Diagnostic yield and safety of CT scans in ICU

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This work was performed at the medical ICU (acute respiratory failure and severe infections) of the Hôpital Nord (Marseille, France), at the medical and emergency ICU of the Hôpital de la Timone (Marseille, France), and at the medico-surgical ICU of the Hôpital Saint-Eloi (Montpellier, France).

Take-home message: Computer tomography as a diagnostic procedure invalidated a diagnostic hypothesis and led to a treatment change in more than half of the cases.

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Abstract *Purpose:* Critically ill patients often require CT scans. Adverse events (AE) can occur during intra-hospital transport (IHT). The aim of this prospective study was to determine the diagnostic and therapeutic yield and the safety of CT scans in ICU patients. *Methods:* All ICU patients having a CT scan for diagnostic purposes were eligible. Diagnostic yield was evaluated by the agreement (full, partial or disagreement) between the physician main diagnostic hypothesis before the CT scan and the diagnosis established after the CT scan. Therapeutic yield was assessed by therapeutic changes after the CT scan. The safety was determined by the AE rate during IHT. *Results:* A total of 533 CT scans were performed on 359 patients in three teaching hospital ICUs. The diagnostic yield of CT scan showed 40.7 % of full agreement, 5.6 % of partial agreement and 53.7 % of disagreement with the main diagnostic hypothesis formulated before the CT scan. The CT-scan brought new elements to the diagnosis in 22.9 % of the cases. There was 54.4 % of therapeutic change after CT scan, while 22.3 % of AE occurred during IHT, including 6.7 % of life-threatening events. AE occurred more frequently in the first 48 h after ICU admission, in the most severely ill patients (higher SAPS II at admission), and when there was a large amount of equipment required for transport. *Conclusions:* The CT scan as a diagnostic procedure invalidated a diagnostic hypothesis and led to a therapeutic change in more than half of the cases.

Keywords CT scan · Tomography · Intra-hospital transport · Intensive care unit · Critically ill · Complications · Adverse events · Diagnostic yield · Therapeutic yield · Safety

Introduction

Critically ill patients hospitalised in the intensive care unit (ICU) often require diagnostic procedures, mainly CT scans, which lead to repeated intra-hospital transports (IHT) [1–3]. ICU patients are usually clinically unstable, requiring heavy therapeutic support such as mechanical ventilation, vasopressors and fluid expansion, and continuous sedation, complicating IHT. These factors are sometimes responsible for adverse events (AE) and may worsen the prognosis. Numerous studies in critically ill adults have reported patient-related or life support equipment-related AE during IHT for diagnostic testing, with an overall rate up to 70 % [4–11]. IHT complications from respiratory or haemodynamic issues can be life threatening. Indeed, Beckmann et al. [5] report a 2 % mortality rate associated with the IHT of critically ill patients. Therefore, evaluation of the risk/benefit ratio of IHT for CT scan is necessary [12]. Only a few single-centre studies [13–15] report therapeutic changes following a diagnostic procedure with an IHT (more than 80 % were CT scans), varying from 24 to 39 %, with a global AE rate up to 68 % during transport. However, these retrospective studies had a limited number of patients (100 or fewer patients), included only trauma and surgical patients, and did not focus on IHT for CT scan as a diagnostic procedure. To our knowledge, there is no prospective study that specifically evaluates the CT scan risk/benefit ratio as a diagnostic procedure in ICU patients. The main objective of this study was to evaluate the CT scan diagnostic and therapeutic yield. A secondary objective was to assess its safety during transport and during the exam.

Methods

This prospective, observational multicentre cohort study was conducted in two 14- and 12-bed medical ICU's and one 16-bed medical-surgical ICU in three teaching hospitals. Admissions occurred between January, 2012 and November, 2013. The local ethics committee approval was obtained for this study.

Inclusion criteria

All consecutive patients over 18 years of age were included when a CT scan for diagnostic purposes was performed. The decision to perform a CT scan was made by the senior physician in charge of the patient.

CT scans performed for systematic monitoring or interventional imagery, such as a CT scan-guided percutaneous aspiration or drainage, were not included.

IHT for CT scan procedure

We defined IHT as transportation of a patient to and from his ICU bed to the radiology department located outside the ICU, but within the hospital, with a priority path. The initiation and completion times for the CT scan were counted in the IHT. Each participating ICU had a written procedure for IHTs. IHTs occurred under medical supervision of at least one ICU staff member (junior or senior physician) and a second person (med student or porter). Recommendations for IHT were followed to limit AE [1].

Study protocol

Clinical patients' characteristics, CT scan and IHT characteristics were prospectively recorded. Data were collected through a case report form (CRF) by the physician in charge of the daily care of the patient. This CRF included three parts.

The first part was related to the period prior to the CT scan. The physician recorded the diagnostic hypotheses to be tested by the CT scan and classified them by order of relevance. There was a pre-established list of hypotheses: infectious cause, intracranial disease, extra cranial bleeding, venous thromboembolism (pulmonary embolism or deep venous thrombosis), pleural effusion or lung atelectasis, malignant tumour or another diagnosis (specification of this diagnosis was required). Expected therapeutic changes were also stipulated, whether medical (treatment initiation or withholding) or interventional (any change concerning surgery, drainage, interventional radiology or endoscopy).

Data concerning IHT were recorded in the second part of the CRF, starting with the patient's equipment: invasive mechanical ventilation (MV) with or without severe hypoxemia criteria (PEEP $\geq$ 10 cm H_2O or $FiO_2 \geq 60$ %), any type of vasopressor support, continuous sedation, drains (chest tube or surgical drainage) and extra corporeal life support (ECLS). We predefined different types of AE [16] and prospectively recorded them for all IHT: respiratory AE (oxygen desaturation: pulse oximetry (SpO_2) $<$95 % or a decrease of more than 5 % in baseline SpO_2 for more than 1 min [8, 17]; bronchospasm; pneumothorax; accidental extubation; selective intubation; patient–

ventilator asynchrony), cardiocirculatory AE (severe hypotension defined as a systolic blood pressure <90 or 20 mmHg decrease in systolic or diastolic blood pressure more than 1 min [6, 10, 17]; arrhythmia; cardiac arrest), neurological AE (agitation, intracranial hypertension) and material malfunction AE (any intravenous or intra-arterial catheter disconnection, dislodgment or thrombosis, accidental dislodging of urinary catheter or nasogastric tube; incidents with airway equipment: disconnection of endotracheal tube, alarms or transport ventilator malfunction, or problems with oxygen supply; electric syringe battery down; bed electric command or elevator out of order). In addition, the physician in charge of the IHT was asked about his/her perception of the difficulty of IHT after CT scan (safe or difficult) and, when an AE occurred, they were asked about its potential or proved major consequences for the patient's stay. The final clinical impact of AE was assessed at day 3.

Serum creatinine was recorded on the CT scan day and the 2 days following the procedure, as was the presence of renal replacement therapy.

Three days later, the physician filled in the last part of the CRF concerning diagnostic yield (main diagnostic hypothesis confirmed or invalidated by CT scan) and therapeutic yield after CT scan: effective therapeutic change: medical (treatment initiation or withholding) or intervention (any change concerning surgery, drainage, interventional radiology or endoscopy). Effective therapeutic changes were evaluated on the same principle as the proposed changes before CT scan.

Data analysis and statistics

Diagnostic yield was defined by the agreement between the main diagnostic hypothesis proposed by the physician (before CT scan) and the effective diagnosis established by the CT scan. Diagnostic yield was classified as full agreement when the main hypothesis before CT scan was confirmed by the scan, partial agreement when the main hypothesis before CT scan was confirmed but new diagnostic elements were determined by the scan and disagreement when the main hypothesis before CT scan was completely different than effective diagnosis established by the scan. In case of disagreement, there were two possibilities, either new diagnostic elements unanticipated by the clinician were found or no diagnosis was established by the CT scan. Therapeutic yield was evaluated by therapeutic changes after the CT scan and compared to what was expected by the physician before the CT scan, in cases where the main diagnostic hypothesis is confirmed by CT scan. Safety was evaluated by the AE occurrence rate and its association with equipment and timing of the CT scan after ICU admission. Concordance between difficulty of IHT and the rate of AE, the number of equipment and severity was analysed. We counted one point for each item (except MV with severe hypoxemia criteria, two points) to evaluate the influence of the amount of equipment on transport perception or AE occurrence. The Acute Kidney Injury Network (AKIN) definition for ICM-associated acute kidney injury was used [18–21]: ≥25 % increase in serum creatinine over 48 h. The day-28 ICU-free days were calculated by subtracting the actual ICU length of stay in days from 28. The day-28 ICU-free days was considered as 0 if a patient died before hospital discharge or stayed in ICU for >28 days. The variable distribution was evaluated using the Kolmogorov–Smirnov test. According to the distribution, quantitative variables were expressed as the median and interquartile range (IQR) or mean (±standard deviation) and qualitative variables as the percentage. Qualitative variables and proportions were compared using the Pearson χ^2 test. For the contingence tables with more than 2 × 2, we used the χ^2 test for trend. When possible, the diagnostic accuracy of the CT-scan was reported in accordance with the guidelines of the Standards for the Reporting of Diagnostic accuracy studies (STARD) [22]. The degree of agreement between the main diagnostic hypothesis before CT scan and effective diagnosis after CT scan was quantified by Cohen's kappa (κ). A p value <0.05 was considered to be significant. Statistical analysis was conducted using SPSS v.20.0 (IBM, NY, USA).

Results

Patients

During the study period, 359 patients were included. Of these, 32.6 % had more than one CT scan. Table S1 (electronic supplementary material) presents patients' characteristics in the three participating ICUs. Causes of ICU admission were: surgical emergency or complications from a scheduled surgery in 92 cases (25.6 %), respiratory failure in 76 cases (21.2 %), neurological failure in 75 cases (20.9 %), septic shock in 62 cases (17.3 %) and haemodynamic failure (cardiogenic shock or cardiac arrest) in 33 cases (9.2 %).

CT scans and IHT characteristics

CT scan characteristics

A total of 533 CT scans were included. Figure 1 presents the flow chart of CT scans inclusion. Anatomical regions explored by CT scan are shown in Table 1. A total of 39.2% (209) of the CT scans were performed within the first 48 h of ICU stay and 60.8 % (324) after 48 h. The prescriber was a single senior intensivist in 80.1 % of the cases, and a staff decision was made in 19.9 % of the cases.

Table 1 CT scans and IHT characteristics

Anatomical regions explored by CT scan, % (*n*)		Patient's equipment during IHT, % (*n*)	
Thoraco-abdominal-pelvic	36 (192)	Invasive mechanical ventilation (MV)	70.4 (375)
Brain	27.4 (146)	MV with PEEP >10 cm H_2O or FiO_2 >60 %	24 (90)
Whole body	13.5 (72)	Vasopressors support	32.1 (171)
Chest	10.1 (54)	Continuous sedation	43.7 (233)
Abdominal-pelvic	7.3 (39)	Drains (chest tubes or any surgical drainage)	30.4 (161)
Brain and chest	5.6 (30)	Extra corporeal life support (ECLS)	1.1 (6)

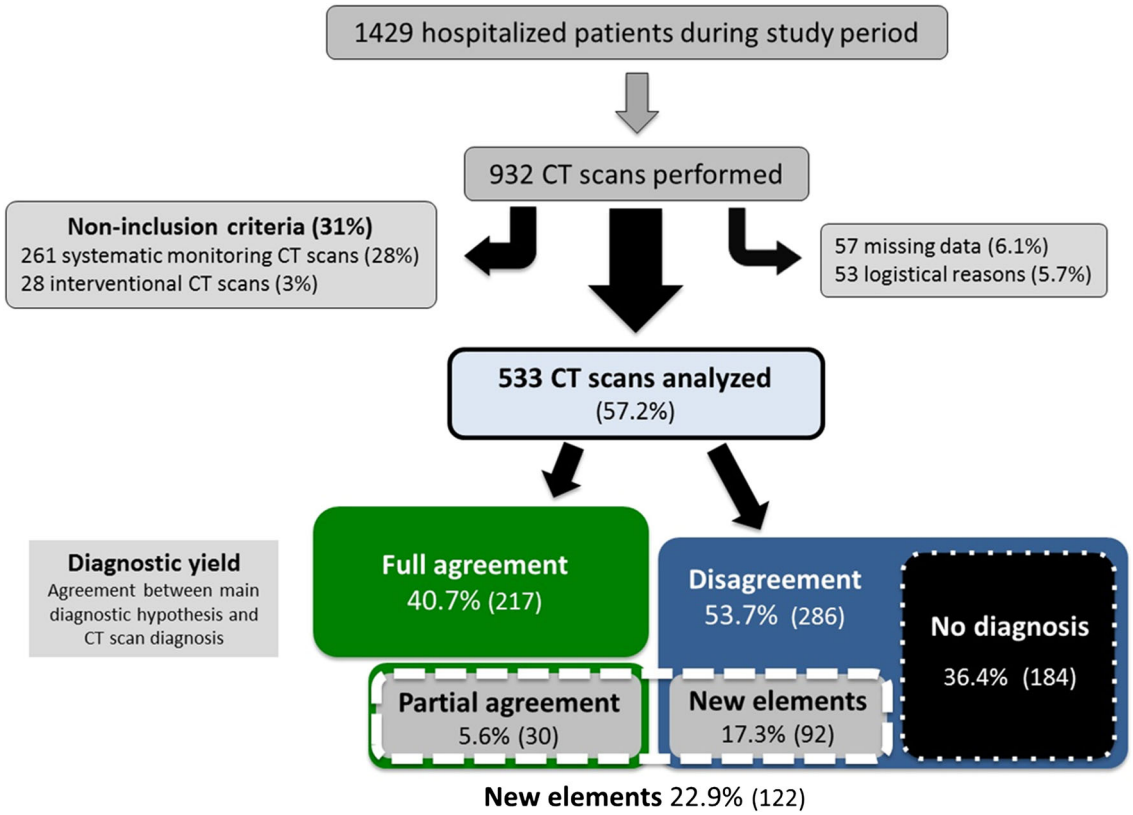

Fig. 1 Flow chart and diagnostic yield of CT scans

IHT characteristics

A total of 81.6% of transports to and from the ICU to the radiology department were performed with patients who had one or more pieces of the equipment listed in Table 1, while 18% (98) of IHTs were performed with patients who had no equipment listed, 25.1 % (134) with one piece, 22.7 % (121) with two pieces, 16.7 % (89) with three pieces, 11.6 % (62) with four pieces and 5.4 % (29) with five or six pieces of the equipment listed.

Diagnostic and therapeutic hypotheses before CT scan

The main diagnostic hypotheses formulated by senior physicians before the CT scan are presented in Table 2. In 42.6 % (227) of the CT scans, a second diagnostic hypothesis was formulated: intracranial disease in 26.8 % (61) of those CT scans, infectious cause in 22.5 % (51) of CTs, pleural effusion or lung atelectasis in 22 % (50) of CTs, venous thromboembolism in 13.2 % (30) of CTs, extra-cranial bleeding in 7.9 % (18) of CTs, malignant tumour in 1.8 % (4) of CTs and other varied causes in 5.7 % (13) of CTs.

Expected therapeutic changes (before CT scan) concerned interventional procedures in 69.8 % (372) of the CT scans and medical treatment in 30.2 % (161) of the CT scans.

Diagnostic and therapeutic yields after CT scan

Diagnostic yield

There was a full agreement between the main diagnostic hypothesis formulated before CT scan and the diagnosis

established after the CT scan in 217 (40.7 %) cases. Main diagnostic hypotheses confirmations by CT scan are shown in Table 2. There was partial agreement in 30 (5.6 %) cases and a disagreement in the remaining 286 (53.7 %) cases. In 36.4 % (184) of the cases, no effective diagnosis was made by CT scan. Interestingly, new unexpected diagnostic elements were reported in 22.9 % (122) of the CT scans. Finally, 17.3 % (92) of them were found after CT scans invalidating the main diagnostic hypothesis and 5.6 % (30) in addition to the main diagnostic hypothesis. These results are summarized in Fig. 1.

The Cohen's kappa coefficient ($\kappa = 0.29$) indicated a low level of agreement between the main diagnostic hypothesis formulated before CT scan and the effective diagnosis established after CT scan.

Therapeutic yield

There was a therapeutic change within 3 days after CT scan in 54.4 % (290) of the cases. An interventional procedure (surgery, drainage, interventional radiology or endoscopy) occurred in 28.7 % (153) of the cases, and a medical change (treatment initiation or withholding) was made in 25.7 % (137) of the cases. Table 3 shows the comparison between before CT scan expected therapeutic change and after CT scan effective change. Among the 290 CT scans that induced therapeutic change, the modification was in accordance with the one that was expected before the CT scan in 207 (71.4 %) of the cases. As presented in Figure S1 (electronic supplementary material), therapeutic change differed depending on whether the main diagnostic hypothesis was confirmed by the CT scan. Among the 122 CT scans which discovered new elements, 68.9 % (84) led to a therapeutic change.

Table 2 Main diagnostic hypotheses formulated by physician and confirmation by CT scan

	Diagnostic hypothesis before CT scan, % (*n*)	Diagnostic confirmation by CT scan, % (*n*)
Infectious cause	42.2 (225)	48.9 (110)
Intracranial disease	33.0 (176)	46.0 (81)
Venous thromboembolism	8.8 (47)	27.7 (13)
Extracranial bleeding	7.7 (41)	39.0 (16)
Pleural effusion or Lung atelectasis	3.6 (19)	63.2 (12)
Malignant tumour	0.9 (5)	40.0 (2)
Other varied causes	3.8 (20)	65.0 (13)

Safety

Transport difficulty perception

In 55.5 % (296) of the cases, IHT was estimated as safe by the physician. Among the 44.5 % (237) IHTs that were estimated as difficult, 24.1 % (57) were felt to be very difficult. As presented in Fig. 2, IHT difficulty perception significantly increased with the amount of equipment. Among the 170 patients having a CT scan within 48 h after ICU admission (209 CT scans), the patient's admission severity, assessed by SAPS II score at admission, was higher when transport was perceived to be difficult (56.2 ± 17.7 when transport was difficult and 49.2 ± 17.0 when transport was safe, $p = 0.011$).

Adverse events

An adverse event happened in 22.3 % (119) of the IHTs for CT scan. A detailed list is shown in Figure S2 (electronic supplementary material). Of these AEs, 37 % were considered by the clinicians to alter ICU duration of stay or hospital mortality, including almost 7 % considered life threatening. Among them, two cardiac arrests occurred, one fatal. Mean day-28 ICU-free days and mortality in patients having an AE considered by the clinicians to alter ICU duration of stay and/or mortality were respectively 4.7 ± 8.9 days and 50 % as compared to 7.4 ± 9.9 days and 34 % when AE was not considered to have consequences ($p = 0.22$ for ICU-free days and $p = 0.16$ for ICU mortality). As shown in Fig. 2, the amount of equipment had an influence on AE occurrence ($p_{trend} = 0.006$). Patients transported with continuous sedation or with vasopressor support had an increased risk of AE. Indeed, 27.5 % (64) of patients with sedation had an AE, compared to 18.3 % (55) of AEs in patients who were not sedated ($p = 0.012$). Of patients with vasopressors, 29% (69) had an AE, compared to 19.1 % (69) in patients without vasopressors ($p = 0.008$). No

Table 3 Comparison of expected therapeutic change (before CT) and effective therapeutic change (after CT)

		Effective therapeutic change after CT scan % (*n*)		
		Interventional	Medical	No change
Expected therapeutic change before CT scan % (*n*)	Interventional 69.8 (372)	37.1 (138)	18.3 (68)	44.6 (166)
	Medical 30.2 (161)	9.3 (15)	42.9 (69)	47.8 (77)

Definitions of therapeutic changes are the following: (1) interventional: any change concerning surgery, drainage, interventional radiology or endoscopy; (2) medical: treatment initiation or withholding

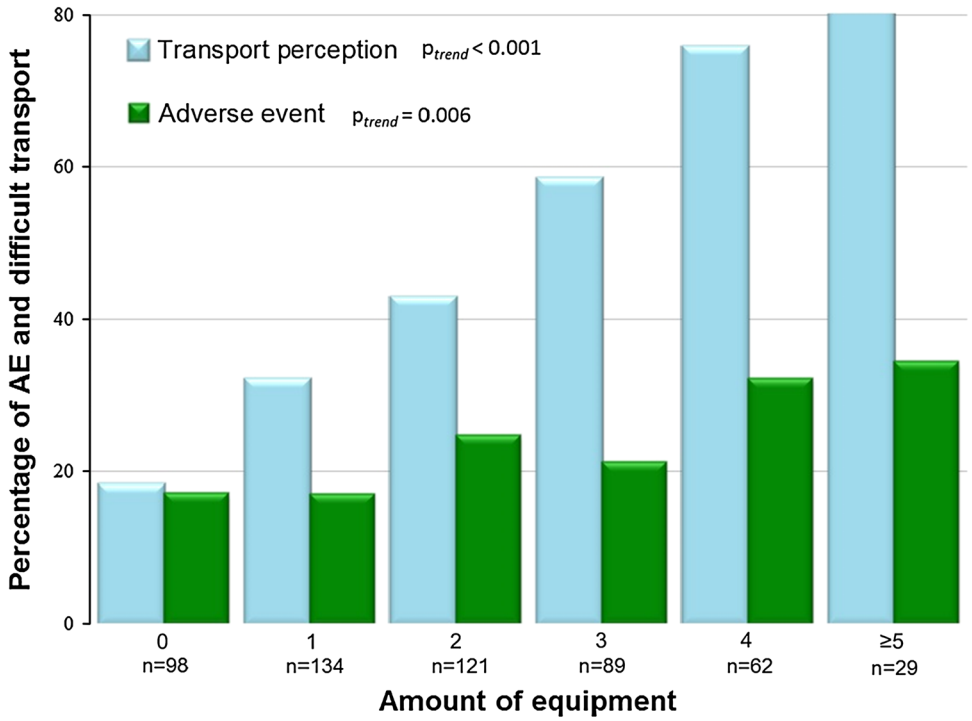

Fig. 2 Influence of amount of equipment on transport perception and adverse event (*AE*) occurring during intra-hospital transport equipment included: mechanical invasive ventilation (*MV*) = 1 point; MV with severe hypoxemia criteria (PEEP $\geq$10 cm H_2O or FiO_2 $\geq$60 %) = 1 extra point; any type of vasopressors = 1 point; continuous sedation = 1 point; drains (chest tube or surgical drainage) = 1 point; and extra corporeal life support = 1 point

significant differences were shown for the other types of equipment.

There was a more significant AE rate during IHT in the first 48 h after ICU admission, 27.8 % (58) compared to 18.8 % when IHT was performed after 48 h (61), $p = 0.016$. In addition, in the first 48 h after ICU admission, the mean amount of equipment was more significant in IHT with AE occurrence (2.5 $\pm$ 1.5) than without AE (1.9 $\pm$ 1.4), $p = 0.005$. Among the patients having an IHT for CT scan within 48 h after ICU admission, the SAPS II score at admission was higher when an AE occurred (57.4 $\pm$ 18.6) during IHT compared to the SAPS II of patients having an IHT without AE (50.2 $\pm$ 16.9), $p = 0.018$.

Serum creatinine

An iodinated contrast medium (ICM) was injected in 82 % (437) of the CT scans. After those 437 CT scans, 13 % (57) of the patients met AKIN criteria for CIN. Among them, 15 patients had renal replacement therapy for the first time in the 48 h following CT scan.

Risk benefit ratio of CT scans

An AE happened in 14.9 % (29 of 194) of IHTs for CT scans with no diagnosis established as compared with 26.5 % (90 of 339) when a diagnosis was established ($p = 0.002$). There was a higher rate of CT scans providing radiological diagnosis when there was an AE during IHT than when there was not (75.1 vs. 60.1 %, respectively; $p = 0.002$). There was also a higher rate of CT scans leading to a therapeutic change when there was an AE during IHT than when there was not (67.2 vs. 50.7 %, respectively; $p = 0.002$).

Discussion

In this multicentre, prospective observational cohort study, CT scan contributed to diagnosis by a disagreement in 53.7 % (286) of the cases, a partial agreement in 5.6 % (30) of the cases and a full agreement in 40.7 % (217) of the cases with the main diagnostic hypothesis formulated before CT scan. Unexpected new elements related to diagnosis were reported in 22.9 % of the cases. A therapeutic change after the CT scan was observed in 54.4 % of the cases. Twenty-two percent of AE occurred during intra-hospital transport for CT scan while 37% of these AEs were considered by the clinicians to alter ICU duration of stay or hospital mortality, including almost 7 % considered life threatening. AE occurred more frequently when IHTs for CT scan were performed in the first 48 h after ICU admission. In this period, AE were significantly increased in the most unwell patients (higher SAPS II at ICU admission) and when the amount of equipment was greater.

To our knowledge, this is the first prospective study focused on CT scan as a diagnostic procedure, exploring

several aspects including both diagnostic and therapeutic yields and safety in IHT. To evaluate diagnostic yield, we chose an approach based on the agreement between the physician's diagnostic hypothesis before the CT scan and its confirmation or lack thereof after the CT scan. This original approach seemed to us to be the closest to questions a physician asks himself to evaluate the risk/benefit ratio of a CT scan for a critically ill patient. However, our study only considered the main diagnostic hypothesis to assess agreement before and after the CT scan because there was no second hypothesis in more than half of the CT scans. In this study, we have shown that a CT scan invalidated a diagnostic hypothesis more often (53.7 %) than it confirmed it. Nevertheless, a CT scan led to a therapeutic change in 54.4 % of the cases. In some cases, the CT scan could have been performed to rule out a life-threatening condition (e.g. pulmonary embolism), and a disagreement between physician's expectation and CT scan result would not reflect the value added by the CT scan. The design of this study does not allow us to see how many unnecessary therapeutic changes have been avoided thanks to CT scan results.

As reported by Indeck [14] and Hurst [15], we evaluated therapeutic yield by the number of therapeutic changes; moreover, we specified the type of treatment changed: medical treatment (initiation or withholding) or interventional treatment (any surgery, drainage, interventional radiology or endoscopy). Those single-centre studies included $\leq$100 trauma and major surgery ICU patients and were not entirely focused on CT scans for diagnostic purposes. Our study gathered a larger population of critically ill medical and surgical patients. Trauma patients were not included to avoid systematic CT scans at admission, and also systematic monitoring imagery. Our inclusion criteria might explain the higher therapeutic change rate observed after the CT scan (54.4 %) compared to the Indeck [14] (24 %) and Hurst [15] (39 %) studies.

Safety of the entire CT scan procedure included adverse event analysis and the influence of patients' severity rating, transport equipment and timing of IHT after ICU admission. Patients with continuous sedation and/or vasopressors appeared to have a higher rate of complications during IHT compared to those who had none. Our results for sedation are in line with the Damm study, in which sedated patients had an excess risk of demonstrating agitation or haemodynamic problems [8]. A difference between the level of sedation required for comfort in an ICU bed and that needed for transport and transfer onto the CT scan table might explain this phenomenon. Moreover, sedation and vasopressors are used with severely ill patients [23]. The relationship between AE and patient illness severity, quantified by SAPS II at ICU admission, or the amount of pieces of medical equipment, particularly in the first 48 h of ICU admission, is an important result for clinical practice. However, the design of this study did not enable us to know how many times the CT scan was not performed due to the critical condition of the patient. Our study emphasises that the risk/benefit ratio evaluation must be rigorous, especially in the first 48 h after ICU admission, where patients seem to be less stable. In our study, the association of life-threatening AE were not in line with the results of Schwebel et al. [24], where IHT was not shown to impact hospital mortality. However, the purpose and the methods of our study were not comparable with the Schwebel et al. [24] study.

Many professional societies have developed guidelines to improve safety during the transport of critically ill patients by setting rules for pre-transport planning and coordination, escort, equipment and monitoring procedures [1, 3, 16, 25]. In our study, each participating ICU had a written procedure but no checklist for IHTs. Numerous studies confirmed that the IHT of critically ill patients leads to a significant number of AE. However, it remains difficult to compare these because the definitions of AE vary from study to study. Our classification of AE was inspired by the Fanara [16] review because it seemed the most clinical relevant approach.

The overall prevalence of contrast-induced nephropathy (CIN) in the literature is highly variable and estimated to be between 1 and 30 % [19, 21, 26, 27], which is linked to the studied population's baseline characteristics but also to a lack of uniformity in the definition used [28]. Patients in the ICU frequently have multiple, unavoidable, confounding Acute Kidney Injury (AKI) risk factors (sepsis, shock and nephrotoxic medications) [29]. Our study showed that 13 % of patients meet the AKIN criteria for CIN after an ICM injection. The design of our study does not allow us to establish a causal link. In a recent prospective matched cohort study, Ehrmann et al. [20] showed that, contrary to the Sequential Organ Failure Assessment score at inclusion and the number of other nephrotoxic agents, ICM infusion was not an independent risk factor for AKI.

We were unable to assess the potential effects of factors, such as CT scan procedure timing (off-hours, weekdays, elective compared to emergency procedures). We did not collect information on the experience and seniority of accompanying staff members. The fact that data for AE during IHT were collected by the physician in charge of the patient is also a limit in this study. It is likely that some episodes (e.g. hypotension) were not recorded. An electronic recording would have been more accurate.

In conclusion, the CT scan is a major diagnostic tool in critically ill patients. Indeed, the CT scan invalidates a diagnostic hypothesis and leads to a therapeutic change in more than half of the cases. However, transporting patients out of ICU is a period of increased risk for AE.

Acknowledgments The authors thank the residents, physicians and nurses, in the three ICU departments for their significant contribution in this study.

Conflicts of interest The authors declare that they have no conflict of interest.

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