$ ($p = .04$), $IAP_{mean}$ ($p = .002$), APP ($p = .02$), age ($p = .009$), gender ($p = .043$), APACHE II ($p < .001$), McCabe score ($p = .033$), use of mechanical ventilation ($p < .001$), and days of mechanical ventilation.

In the final regression model, $IAP_{max}$ was independently associated with mortality after adjusting with APACHE II and McCabe scores (Table 4). $p$ value for Hosmer-Lemeshow test value was .20, which indicates good calibration (no difference between observed and predicted events or deaths). Discrimination was also good (AUROC = .81; 95% confidence interval, .72–.90). A similar model constructed with $IAP_{mean}$ showed good calibration (Hosmer-Lemeshow test = .60) and discrimination (AUROC = .83; 95% confidence interval, .74–.92). Finally, a third model including APP and also adjusted by APACHE II and McCabe scores was created. This model had a very good performance too (Hosmer-Lemeshow test = .80; AUROC = .81).

**Table 1.** Clinical characteristics of the whole cohort and comparisons between patients with and without intra-abdominal hypertension. Maximal IAP was considered

| | ALL | IAH (IAP ≥12 mm Hg) | Non-IAH (IAP <12 mm Hg) | $p$ Value |
|---|---|---|---|---|
| Patients (n, %) | 83 | 53 (64) | 30 (36) | |
| Age (yrs) | 45 ± 18 | 46 ± 17 | 43 ± 20 | NS |
| Male (n, %) | 45 (54) | 31 (59) | 14 (47) | NS |
| APACHE II score | 19 ± 8 | 20 ± 7 | 16 ± 8 | 0.03 |
| Mortality risk (%)[a] | 32 | 35 | 25 | |
| McCabe score n, (%) | 1.5 ± 0.7 | 1.4 ± 0.7 | 1.6 ± 0.9 | NS |
| Medical admission (n, %) | 39 (47) | 23 (43) | 16 (53) | NS |
| Sepsis | 18 | 11 | 7 | |
| COPD | 1 | 1 | 0 | |
| Cardiovascular | 4 | 2 | 2 | |
| Other | 13 | 9 | 6 | |
| Surgical admission (n, %) | 44 (53) | 30 (53) | 14 (47) | NS |
| Emergency surgery (n, %) | 27 (33) | 19 (36) | 8 (27) | NS |
| Trauma (n, %) | 22 (27) | 16 (30) | 6 (20) | NS |
| Trauma emergency surgery (n, %) | 12 (14) | 10 (19) | 2 (7) | NS |
| Mean APP (7-day)[b] | 80 ± 11 | 75 ± 6 | 92 ± 15 | 0.001 |
| Mean SOFA (7-day) | 6 ± 3 | 8 ± 4 | 4 ± 3 | 0.0001 |
| Renal dysfunction/failure (n, %) | 39 (47) | 31 (58) | 8 (27) | 0.006 |
| Mechanical ventilation (n, %)[c] | 51 (61) | 40 (75) | 11 (37) | 0.0005 |
| Difficulties in weaning | 21 (25) | 17 (32) | 4 (13) | NS |
| ICU mortality n, (%) | 34 (41) | 26 (49) | 8 (27) | NS |
| Hospital mortality | 36 (43) | 28 (53) | 8 (27) | 0.02 |
| Length of MV (days)[d] | 9 [4–18] | 9 [4–20] | 8 [4–10] | NS |
| Length of ICU stay (days)[d] | 7 [3–19] | 10 [4–21] | 3 [1–9] | 0.001 |

IAH, intra-abdominal hypertension; IAP, intra-abdominal pressure; APP, abdominal perfusion pressure (mm Hg); MV, mechanical ventillation; APACHE, Acute Physiology and Chronic Health Evaluation; COPD, chronic obstructive pulmonary disease; SOFA, Sequential Organ Failure Assessment; ICU, intensive care unit; MAP, mean arterial pressure.

Data are presented as mean ± standard deviation, unless specified.

[a]According to APACHE II score; [b]APP was calculated as: MAP − IAP; [c]Renal dysfunction/failure was expressed as renal SOFA subscore >1 point; [d]Data are presented as median and [0.25–0.75] percentiles.

**Table 2.** Risk factors for the development of intra-abdominal hypertension

| Risk Factor | RR | CI 95% | $p$ Value |
|---|---|---|---|
| Fluid resuscitation | 2.50 | 0.91–6.90 | 0.04 |
| Acidosis | 1.85 | 1.11–3.07 | 0.03 |
| Hypotension | 2.01 | 1.05–3.83 | 0.02 |
| Gastroparesis/ileus | 1.93 | 1.23–2.99 | 0.02 |
| ARDS | 3.19 | 1.55–6.46 | 0.0003 |
| Hypothermia | 1.41 | 0.75–2.63 | NS |
| Mechanical ventilation | 5.26 | 1.85–15.13 | 0.00001 |
| Abdominal surgery | 1.28 | 0.93–1.75 | NS |
| Abdominal infection | 1.19 | 0.82–1.73 | 0.42 |
| Pneumonia | 1.25 | 0.85–1.85 | NS |
| Bacteremia | 1.13 | 0.81–1.58 | NS |

ARDS, acute respiratory distress syndrome; RR, relative risk; CI, confidence interval.

## DISCUSSION

The main findings of the study are the high incidence of IAH in a prospective cohort of consecutive ICU patients; the independent association between mortality and IAH, diagnosed either by $IAP_{max}$ or $IAP_{mean}$, or indirectly by APP, after adjusting for acuity on admission and underlying diseases; and the relationship of IAH with a greater degree of organ failures/dysfunctions throughout the study period, particularly with renal and respiratory dysfunctions. This was consistent and significantly reflected by total and re-

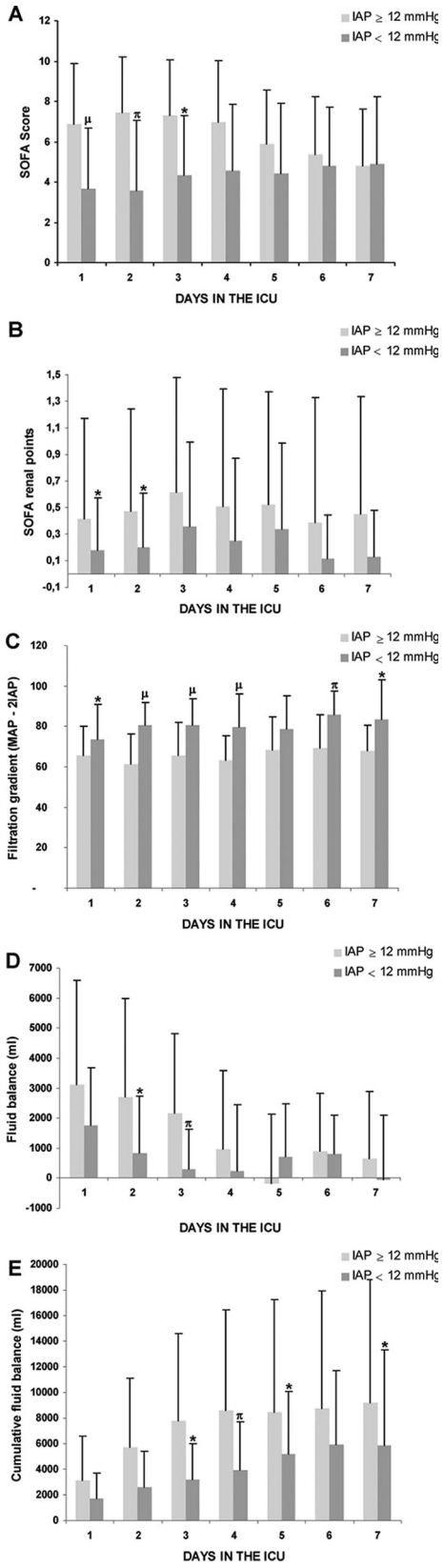


**Figure 2.** Differences in the evolution of total organ dysfunctions and failures (Sequential Organ Failure Assessment [*SOFA*] score) (*A*), SOFA renal subscore (*B*), renal filtration gradient (*C*), daily fluid balance (*D*), and cumulative fluid balance (*E*) across patients with and without intra-abdominal hemorrhage, considering maximum intra-abdominal pressure (IAP). *$p < .05$ for IAP <12 vs. ≥12 mm Hg on the same day. π$p < .01$ for IAP <12 vs. ≥12 mm Hg on the same day. μ$p < .001$ for IAP <12 vs. ≥12 mm Hg on the same day. *ICU*, intensive care unit.

nal SOFA and by FG (a surrogate of renal perfusion); by a more frequent use of mechanical ventilation; and by an increased length of ICU stay. Lastly, the extremely sick subset of patients with ACS is described.

## Epidemiology of Intra-abdominal Hypertension

IAH was frequent in this group representative of a medical–surgical ICU population. Considering $IAP_{max}$, 31% of patients had IAH on admission day, and the remaining 33% developed it during their ICU stay. For $IAP_{mean}$, figures were 23% and 31%. Data on admission day (equivalent to a 1-day point prevalence study) are similar to those reported in the prospective, multiple-center epidemiologic study of Malbrain et al. (1) (32% of incidence, using $IAP_{mean}$). In another study of the same group, a 1-day point prevalence study using $IAP_{max}$, the prevalence of IAH was 58.8% (2). This last discrepancy might be ascribed to different definitions of IAH. In Malbrain's study (2), IAH was defined as a $IAP_{max}$ ≥12 mmHg in at least one measurement, whereas we considered a sustained elevation of pressures ≥12 mm Hg, as suggested (6). Nevertheless, in intermittent measurements, random, spontaneous, physiological, or disease-caused fluctuations might also play a role.

Which measurement best reflects physiology, $IAP_{max}$ or $IAP_{mean}$? The issue might be subjected to debate. Most studies have used $IAP_{max}$, although $IAP_{mean}$ might probably be more appropriate (6). We used $IAP_{max}$ in most analyses, as suggested (4), but repeated the analysis with $IAP_{mean}$. In all cases, both variables were equivalent. Given that visceral perfusion might be affected by IAP starting from values as small as 10 mm Hg (17), the choice of any of them when sustained in time remains meaningful. A third variable is APP, which might be physiologically advantageous; it reflects the severity of IAH plus the appropriateness of organ perfusion (18). An APP ≥60 mm Hg has been considered a goal of resuscitation and failure to maintain it discriminated between survivors and nonsurvivors (19).

At the present time, the ideal frequency of IAP monitoring remains unclear. In a recent survey, most respondents would measure IAP just "when they feel it clinically indicated"; only 27% would do it every 4 to 8 hrs (20). The chance of missing episodes of IAH thus might be important. In the future, bedside use of continuous

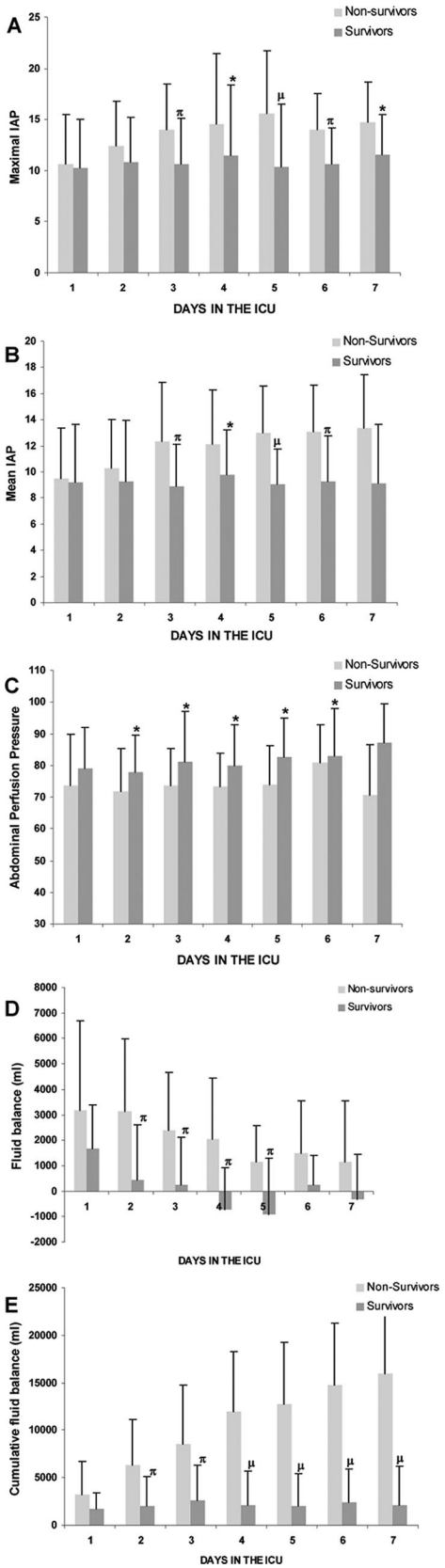


**Figure 3.** Patterns of maximal intra-abdominal pressure (*IAP*) (*A*), mean IAP (*B*), abdominal perfusion pressure (*C*), daily fluid balance (*D*), and cumulative fluid balance (*E*) along the study period in survivors and nonsurvivors. *$p < .05$ for IAP <12 vs. ≥12 mm Hg on the same day. π$p < .01$ for IAP <12 vs. ≥12 mm Hg on the same day. μ$p < .001$ for IAP <12 vs. ≥12 mm Hg on the same day. *ICU*, intensive care unit.

measurement techniques will shed light on the natural evolution of IAH and guide therapeutic decisions, like decompressive laparotomy (21–23).

## Causes of Intra-abdominal Hypertension

Usual risk factors for IAH were present in our cohort. Intense fluid resuscitation, key to the pathophysiology of IAH/ACS, was significantly greater in patients with IAH and in nonsurvivors (see daily and cumulative fluid balances in Figs. 3 and 4). If excessive, fluid resuscitation might lead to bowel edema and further impair gut perfusion in the face of the capillary leak syndrome described in severe trauma and sepsis. Observational studies have demonstrated a strong association between negative fluid balance and survival (24, 25), although this might just mean that the sickest patients, expected to have poorer outcomes, have greater fluid requirements. Supranormal trauma resuscitation has led to more ACS, organ failures, and death (26). Conversely, an early goal-directed resuscitation strategy in severe sepsis/septic shock that used more fluids has demonstrated better outcomes (27). In any case, measuring IAP and APP in patients with at least two risk factors for IAH sounds convenient (6).

## The Prognostic Significance of Intra-abdominal Hypertension

Reduced organ perfusion pressure (4) and interference with cardiopulmonary interactions (28, 29) account for the harmful effects of IAH. Its more severe form, ACS, has been repeatedly linked to a dismal prognosis (7, 30).

IAP and APP consistently and significantly differed between survivors and nonsurvivors across the study. In addition, and similar to the findings of a multicenter study recently published (1), we were able to demonstrate a clear, independent effect of IAP, either maximal or mean, and of APP on mortality, after adjusting for severity of illness and comorbid states, in a general ICU population. The associative logistic regression models displayed good calibration and discrimination.

To identify threshold pressure values that best predict outcome, ROC curves were generated for $IAP_{max}$ and $IAP_{mean}$ with mortality. Respective areas were .70 and .71 (Fig. 5), which compare well to the .69 reported for $IAP_{max}$ (16). A ROC curve for APP as a predictor of survival

Table 3. Characteristics of patients with abdominal compartment syndrome (ACS)

| | No of patient | Diagnosis | Age | Outcome | Medical or Surgical Status | APACHE II | Risk of Death (%) | Cumulative Fluid Balance | Max IAP | SOFA in Max IAP |
|---|---|---|---|---|---|---|---|---|---|---|
| Primary ACS | 1 | Acute, severe pancreatitis | 41 | NS | S | 13 | 18 | 21,270 | 22 | 6 |
| | 2 | Septic shock. Kidney transplantation | 24 | S | M | 27 | 63 | — | 20 | 12 |
| | 3 | Peritonitis. Inflammatory pelvic disease | 38 | S | S | 16 | 33 | 1,809 | 21 | 5 |
| | 4 | Intestinal ischemia and resection | 63 | NS | M | 24 | 45 | 22,703 | 25 | 9 |
| | 5 | Septic shock. Inflammatory pelvic disease | 35 | NS | M | 15 | 30 | 15,557 | 40 | 6 |
| Secondary ACS | 6 | Moderate cranial trauma | 43 | NS | M | 21 | 28 | 12,343 | 21 | 10 |
| | 7 | Polytrauma | 63 | NS | S | 21 | 16 | 19,802 | 21 | 7 |
| | 8 | Moderate cranial trauma | 26 | NS | M | 12 | 7 | 2,900 | 22 | 11 |
| | 9 | Severe cranial trauma | 20 | NS | S | 24 | 41 | 11,069 | 23 | 12 |
| | 10 | Intracranial hemorrhage | 52 | NS | S | 34 | 78 | 13,600 | 24 | 10 |
| All | | | 41 ± 15 | 80% NS | 50% M | 21 ± 7 | 36 | 13,450 | 24 ± 6 | 9 ± 3 |

Data are presented as mean ± standard deviation, unless specified.

NS, Non-survivor; S, Survivor; M, Medical status; S, Surgical status; Max IAP, maximal intra-abdominal pressure; APACHE, Acute Physiology and Chronic Health Evaluation; SOFA, Sequential Organ Failure Assessment.

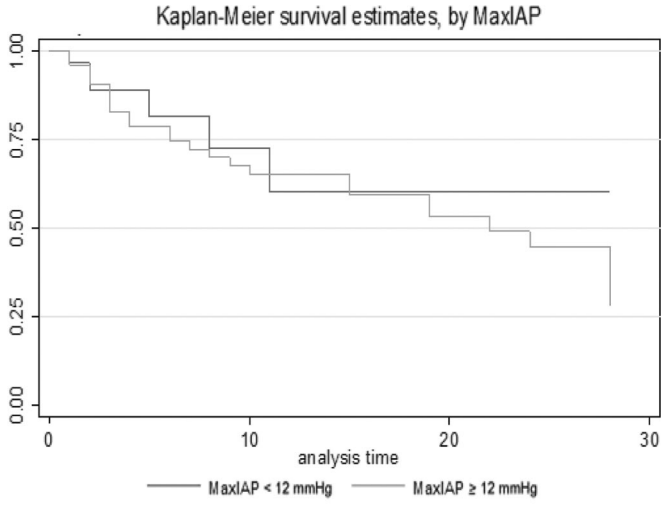


Figure 4. Twenty-eight-day Kaplan-Meier survival curves for patients with and without intra-abdominal hemorrhage according to maximum intra-abdominal pressure (*MaxIAP*).

was also constructed and the area under the curve was .69. Reported values are .73 (19) and .78 (16).

Therefore, there is a strong physiological basis for considering IAP and derived variables as "vital signs" to monitor in the critically ill and to be added eventually to predictive scores (1). This validation, however, should be performed in prospective, multiple-center, and preferably international studies.

## The Association of Intra-abdominal Hypertension to Organ Dysfunctions

IAH and subsequent gut edema and ischemia might lead to mucosal barrier failure and translocation of intestinal bacteria, toxins, and/or cytokines, which might initiate distant organ dysfunction (7, 31–33). We, like others (1), found that patients with IAH displayed significantly higher SOFA scores during the first 3 days in the ICU.

Renal dysfunction was significantly more frequent in patients with IAH in line with its effect on renal perfusion (34, 36). Interestingly, FG, which represents the difference between glomerular filtration and proximal tubular pressures (Appendix), was significantly lower in patients with IAH along the study period (Fig. 2). This seems to confirm that when IAH occurs, proximal tubular pressure equals IAP (4).

Patients with IAH used mechanical ventilation more frequently and tended to have more difficult weaning, both of which represent respiratory organ failure. They too had an increased ICU length of stay. These secondary outcomes are relevant given their clear impact on health costs.

## Abdominal Compartment Syndrome

Twelve percent of patients developed ACS. Half had extra-abdominal causes of injury, mainly cranial trauma, evidencing the etiologic effect of early, intense resuscitation. Organ failures and death were frequent (80% of patients). Although evaluated by experienced surgeons in a university hospital, decompressive laparotomy was never performed (4, 30). This has been repeatedly described, especially for secondary ACS (17, 37).

Underdetection, differences in diagnostic methods and treatments, and, above all, lack of evidence-based guidelines on IAH/ACS might account for the widespread variations in the approach to IAH (20, 38–43). The publication of a recent consensus will surely result in advances in homogenization (4–6). Yet, it is known that awareness of a condition does not lead to an immediate change of behavior; even after publication of randomized, controlled trials, barriers to setting their conclusions into practice are not easily overcome (44).

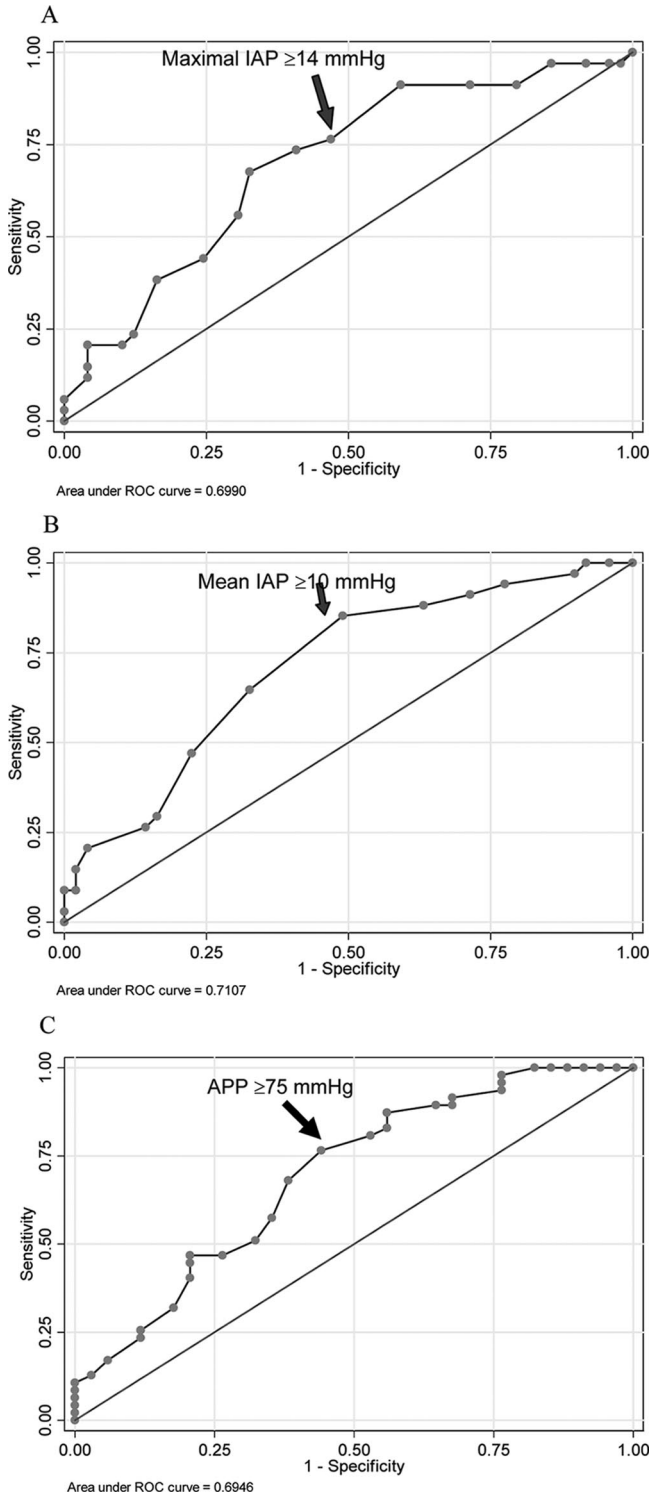


**Figure 5.** *A–B*, Receiver-operator characteristic (*ROC*) curves for maximum intra-abdominal pressure (*IAP*) and mean IAP and mortality are displayed with the values of their resultant areas. *C*, The ROC curve for abdominal perfusion pressure (*APP*) and survival is shown. The arrows point to the selected cutoff points that identify the best thresholds (the ones that correctly classify the higher number of patients). For the corresponding sensitivity, specificity, and proportion of correctly classified patients, see the text.

### Limitations of the Study

This study has several limitations. As a single-center study, the conclusions arrived at might not be generalizable to other ICUs. Another limitation pertains to the measurement of IAP. We considered symphysis pubis for zeroing the bladder catheter, and we used 50 mL of saline instead of the recently recommended midaxillary line and 25 mL (4–6, 45). At the time our study was planned, such was standard practice (2).

## CONCLUSIONS

Our study expands previous knowledge in several ways. It provides a prospective, well-documented approach to the epidemiology and clinical features of IAH in a heterogeneous ICU population and is the first to apply the World Society of the ACS Consensus definitions. Second, differences between $IAP_{mean}$ and $IAP_{max}$ are explored for the first time, and a similar prognostic ability for both and for APP is demonstrated. Third, the association described between FG and IAH is a novel finding in the clinical arena. Fourth, this is the first study that calculates each IAP measurement as the mean of two, within a 3-min interval, so as to rule out possible measurement outliers. Finally, the findings about IAH and its correlation with organ dysfunctions reinforce previous, scarce reports on the issue.

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**Table 4.** Logistic regression models for hospital mortality as the dependent variable, either considering $IAP_{max}$ (Panel A), $IAP_{mean}$ (Panel B), or APP (Panel C)

A.

| | Odds Ratio | *p* Value | 95% Confidence Interval | |
|---|---|---|---|---|
| $IAP_{max}$ | 1.17 | 0.003 | 1.05 | 1.30 |
| APACHE II score | 1.15 | 0.001 | 1.057 | 1.25 |
| McCabe score | 2.68 | 0.010 | 1.27 | 5.67 |

Model equation: Logit (Death )= −7.10 + 0.19 (maximal IAP) + 0.13 (APACHE II) + 0.89 McCabe score)

B.

| | Odds Ratio | *p* Value | 95% Confidence Interval | |
|---|---|---|---|---|
| $IAP_{mean}$ | 1.27 | 0.006 | 1.07 | 1.51 |
| APACHE II score | 1.13 | 0.002 | 1.05 | 1.23 |
| McCabe score | 2.04 | 0.044 | 1.02 | 4.07 |

Model equation: Logit (Death) = −6.42 + 0,24 (mean IAP) + 0.12 (APACHE II) + 0.71 (McCabe score)

C.

| | Odds Ratio | *p* Value | 95% Confidence Interval | |
|---|---|---|---|---|
| APP | 0.94 | 0.025 | 0.88 | 0.99 |
| APACHE II score | 1.12 | 0.005 | 1.03 | 1.21 |
| McCabe score | 2.91 | 0.050 | 1.00 | 8.60 |

Model equation: Logit (Death) = 2.24 – 0.07 (APP) + 0.11 (APACHE II) + 1.07 (McCabe score)

IAP, intra-abdominal pressure; APP, abdominal perfusion pressure; APACHE, Acute Physiology and Chronic Health Evaluation.


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## APPENDIX

Abdominal perfusion pressure (APP) was calculated as: mean arterial pressure (MAP) − intra-abdominal pressure (IAP) (4, 5).

Filtration gradient (FG) was calculated as: MAP − 2 × IAP (4, 5). FG = glomerular filtration pressure − proximal tubular pressure = MAP − 2 × IAP.

Abdominal compartment syndrome *(*ACS) was defined as: a sustained IAP 20 mm Hg (with or without an APP <60 mm Hg) that is associated with new organ dysfunction/failure (2, 4–6).

Primary ACS is a condition associated with injury or disease in the abdominopelvic region that frequently requires early surgical or interventional radiologic intervention.

Secondary ACS refers to conditions that do not originate from the abdominopelvic region. Recurrent ACS refers to the condition in which ACS redevelops after previous surgical or medical treatment of primary or secondary ACS.

Sequential Organ Failure Assessment (SOFA) score was calculated according to the original description (12). For each category of organ/system, organ dysfunctions were defined as SOFA subscore points of 1 to 2 and organ failures as 3 to 4 points (13).

Specifically, for renal SOFA subscore, renal dysfunction was expressed as creatinine elevation (mg/dL): 1.2 to 1.9 (1 point), 2.0 to 3.4 (2 points); and renal failure as creatinine elevation or a fall in diuresis: 3.5 to 4.9 mg/dL or urine output <500 mL per day (3 points), and >5.0 mg/dL, or an urine output <200 mL per day (4 points) (13).