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Abdominal compartment syndrome and intra-abdominal hypertension in critically ill patients: diagnostic value of computed tomography

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Abstract

Aims The aims of the present work were to reevaluate, prospectively, the diagnostic value of already-described computed tomography (CT) landmarks of intra-abdominal hypertension (IAH) and abdominal compartment syndrome (ACS) and to study the diagnostic value of some undescribed CT signs for the diagnosis of IAH and ACS.

Materials and methods Consecutive patients admitted to the intensive care unit (ICU) in shock for whom an abdominal CT was clinically indicated were included. CT examinations were reviewed and scored by two reviewers for the 12 proposed CT features of IAH and ACS. Intravesical pressure (IVP) was measured for each patient. Imaging features and clinical data of patients with IAH (IVP ≥ 12 mmHg) were compared to those of patients with normal intra-abdominal pressure (IVP < 12 mmHg).

Results Forty-one patients were included. Twenty-one patients (51%) presented IAH with an IVP value ≥ 12 mmHg. Four patients (10%) were considered to have ACS (10%). Only an increased peritoneal-to-abdominal height ratio (PAR) was associated with the presence of IAH (PAR = 0.45 [0.40–0.49] in patients with IVP < 12 mmHg and PAR = 0.52 [0.48–0.53] in patients with IVP ≥ 12 mmHg; $p < 0.001$). Increased PAR ≥ 0.52 had a specificity of 85% for IAH diagnosis.

Conclusion The present study suggests that a PAR ≥ 0.52 could help radiologists to identify IAH on abdominal CT scan and could lead to adequate identification and/or treatment, even at early stages of IAH.

Key Points

- *CT is an efficient first-intention procedure to evaluate and follow up underlying conditions in critically ill patients at risk of IAH and ACS overcome.*
- *Raising the possibility of an IAH on a CT examination is relevant information for the clinician.*
- *The only factors associated with intra-abdominal hypertension were the peritoneal-to-abdominal height ratio (PAR) and the ratio of maximal anteroposterior to transverse abdominal diameter (which define the round belly sign when > 0.8).*

Keywords Intra-abdominal hypertension · Sagittal abdominal diameter · Intensive care units · X-ray computed tomography · Prospective studies

Abbreviations

ACS	Abdominal compartment syndrome
CT	Computed tomography
IAH	Intra-abdominal hypertension
ICU	Intensive care unit
IVP	Intravesical pressure
PAR	Peritoneal-to-abdominal height ratio
RBS	Round belly sign

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WSACS World Society of the Abdominal Compartment Syndrome

Introduction

Intra-abdominal hypertension (IAH) is defined by the World Society of the Abdominal Compartment Syndrome (WSACS) as a persistent increase of the intra-abdominal pressure ≥ 12 mmHg. Whereas the normal pressure in the abdomen is usually less than 8 mmHg, such IAH can occur in case of an increase of intra-abdominal volume (ileus, ascites, etc.) and/or a decrease in abdominal wall compliance. IAH can be responsible for a decreased venous flow, low cardiac output, renal impairment with oliguria, and decreased respiratory compliance with hypoxemia. Together, these can lead to multiple organ failure and induce the life-threatening phenomenon known as "abdominal compartment syndrome" (ACS), when intra-abdominal pressure rises above 20 mmHg or higher [1].

IAH and ACS are highly prevalent in critically ill patients, with reported frequencies of about 35% to 55% and 5% to 10%, respectively [2–7]. Indeed, critically ill patients share many risk factors for IAH, such as infusion of a large volume of fluids for resuscitation, shock state, or mechanical ventilation. Both IAH and ACS can negatively impact the outcome of critically ill patients [5, 8–14], and thus, early recognition and treatment of ACS is a key to improving the outcome of affected patients [8, 15]. Abdominal CT is useful for the diagnosis of critically ill patients presenting with acute abdomen, in particular in case of acute mesenteric ischemia, severe acute pancreatitis, or intra-abdominal bleeding. Identification of specific signs of IAH on CT might help physicians to diagnose and treat earlier IAH. Several retrospective studies and one prospective study performed in 24 patients identified several CT signs associated with IAH and/or ACS. However, the performance of these signs remains unclear.

We aimed to evaluate prospectively and in a larger cohort of patients the performance of abdominal CT for the identification of IAH. Therefore, we measured intra-abdominal pressure (IAP) among critically ill patients, requiring mechanical ventilation and catecholamine infusion, in whom abdominal CT was required. We evaluated the performance of previously described CT signs, as well as new signs, for the presence of IAH.

Materials and methods

Design and patients

This observational prospective study took place in the medical and surgical intensive care units (ICUs) of a teaching university hospital, between August 2016 and June 2017. The study was carried out in accordance with the ethical standards set forth in the Helsinki Declaration of 1975. The study was approved by the local ethics committee and by the national authority for the protection of privacy and personal data and was registered on ClinicalTrials.gov under the number NCT02814734. In accordance with national bioethics legislation, all relatives received written information about the study, the data collected for analysis, and how to oppose the use of personal data for research purposes. As soon as possible, the same written information was given to the patient. As all data collected were considered part of routine management of the patients and the confidentiality of the data was preserved, the requirement for informed consent was waived.

All consecutive eligible patients were included in this study if they met the following inclusion criteria: patient admitted to ICU, sedated, mechanically ventilated, requiring vasopressors, and with a clinical indication for abdominal CT. Non-inclusion criteria were as follows: age under 18, patients under legal guardianship, pregnancy, cystectomy, contraindication to intravesical catheter, absolute contraindication to iodinated contrast infusion, decompressive laparotomy prior to CT examination, and contraindication to neuromuscular blockade.

The inclusion of a patient in this study did not modify the standard of care. Indeed, iterative measurements of intravesical pressure (IVP) are recommended among critically ill patients presenting with shock, and all of the patients required an urgent abdominal CT.

CT features and measurements

All CT examinations were performed in the radiology department of our institution, using a 64-multi-section scanner (Siemens, Somatom Definition AS). Imaging protocol was an abdominopelvic acquisition in the portal phase, 70 s after intravenous infusion of 90 mL of iodinated contrast enhancement (Iomeron 400, Bracco). Clinically indicated CT examinations for each patient included were reviewed and/or measured independently by two reviewers, who were blinded to the intra-abdominal pressure value and the patient's clinical condition. All CT signs that have already been studied and linked to IAH in previous works were evaluated according to the exact description given by the authors (see Table 1 for details). Figure 1 is an example of round belly sign (RBS), illustrating the ratio between maximal anteroposterior diameter and transverse diameter measurements.

The followings CT signs were also reviewed and/or measured:

- Diffuse mesenteric fat stranding was defined as a moderate diffuse mesenteric fat stranding with superior attenuation as compared to retroperitoneal fat.
- The peritoneal-to-abdominal height ratio (PAR) was defined as the ratio of anteroposterior peritoneal

Table 1 List and description of CT features previously published as potentially linked to IAH

CT features of IAH	Definition
Round belly sign	Ratio of maximal anteroposterior to transverse abdominal diameter exceeding 0.8, at the level of the left renal vein crossing midline (excluding subcutaneous fat)
Shock bowel	Bowel (small or large) wall thickening (> 3 mm) with contrast enhancement
Elevation of the diaphragm	Dome reaching the 10th vertebra body or above
Mosaic liver perfusion	Heterogeneous liver parenchyma with linear hypodensities at the portal phase after infusion of iodinated contrast enhancement
Narrowing of the abdominal veins	Slit-like appearance of the inferior vena cava or renal veins < 3 mm
Narrowing of the intrahepatic portion of inferior vena cava	Slit-like appearance of the intrahepatic portion of the upper vena cava < 3 mm
Pathological intra-abdominal fluids	Ascites, hematoma, hemoperitoneum, pancreatic fluid collection
Deformation of solid abdominal viscera	Compression or displacement of solid abdominal viscera, presence of contour deformity

compartment diameter (namely the distance from the linea alba to the posterior aspect of the duodenum) and anteroposterior abdomen diameter (namely the distance from the linea alba to the posterior fascia, excluding subcutaneous fat), both measured along the midline. An example of PAR measurement is given in Figs. 2 and 3.

- The measurement of the semilunar line was defined as the maximal interfacial distance separating the external side of the rectus abdominis and the internal side of the lateral abdominal muscles.
- Abnormal concavity of pararenal fascia was defined by the loss of the normal convex shape of the pararenal fascia.

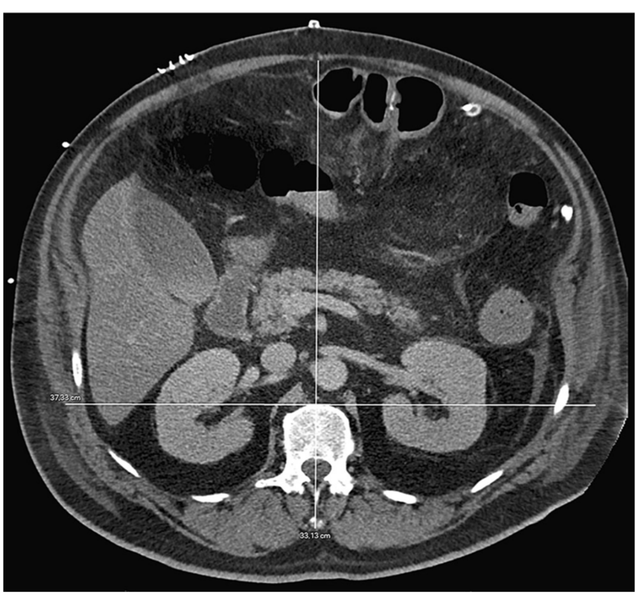

Fig. 1 Contrast-enhanced CT. Positive round belly sign (ratio of maximal anteroposterior to transverse abdominal diameter exceeding 0.8) in a patient suffering from proven ACS

IAP estimation

Intra-abdominal pressure was estimated by measuring the IVP, according to the validated procedure proposed by Kirkpatrick et al [1], Kron et al [13], Iberti et al [14], and Desie et al [16]. Briefly, IVP measurement was done in supine position, 15 min after an intravenous bolus of a neuromuscular blocking drug and within 2 h of the CT examination. Two consecutive measurements were performed, and the mean value of the two measures was recorded as the IAP value. Patients were classified according to their IAP values from normal to grade IV IAH, according to the classification proposed by the WSACS [1] (Table 2). The diagnosis of ACS was left to the appreciation of the physician in charge of the patient and was collected.

Additional data collected

We also recorded, for all patients, the time from admission to CT scan, the indication for abdominal CT scan, the main demographical and clinical variables (age, sex, body mass index (BMI)), and Simplified Acute Physiology Score (SAPS) II [17] at admission to the ICU. The vital status at day 28 (D28) and the duration of stay in intensive care unit were also recorded.

Statistical analysis

Patients were classified in two groups according to the IAP value, namely the IAH group, comprising patients with IAP ≥ 12 mmHg, and the non-IAH group, comprising patients with IAP < 12 mmHg. Qualitative variables are expressed as number (percentage). Quantitative variables are expressed as median [interquartile range]. Intergroup comparisons were assessed using Fisher's exact tests for qualitative variables and the Wilcoxon test for quantitative

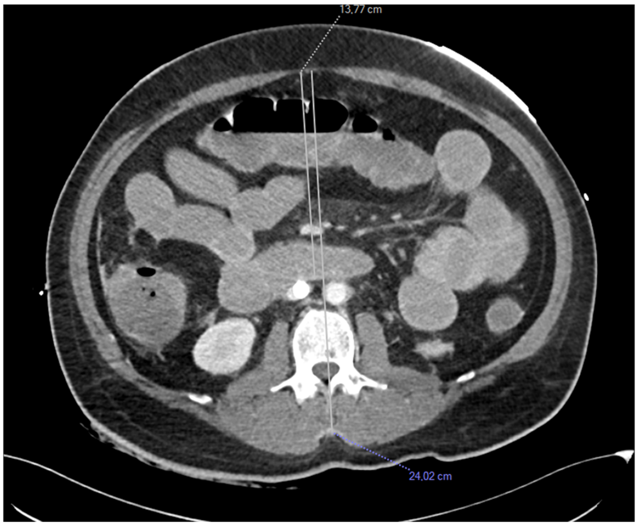

Fig. 2 Contrast-enhanced CT. A 42-year-old patient with ileus. PAR measurement (arrows). The PAR was 0.57, the IVP was 15 mmHg, and the RBS was negative. ACS occurred in this patient within 12 h following CT

variables. The measurements of radiological signs on computed tomography were performed both by a senior radiologist with 4 years of abdominal imaging experience and by a junior radiologist, resident at the end of training. Values in Table 3 correspond to those collected by the senior radiologist. The Kendall rank correlation coefficient was used to evaluate the inter-rater agreement in reviewing CT features of IAH, final consensus being considered as the truth. The diagnostic value of significant radiological signs was studied by estimating the sensitivity, specificity, and positive and negative predictive values for qualitative data and by constructing a receiver operating characteristic (ROC) curve for quantitative data. The area under the

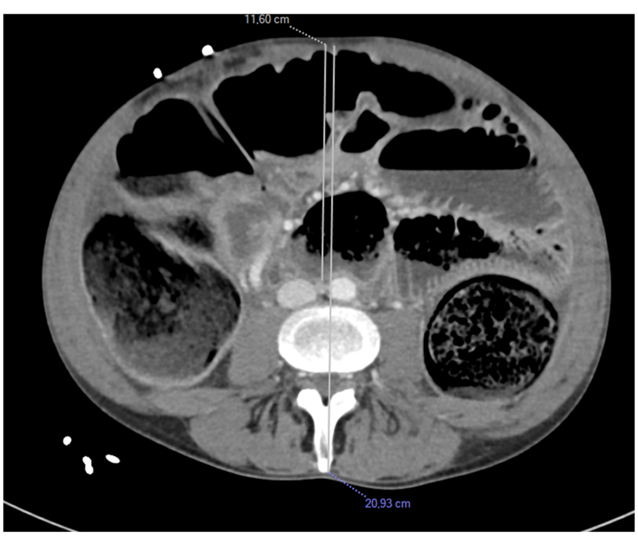

Fig. 3 Contrast-enhanced CT. A 52-year-old patient with obstruction, suffering from ACS at the time of the examination. The PAR was 0.55 (arrows), the IVP was > 20 mmHg, and the RBS was positive

Table 2 Severity grades of IAH according to WSACS

Intra-abdominal pressure	IVP (mmHg)
Normal	0–11
Grade I IAH	12–15
Grade II IAH	16–20
Grade III IAH	21–25
Grade IV IAH	> 25

curve (AUC) and the optimal cutoff value for discriminating patients with or without IAH were also estimated. All estimators are given with their 95% confidence intervals. All statistical analyses were performed using SAS (version 9.3, (SAS Institute, Inc.). A $p < 0.05$ was considered as statistically significant.

Results

Patients

During the study period, 41 patients were included. The main demographic and clinical characteristics are given in Table 3. IAP values ranged from 5 to 28 mmHg, with a median value of 12 mmHg (7–15). Twenty (49%) patients constituted the non-IAH group (IAP < 12 mmHg), and 21 (51%) defined the IAH group (IAP ≥ 12 mmHg). Fifteen patients presented grade I IAH, four patients presented grade II IAH, one patient presented grade III IAH, and one patient presented grade IV IAH. Four patients (10%) (three patients with grade II IAH and one patient with grade III IAH) were considered as suffering from ACS during their stay in the ICU; all were in the IAH group, and all four died.

Factors associated with IAH

The results of the univariate comparisons between the IAP and non-IAH groups are given in Table 3. No difference was observed between groups regarding the main demographical or clinical data. No difference was observed between groups for most of the CT signs evaluated excepted for the RBS, the PAR, and the ratio of maximal anteroposterior to transverse abdominal diameter.

Diagnostic performance of the RBS, the PAR, and the ratio of maximal anteroposterior to transverse abdominal diameter

Sensitivity, specificity, PPV, and NPV for the RBS were respectively 0.24 (95% CI 0.10–0.46), 1.00 (95% CI 0.81–1.00), 1.00 (95% CI 1.00–100), and 0.56 (95% CI 0.39–0.72). In patients suffering from ACS, the RBS was present in two out of four patients. The individual values of PAR and the ratio of

Table 3 Univariate statistical analysis of factors linked to the presence of IAH in the 41 patients included

	Total ($n = 41$)	Control ($n = 20$)	HIA ($n = 21$)	p
Characteristics of patients				
Age (years)	68 (55–77)	72 (54–78)	66 (56–72)	0.36
Body mass index	26 (25–28)	27 (25–30)	26 (24–28)	0.49
SAPS II score at ICU admission	63 (47–76)	64 (49–75)	63 (47–78)	0.97
28-day mortality (%)	22 (56)	12 (60)	10 (53)	0.75
CT features of IAH				
Ratio of maximal anteroposterior to transverse abdominal diameter	0.71 [0.65–0.76]	0.67 [0.63–0.73]	0.73 [0.69–0.79]	*0.004*
Shock bowel	10 (24)	5 (25)	5 (24)	1
Elevation of the diaphragm	26 (63)	10 (50)	16 (76)	0.11
Mosaic liver perfusion	4 (10)	3 (15)	1 (5)	0.34
Narrowing of the abdominal veins	8 (20)	5 (25)	3 (14)	0.45
Narrowing of the intrahepatic portion of inferior vena cava	6 (15)	4 (20)	2 (10)	0.66
Pathological intra-abdominal fluids	27 (71)	14 (78)	13 (65)	0.49
Deformation of solid abdominal viscera	6 (15)	3 (15)	3 (14)	1
Peritoneal-to-abdominal height ratio	0.49 [0.45–0.53]	0.45 [0.40–0.49]	0.52 [0.48–0.53]	*0.0004*
Diffuse mesenteric fat stranding	20 (49)	9 (45)	11 (52)	0.76
Concavity of pararenal fascia	17 (41)	6 (30)	11 (52)	0.21
Semilunar line measurement	18 [16–21]	20 [16–21]	18 [16–21]	0.88

Italic style was only meant to highlight the values with $p < 0.05$

maximal anteroposterior to transverse abdominal diameter, according to the grade of IAP and for patients with or without IAH, are shown in Fig. 4a, b. The ROC curves for the PAR and the ratio of maximal anteroposterior to transverse abdominal diameter are given in Fig. 5. The respective AUCs for the PAR and the ratio of maximal anteroposterior to transverse abdominal diameter were 0.826 (95% CI 0.701–0.952) and 0.767 (95% CI 0.623–0.910). A PAR threshold of ≥ 0.52 was shown to discriminate patients with or without IAH with a sensitivity of 0.57 (95% CI 0.36–0.75), a specificity of 0.85 (95% CI 0.63–0.95), a PPV of 0.80 (95% CI 0.60–1.00), and a NPV of 0.65 (95% CI 0.47–0.84). A PAR threshold > 0.45 can discriminate patients with or without IAH with a sensitivity of 1.00 (95% CI 0.81–1.00), a specificity of 0.55 (95% CI 0.34–0.74), a PPV of 0.70 (95% CI 0.54–0.86), and a NPV of 1.00 (95% CI 1.00–1.00). A ratio of maximal anteroposterior to transverse abdominal diameter > 0.65 can identify patients with IAH with a sensitivity of 0.95 (95% CI 0.75–1.00), a specificity of 0.50 (95% CI 0.30–0.70), a PPV of 0.67 (95% CI 0.50–0.83), and a NPV of 0.91 (95% CI 0.74–1.00). The Kendall rank correlation

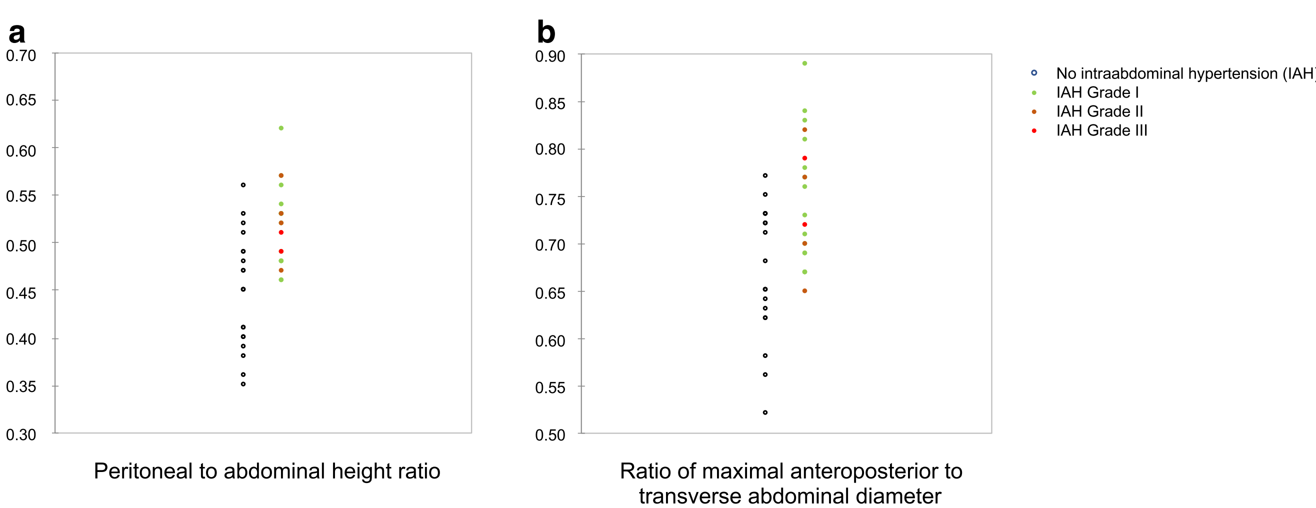

Fig. 4 **a**, **b** Individual values of the PAR and the ratio of maximal anteroposterior to transverse abdominal diameter, according to the grade of IAP and for patients with or without IAH

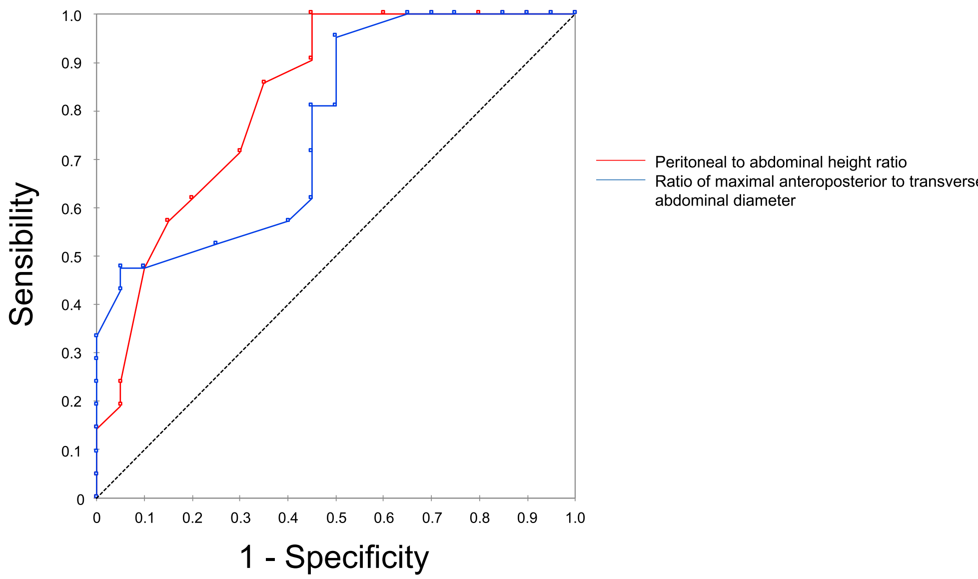

Fig. 5 ROC curves for the PAR and the ratio of maximal anteroposterior to transverse abdominal diameter

coefficient showed a strong inter-rater agreement for the measurement of the PAR and of the ratio of maximal anteroposterior to transverse abdominal (respectively tau = 0.774, $p < 0.0001$, and tau = 0.698, $p < 0.0001$).

Discussion

This study suggests that an increased PAR and an elevated ratio of maximal anteroposterior to transverse abdominal diameter (which define the round belly sign when > 0.8) are statistically associated with a rise in IAP > 12 mmHg in high-risk critically ill patients. Among these, we propose for the first time that a PAR value > 0.52 could be the best predictor for diagnosing patients with IAH, and PAR was easy to assess, with an excellent inter-rater agreement. We therefore believe that PAR measurement could enable radiologists to deliver a simple, early, and relevant warning for the risk of IAH, promoting adequate identification and treatment of this potentially life-threatening condition. In contrast, our study failed to confirm the diagnostic value of all other radiological signs tested.

This study strongly suggests that abdominal CT could be of interest for identification of IAH and/or for the confirmation of the anatomical modifications associated with IAH. As clinical examination is not accurate to detect IAH [18], it has been recommended since 2013 to estimate intra-abdominal pressure, by a standardized trans-bladder measurement of the IVP, in case of any known risk factor for IAH/ACS in a critically ill or injured patient [1, 13, 14, 16]. Abdominal CT is not needed to diagnose ACS or IAH but is generally required to assess the nature of lesions responsible for the rise in intra-abdominal pressure and to guide the treatment in case of IAH or ACS [1]. However, finding out if CT scan is able to identify accurately a rise in intra-abdominal pressure could be of great interest for several reasons. First, as for any recommendation, the compliance to those proposed by the WSACS may be extremely variable throughout the world, while CT is a common and efficient first-intention procedure in critically ill patients. Second, critical illness or conditions leading to IAH or ACS can occur outside from ICUs, where the skills or the resources required to accurately assess the intra-abdominal pressure are not met. Third, the measurement of the intra-abdominal pressure using the recommended technique is not always possible (as for patients presenting bladder troubles) and alternative techniques to detect a rise in intra-abdominal pressure must then be considered.

We propose here a new sign, the PAR, which was strongly associated with IAH. Indeed, we found that PAR was the best predictor for IAH compared to the ratio of maximal anteroposterior to transverse abdominal diameter or RBS. A PAR ≥ 0.52 has mediocre sensitivity but satisfactory specificity (57% and 85%, respectively) and makes it possible to diagnose IAH with a PPV of 80%. Beyond the reproducibility of the measure, another advantage is its intuitive measurement. Indeed, an increased PAR > 0.5 appears to be easily perceived by any CT rater, without the need for a more thorough measurement, and a peritoneal compartment clearly exceeding half of the total abdominal height could constitute a strong point in favor of IAH in at-risk patients.

Although the literature regarding CT features and IAH is scarce, a number of radiological signs have previously been proposed as potentially relevant for diagnosing IAH or ACS [19–26]. Most of these signs presuppose an IAH effect, either on the abdominal shape (measurable rounding effect) or on intra-abdominal (liver, kidneys, vena cava) and adjacent (diaphragm elevation, for instance) organs. Others, such as the shock bowel or the liver mosaic perfusion sign, could be related to ischemia or venous congestion induced by IAH. Taken together, these data seem to give conflicting results.

Our study suggests that CT signs related to a measurable rounding effect induced by IAH could be the more reliable signs to discriminate patients with or without IAH. This is in accordance with the results of some previous published works [20, 21, 24, 27], particularly those of Al-Bahrani et al [22] that showed that the round belly sign was associated with IAH.

In contrast, our study failed to confirm the diagnostic values of CT signs proposed by others previous works. Several reasons could explain this discrepancy. First, most of the reports to date were case reports, with no control group, and describing a selected population of patients with obvious ACS, whereas we included an unselected population of critically ill patients, with a majority of low-grade IAH in the IAH group. Second, some of the reported CT signs are not absolutely specific for IAH or can be influenced by other factors than IAH. For instance, the vena cava shape and its degree of narrowing that have been described as a marker of IAH in some studies [19–21, 27] can also be linked to deep hypovolemia or be modified in case of right heart dysfunction [26]. Shock bowel sign can be observed independent of IAH or ACS [28, 29]. Several lessons can be inferred from these considerations. Firstly, correct interpretation of CT features for the diagnosis of IAH should always take the clinical context into account. Secondly, the fact that we did not find any link between most of the CT features and IAH does not rule out their potential added diagnostic value in other clinical situations with higher-grade IAH or specific causes for IAH. Thirdly, it should be noted that a combination of several signs could be of interest to increase the specificity for diagnosing or ruling out IAH or ACS [23]. Finally, we believe it is unsurprising that continuous measurable rounding abdominal deformation assessed by an increased PAR or an increased ratio of maximal anteroposterior to transverse abdominal diameter should be the most relevant parameters for discriminating low-grade IAH in unselected critically ill patients. Indeed, other CT features potentially more prevalent in higher-grade IAH or ACS, or depending on more specific causes, may have gone unidentified in the present study.

Most of the patients included in this study presented grade I IAH (IVP 12–15 mmHg) with no acute abdominal condition and no further ACS occurrence. The impact and prognosis of such a condition remains a matter of debate [30]. Furthermore, even though all were critically ill patients, some may have presented chronic low-grade IAH (generally linked to obesity or other medical conditions), whose exact consequences are unknown, especially in critical illness [31, 32]. An increased PAR may not make it possible to distinguish chronic IAH from an acute rise in IAP. However, it is known that IAH, whatever its nature, remains a precursor state and a risk factor for ACS. Furthermore, an IAH of grade I can be responsible for an alteration of visceral perfusion and micro-circulation [10, 32]. Identifying possible IAH on a CT examination, even if it is of low grade and asymptomatic, is highly relevant information for the clinician. Another potential advantage lies in the interest of measuring the PAR on consecutive CT scans, during patient follow-up, to increase the accuracy for the diagnosis of IAH [24]. However, our study was not designed to address this point.

Our study presents some limitations. First, this was a single-center study with the inherent caveats regarding extrapolation of our results. However, the patients included in the study correspond to an unspecific population of medical and surgical critically ill patients and IAH or ACS prevalence corresponds to that seen in a larger epidemiological series of critically ill patients. Second, although this study represents the largest study to date investigating CT features and IAH, the total number of patients included is relatively low, resulting in a potential lack of power. Thirdly, the low number of ACS that occurred during the study precludes adequate assessment of CT features for this specific condition. The low number of ACS cases may result from an increasingly early standardized surgical management in cases of refractory IAH with ACS, as suggested by De Waele et al [30], without the need for preoperative imaging.

In summary, the present study suggests that a PAR ≥ 0.52 could help radiologists to identify IAH on abdominal CT scan and could lead to adequate identification and/or treatment, even at early stages of IAH. Diagnostic values of PAR warrant confirmation in further larger studies.

Compliance with ethical standards

Guarantor The scientific guarantor of this publication is Pr Eric Delabrousse.

Conflict of interest The authors declare that they have no competing interests.

Statistics and biometry One of the authors has significant statistical expertise.

Informed consent Written informed consent was obtained from some subjects in this study.

Written informed consent was not required for all the patients of this study because the subjects were critically patients.

Ethical approval Institutional review board approval was obtained.

Methodology
• prospective
• observational
• performed at one institution

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