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Cost effectiveness of imaging strategies in the emergency department for the diagnostic workup of community-acquired pneumonia: a real-life retrospective study

Sabrina Kepka[1,2,3*], Kevin Zarca[4], Mickaël Ohana[2,5], Louise Hoffbeck[1], Charlène Heimann[6], Pierrick Le Borgne[1,7], François Severac[2,3], Joris Muller[8], Erik-André Sauleau[2,3], Pascal Bilbault[1,7] and Isabelle Durand Zaleski[4,9]

Abstract

Background The purpose of this study was to compare the length of stay (LOS) and costs of diagnostic workup by Ultra Low Dose (ULD) chest computed tomography and radiography for patients treated for a community-acquired pneumonia (CAP) in the emergency department (ED).

Methods We conducted a real-life retrospective study of patients treated for a CAP in two ED between March 1, 2019 and February 29, 2020. We estimated length of stay (LOS) as the difference between ED discharge and entry times, total hospital costs at 60 days including ED, initial admissions and readmissions. Patients with initial radiography were compared with patients with initial ULD CT using inverse probability weighing of the propensity score calculated from demographic variables, vital parameters and clinical presentation. We calculated the incremental cost effectiveness ratio as the difference between costs and the difference between LOS. Variability of the results was assessed using non-parametric bootstrapping.

Results We included 1609 consecutive patients, 1476 patients with radiography and 133 patients with ULD CT. The average costs were respectively €4317 [3483; 5067] and €4223 [4034; 4612] with 11.9 [10.1; 13.2] and 11.7 [11.5; 12.2] hours of LOS in the ED for chest radiography and ULD chest CT respectively, resulting in lower costs of € -94 [-870; 819] and a decreased LOS of 12 [-108; 76.9] minutes in favor of ULD chest CT.

Conclusions In this real-life study, the management of CAP in ED by ULD chest CT compared with chest radiography resulted in lower costs without increasing LOS.

Trial registration This study was registered with the Clinical Trials Registry (NCT05140408).

Keywords Tomography, Emergency department, Cost-effectiveness analysis, Community acquired pneumonia, Chest radiography

*Correspondence:
Sabrina Kepka
sabrinakepka@yahoo.fr

Full list of author information is available at the end of the article

Background

Community-acquired pneumonia (CAP) represents a clinical and economic burden, contributing to high mortality and being one of the most frequent causes of hospital admissions in Europe and the United States [1]. Indeed, the incidence of the disease has increased significantly in recent years, reaching 1.5 to 14 cases per 1000 person-years [2–5]. In the study of Kennedy et al., estimated rates of infectious disease hospitalizations in the USA were calculated by using the National Inpatient Sample and revealed that the most commonly listed principal diagnoses among infectious disease hospitalizations were "pneumonia, organism unspecified," with the higher rate of hospitalization of 20% [6]. For Europe, 1 million patients are hospitalized annually for CAP [7]. Because of high hospitalization rates with long hospital stays, the economic impact of CAP is significant in Europe representing ~10.1 billion euros per year, mainly for hospital care, accounting for 5.7 billion euros (0.5 billion euros for outpatient care and 0.2 billion euros for drugs) [8].

CAP is a frequent reason for consultation in emergency departments (EDs), which are the first line of diagnostic workup for patients with respiratory symptoms and suspected pneumonia. Indeed, in a large cohort of 16,313 adults included in the British Thoracic Society's national CAP database, 75% of hospitalized patients were admitted via the ED [9]. Given the frequency of this pathology, the burden on EDs for diagnosis and initial management is significant. What's more, the high proportion of hospitalizations for these patients further accentuates this burden on EDs, making a pertinent diagnostic strategy essential.

The diagnostic workup of CAP in the ED is based on clinical presentation and investigations, i.e. laboratory tests and imaging. The British Thoracic Society, the Infectious Disease Society of America and the American Thoracic Society thus recommend chest imaging (chest radiograph or other imaging technique), with or without supporting microbiological data [10, 11]. There are no recommendations on the choice of initial chest imaging [12]. However, diagnostic performance with under- or overdiagnosis leads to adverse events through delayed treatment or treatment-related complications. Then a recent study revealed that among 17 290 hospitalized patients treated for CAP in the United States, 2079 (12.0%) met criteria for inappropriate diagnosis of whom 1821 (87.6%) received full antibiotic courses [13]. Full vs. brief duration of antibiotic treatment among patients was associated with antibiotic-associated adverse events (31 of 1821 [2.1%] vs. 1 of 258 [0.4%]; $p = 0.03$).

Despite its poor diagnostic accuracy, chest radiography remains the *de facto* standard of care in the ED. Yet, computed tomography (CT) is increasingly available in these departments allowing accurate and rapid identification of patients with CAP due to better diagnostic accuracy than chest radiography [14, 15]. For example, CT in the ED can rule out the diagnosis in 30% of patients compared to chest radiography, and also reduces inappropriate antibiotic prescribing, with changes in antimicrobial therapy after CT involving 61% of patients [14–16]. However, limitations including radiation exposure and higher examination costs compared to radiography should be noted [17, 18]. In recent years, ultra-low dose (ULD) chest CT has been an alternative to standard chest CT reducing radiation exposure to a level comparable to that of chest radiography (0.1 vs. 0.05 mSv) with better diagnostic accuracy [15].

The diagnostic superiority of CT over radiography is thus well established for the diagnosis of CAP, but the organizational benefits and costs have not been evaluated in the ED. Indeed, the cost of using CT scan appears to be one of the main obstacles to their use in EDs for diagnosing pneumopathy, despite the advantages in terms of diagnostic performance detailed above [16]. In the ongoing OCTOPLUS study, authors purposed to compare the diagnostic accuracy, the clinical and cost outcomes and the use of antibiotics associated with three imaging strategies (chest radiography considered as standard of care, low-dose CT scan and lung ultrasonography) in patients > 65 years old with suspected pneumonia in the ED [19]. Furthermore, in the published protocol study, Prendki et al. pointed out that the impact of reducing false-positive and false-negative diagnoses on costs, as well as the costs associated with the imaging modalities, should be assessed [19]. Imaging modalities were also evaluated for emergency triage of COVID patients during the first wave and workup with systematic ULD chest CT was the more cost-effective strategy compared with chest radiography (average LOS of 6.89 h; average cost of €3646), allowing for an almost 4-hour decrease in LOS in the ED at a cost increase of €98 per patient [20].

Therefore, the primary objective of this study was to compare the length of stay (LOS) in the ED and the costs of diagnostic workup by ULD chest CT and chest radiography for patients treated for CAP in these units. Our secondary objectives were to describe the course of care after ED workup, concordance between ED diagnosis and discharge diagnosis for admitted patients, length of hospital stay for admitted patients, and 60-day mortality.

Methods

Study population, setting and location

From March 1, 2019, to February 29, 2020, 1609 consecutive patients were included in one of the two ED of the same university hospital in France and were older than 18 years, treated for pneumonia (diagnosis code J18 and J15), and with a chest radiograph or ULD chest CT scan performed for diagnostic workup (Fig. 1).

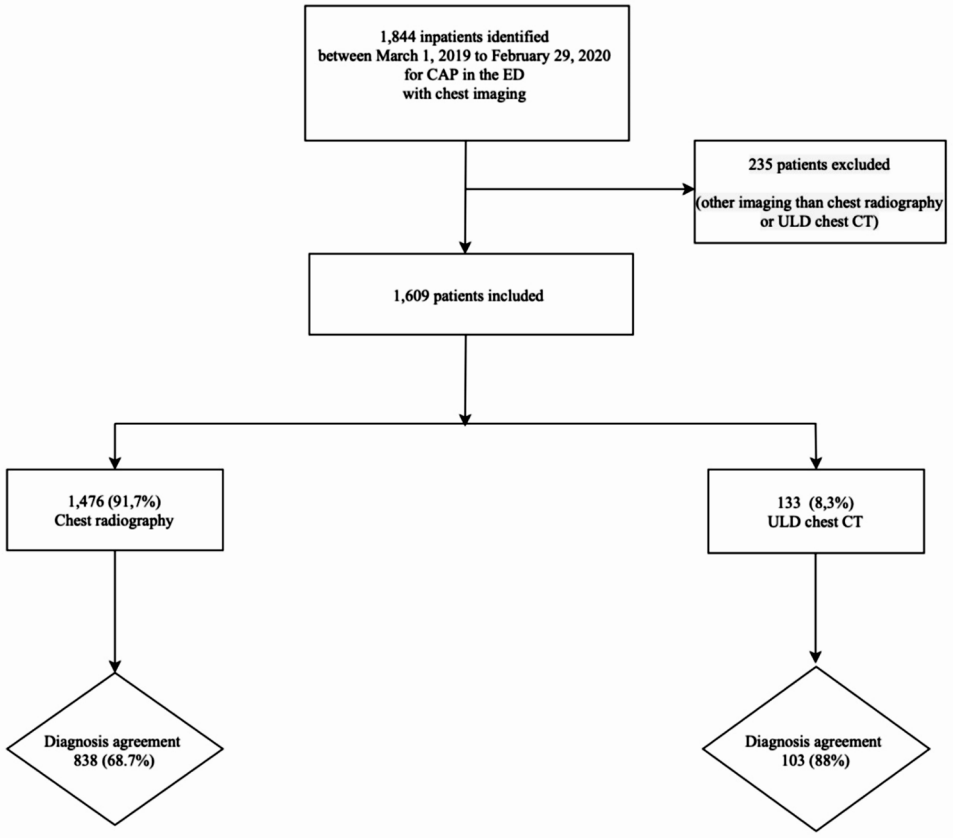

Fig. 1 Flowchart of the study conducted in the ED of a University Hospital in France. ED Emergency department, ULD Ultra-low-dose, Agreement between diagnosis in the ED and diagnosis at hospital discharge for inhospital management, diagnosis as discharge was considered as the gold standard

Comparators

Patients were divided into 2 groups according to the initial chest imaging ordered in the ED: "chest radiography" and "ULD chest CT" under real-life conditions according to the opinion of the emergency physicians and radiologists. Subsequent patient management and referral was performed by the emergency physicians based on the imaging results, clinical presentation and laboratory test results.

Perspective

The analysis was conducted from the perspective of the French healthcare provider using hospital production costs or proxies (tariffs) when costs were not available.

Time horizon

The time horizon was 60 days after the discharge of the hospital or ED.

Discount rate

No discount rate was applied.

Selection, measurement and valuation of effectiveness

We evaluated the impact of the initial choice of imaging on the LOS in the ED of patients with CAP. ED LOS is influenced by the imaging strategy and was chosen as the effectiveness criteria rather than diagnostic performance or clinical outcomes because of ED and pathology specificity. Indeed, rapid decision making is essential to initiate antibiotic treatment if necessary and the organizational impact of strategies is decisive for patients and the care system in a context of service overcrowding, requiring optimization of patient flow. LOS was measured as the time from admission to the ED to discharge from the ED (discharge or transfer to a medical service), as recorded in the ED electronic medical record. Incremental cost-effectiveness ratio (ICER) was the primary endpoint and was calculated as the difference in total 60-day costs divided by the difference in ED length of stay.

As the secondary endpoints, we measured:

1. Care pathway after ED assessment: discharge, hospitalization (by type of medical service, including intensive care unit [ICU] and short-stay unit)
2. Concordance between ED diagnosis and discharge diagnoses for patients admitted to hospital; discharge

diagnoses from patient records were considered the gold standard.
3. Length of hospital stay for admitted patients.
4. Mortality at 60 days.

Measurement and valuation of resources and costs

Data for the economic evaluation were retrospectively collected:

Costs items

- Number and unit costs of ULD chest CT and chest radiography performed in the ED;
- Costs of initial hospitalization and readmissions related to the initial CAP during the 60 days follow up period.

Currency, price date, and conversion

Hospitalization and monitoring data were obtained from local hospitals' claims databases. Hospitalizations were valued using the corresponding French disease-related group (DRG) cost, adjusted by LOS and number of days in intensive care [21–23]. For patients who were not hospitalized, we imputed the average cost of outpatient visits to the ED plus the cost of ED imaging, assessed using the statutory health insurance tariffs (Table S1).

Rationale and description of model

To compare outcomes between ULD chest CT and radiography in the EDs in this non-randomized study, we used a propensity score inverse probability weighted regression model using demographic variables (age, sex), vital parameters and clinical presentation (heart rate, oxygen saturation, systolic blood pressure, fever, respiratory failure), medical history (chronic obstructive pulmonary disease, heart failure, cancer). For missing data, we performed multiple imputation with chained equations (MICE) on variables used for the propensity score weighting. We used a generalized linear model to model LOS in EDs and employed a Gaussian family with a log link, given that the distribution of LOS in the ED was skewed and bounded less than 0. For costs, we used a generalized linear model with a gamma family with a log link.

Analytics and assumptions

We computed the groups' marginal effectiveness and costs with chest radiography as a reference. For the main effectiveness measure, we used the negative value of ED LOS (1 h becoming – 1 h) to reflect the incremental cost saved for 1 less hour spent in the ED.

Quantitative variables were described as mean ± standard deviation, whereas categorical variables were described as numbers and percentages. Chi-square or Fisher's exact tests, analysis of variance (ANOVA), and the Kruskal-Wallis test were used as appropriate. A p-value < 0.05 was considered significant.

Characterising uncertainty

Variability in the results was assessed using nonparametric bootstrapping, which provided multiple estimates of the ICER by randomly resampling the patient population 1000 times. For each iteration, we calculated propensity scores and new regression models. The results are presented as a scatterplot of 1000 ICERs on the cost-effectiveness plane.

Characterising heterogeneity

We performed a deterministic sensitivity analysis to compare the ULD chest CT strategy with the chest radiography strategy to examine the independent effect of the following variables on the ICER:

- substituting LOS in the ED by.
- time from ED admission to imaging as recorded in the ED electronic health record.
- the time from imaging to discharge from the ED (to a medical service or home) as recorded in the ED electronic health record.
- substituting cost of chest radiography, cost of chest CT, cost of ED visits, and cost of hospitalization with five times the base case for each parameter.

All analyses were performed using R software version 4.0.3. (R Core Team).

Ethics approval, data and safety monitoring

This study was conducted in accordance with the principles set forth by Good Clinical Pratice guidelines and the declaration of Helsinski. The study was approved by the Ethics Comitte (CE 2021-50). A declaration of conformity was obtained from the Commission nationale de l'informatique et des libertés (CNIL) (agreement number 2208067v0).). This study was registered with the Clinical Trials Registry (NCT05140408). In accordance with French legislation, formal written informed consent was not required for this type of study because data were entirely retrospectively studied [24].

Results

The majority (N = 1476) of the 1609 patients underwent a chest radiography and 133 a ULD chest CT. The mean age was 76 (± 17.7) in the "chest radiography group" and 71 (± 18.2) in the "ULD chest CT group" (p = 0.01) (Table 1). There were no differences between the groups in medical history, clinical presentation and laboratory tests (Tables 1 and 2).

Table 1 Baseline patient characteristics

	Chest radiography *N* = 1476	ULD chest CT *N* = 133	*p*
Age (Mean ± SD)	76 (± 17.7)	71.0 (± 18.2)	**0.01**
Gender			
Men (N, %)	815 (55.2)	71 (53.4)	0.75
Women (N, %)	661 (44.8)	62 (46.6)	
Medical history			
Heart failure (N, %)	188 (12.7)	22 (16.5)	0.26
COPD (N, %)	389 (26.4)	32 (24.1)	0.63
Cancer (N, %)	310 (21.0)	32 (24.1)	0.47
Smoke habits (N, %)	281 (19)	28 (21.1)	0.65
Clinical presentation			
Saturation (Mean ± SD)	95 (± 3.9)	95 (± 3.9)	0.96
Heart rate (Mean ± SD)	95 (± 20.2)	93 (± 19.8)	0.26
Systolic blood pressure (Mean ± SD)	130 (± 22.0)	132 (± 21.1)	0.58
Shortness of breath (N, %)	761 (51.6)	78 (59)	0.14
Fever (N, %)	567 (38.6)	45 (34.1)	0.36

ED Emergency department

COPD Chronic Obstructive Pulmonary Disease

ULD Ultra-low-dose

Table 2 Length of stay in the ED and outcome

	Chest radiography *N* = 1476	ULD chest CT *N* = 133	*p*
Laboratory tests			
Leukocytes (Mean ± SD)	12.1 (± 4.88)	12.3 (± 3.51)	0.61
Creatinine (Mean ± SD)	75 (± 63.5)	71.4 (± 55.7)	0.23
CRP (Mean ± SD)	73 (± 96.2)	87 (± 109)	024
Antibiotics in the ED (N, %)	1308 (88.6)	110 (82.7)	**0.05**
Time from imaging to discharge in the ED in hours (Mean ± SD)	9.2 (± 7.1)	7.1 (7.6)	**0.001**
Length of stay in the ED in hours (Mean ± SD)	11.9 (± 7.4)	11.7 (± 7.7)	0.74
Care pathway after ED			
Discharge from the ED (N, %)	376 (25.5)	32 (24.1)	0.79
Hospitalization in the short time stay unit (N, %)	763 (51.7)	62 (46.6)	0.23
Hospitalization in intensive care unit (N, %)	101 (6.8)	8 (6)	0.74
Hospitalization in a medical ward (N, %)	236 (16)	31 (23.3)	0.07
Management during hospitalization			
Another imaging during hospitalization (N, %)	750 (59)	43 (36)	**< 0.001**
Antibiotics during hospitalization (N, %)	872 (91)	80 (88)	0.38
Length of hospitalization in days (Mean ± SD)	8.71 (± 9.7)	9.45 (± 8.1)	0.39
Diagnosis agreement † (N, %)	838 (68.7)	103 (88)	**< 0.001**
Death 60 days (N, %)	113 (7.2)	3 (2.1)	**0.023**

*hours

‡ days

† Agreement between diagnosis in the ED and diagnosis at hospital discharge for inhospital management, diagnosis at discharge was considered as the gold standard

ED Emergency department

ULD Ultra-low-dose

Study parameters

Effectiveness

LOS was shorter when a ULD chest CT was initially performed in the ED, with a mean LOS of 11.7 (± 7.7) hours versus 11.9 (± 7.4) hours for an initial chest radiography despite the lack of a significant difference ($p = 0.74$) (Table 2).

For the 1201 hospitalized patients ($n = 1100$;74.5% in the "chest radiography" group and $n = 101$;75.9% in the "CT ULD" group, respectively), the concordance between the diagnosis in the ED and the diagnosis at discharge was 68% for the "chest radiography" group and 88% for the "ULD chest CT" group ($p < 0.001$).

More patients received antibiotics in the ED when chest radiography was performed than when ULD chest CT was performed, 89% and 83%, respectively (1308/1476 versus 110/133; $p = 0.05$). However, there was no statistical difference for antibiotic prescription during hospitalization when chest radiography and ULD chest CT were performed, respectively for 91% (872/958) and 88% (80/91) of them ($p = 0.38$). No difference was found in the care pathways between the groups or in the length of hospital stay. Additional post-emergency imaging was performed during hospitalization for 59% of patients when a chest radiography was performed in the ED, more than after an initial ULD chest CT in the ED for 36% ($p < 0.001$). At 7%, 60-day mortality was higher in the chest radiography group ($n = 113$, 7.2%) than in the ULD chest CT group ($n = 3$, 2.1%) ($p = 0.023$).

During the 60-day follow-up period, 20.3% of patients in the ULD chest CT group were rehospitalized, compared with 20.9% in the chest radiography group.

Incremental costs and outcomes

Costs

The unadjusted mean 60-day costs in euros were estimated to be €4317 (± 5643) and €3990 (± 3983) for the "chest radiography" and "ULD chest CT" groups, respectively (Table 3).

Group comparisons

The overall proportion of missing data was 11%. Given that missingness was assumed to be at random (MAR), MICE was chosen as it provides unbiased estimates under this assumption by leveraging the joint distribution of observed data. We generated 11 imputed datasets to ensure stability of the estimates, and results were pooled using Rubin's rules. We assessed the adequacy of

Table 3 Average costs per patient in € in the group chest radiography and ULD chest CT in the ED for the unadjusted population

Costs expressed as mean ± SD		Chest radiography *N* = 1476	ULD chest CT *N* = 133
Consultation in the ED		€10.2 (± 26.7)	€5.14 (± 19.7)
Imaging	Radiography	€2.73 (± 7.11)	€0 (± 0)
	CT	€0 (± 0)	€1.62 (± 6.22))
Hospitalization		€3587 (± 5013)	€3322 (± 3001)
Rehospitalization		€717 (± 2478)	€661 (± 2528)
Total cost		€4317 (± 5643)	€3990 (± 3983)

ULD: ultra-low-dose

ED: Emergency department

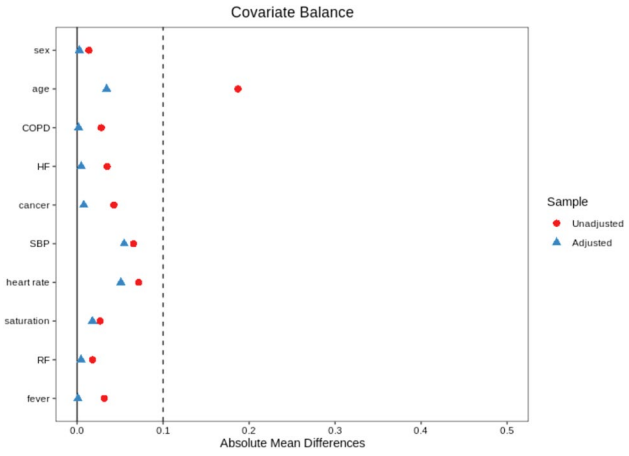

Fig. 2 Standardized mean difference (SMD) in the unadjusted and adjusted with propensity score populations. COPD: Chronic obstructive pulmonary disease. HF: Heart failure. SBP: Systolic blood pressure. RF: Respiratory failure

imputation by comparing the distribution of observed vs. imputed values. To evaluate the robustness of our results, we also performed a complete case analysis. These additional analyses yielded consistent findings, supporting the validity of our approach to handling missing data.

Inverse probability weighting using propensity scores led to a better standardized difference in means for the variables included in the logistic model: all were less than 0.2 after weighting (Fig. 2).

The average LOS in the ED and the average cost in euros with the inverse probability weighting are presented in Table 3. The point estimate of ICER was €7.8

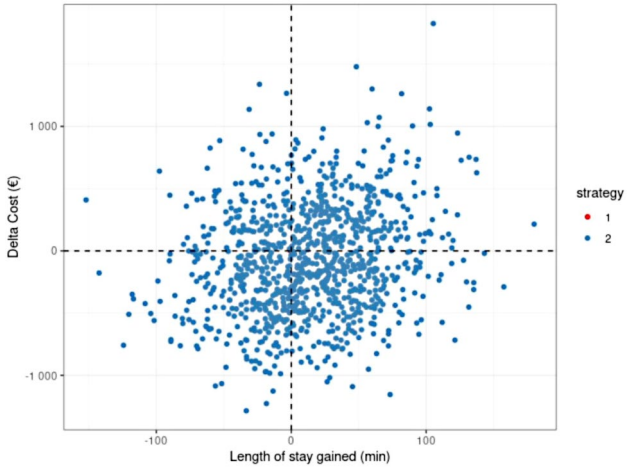

Fig. 3 Scatter plot of incremental cost and effectiveness of ULD chest CT (strategy 2) compared to the strategy chest radiography (strategy 1) as the reference. ULD Ultra-low-dose

(saved)/for an efficiency gain of 1 min (emergency department length of stay) by the "ULD chest CT" group compared with the "chest radiography" group (cost difference of €94/ efficacy difference of 12 min) (Table 4).

Characterising uncertainty

The set of ICERs estimated by the non-parametric bootstrap are presented on the cost-effectiveness plane, with "chest radiography" as the reference (Fig. 3). Approximately 35% of these replications were located in the bottom right-hand quadrant, indicating a lower cost for greater effectiveness of the "ULD chest CT" (Fig. 3).

Characterising heterogeneity

In the deterministic sensitivity analysis, "ULD chest CT" remained even more cost-effective when time from imaging to ED discharge was substituted for ED length of stay (Table 5). The time from ED admission to imaging was longer for "ULD chest CT" than for "chest radiography," 276 and 162 min, respectively, with a lower cost of €94 per patient.

We performed another sensitivity analysis to determine the robustness of our results, when substituting cost items (cost of chest radiography, cost of chest CT, cost of ED visits, cost of hospitalization) with five times the base

Table 4 Costs and effectiveness for each strategy of imaging (weighted endpoints)

Strategy [95% CI]	LOS in the ED	Cost per patient	Difference of LOS in the ED	Difference of cost	ICER
Chest radiography	714 [607; 791]	€4317 [3483; 5067]	NA	NA	NA
ULD Chest CT	702 [692; 736]	€4223 [4034; 4612]	12 [-108; 76.9]	€-94 [-870; 819]	-7.8[-119;142]

ULD: ultra-low-dose

LOS: Length of stay

ED: emergency department

LOS is presented in minutes

Table 5 Deterministic sensitivity analysis

Determinant of analysis	Strategy [95% CI]	LOS in the ED	Cost per patient	Difference of LOS in the ED	Difference of cost	ICER
Time between admission and imaging*	Chest radiography	**162**	€4317	NA	NA	NA
	ULD Chest CT	276	€4223	-114	€-94	0.82
Time between imaging and discharge‡	Chest radiography	**552**	€4317	NA	NA	NA
	ULD Chest CT	426	€4223	126	€-94	-0.74

*Time in minutes between the admission in the emergency department and when the imaging was performed, i.e. chest radiography or ULD chest CT

‡ Time in minutes between the imaging, i.e. chest radiography or ULD chest CT, and the discharge from the emergency department, at home or in a medical ward

ULD: ultra-low-dose

LOS: Length of stay

ED: emergency department

case for each parameter. "ULD chest CT" remained cost-effective when substituting multiplying each cost by 5 with the average cost of "ULD chest CT" and "chest radiography", being respectively €20,012 and €20,664, with an ICER of €54/hour gained in the ED.

Discussion

In our study, the strategy involving chest CT in ULD for patients managed in the ED for CAP was a cost-effective intervention. However, ULD chest CT not significantly reduce the LOS in the ED, being on average 12 min [-108; 76.9] less than the group that received a chest radiography while saving money with a reduction of €94 [-870; 819] per patient, thus being cost reducing compared to chest radiography. Length of stay was not significantly reduced in the ULD CT group. We could even have expected an increase in LOS, as it takes longer to install a patient in the scanner, and access to imaging is often more complicated than for a standard radiography. this may also be an obstacle for practitioners in terms of its use. Although imaging time was longer with ULD chest CT, the time from imaging to decision was shorter, giving a clear benefit to the patient while presenting an organizational benefit in favor of ULD chest CT. In addition, although the rate of antibiotic prescribing was the same during the hospital stay, more antibiotics were dispensed in the ED when a chest radiography was performed, 89% and 83%, respectively. Furthermore, a higher percentage of patients received additional imaging during hospitalization in the chest radiography group than in the ULD chest CT group. Finally, 60-day mortality was higher in the chest radiography group than in the ULD chest CT group ($p = 0.023$). This difference between the groups could be related to the age difference, as patients in the chest radiography group were older than those in the ULD chest CT group. This difference may be due to chance given the small sample size in the ULD CT group, it cannot be attributed solely to the better diagnostic accuracy of CT compared to chest X-ray allowing for appropriate and timely management.

The imaging strategy in the ED for the diagnostic workup of CAP has implications for hospital management and also for costs. Some studies have shown a reduction in hospital LOS with chest CT performed in the ED for the diagnosis of CAP [14, 15], resulting in estimated savings of $457 to $846 per episode or $500 to $900 million per year in the United States [25]. However, there are few published studies on the impact of imaging strategies on ED LOS. Kutz et al. found that the ED LOS was 326 min [95% CI 268; 359] in France for CAP, which is shorter than in our study [26]. This may be explained notably by the increase in ED LOS due to overcrowding. However, even if the reduction in length of stay was small in our study, we at least showed that the use of chest CT did not increase the LOS in the ED [27]. Other authors have found that CT performed in the ED was associated with an ED LOS greater than 180 min (Odd ratio [OR], 3.78; 95% confidence interval [CI], 1.56–9.18; $p = 0.003$) [28]. However, this study did not evaluate ULD chest CT. Reducing ED LOS is a challenge for clinicians because the increase in ED boarding (time between the decision to admit and the departure from the ED) and the overcrowding of these units are associated with several adverse effects such as mechanically ventilated pneumonia, increased length of stay and mortality [29–34]. Finally, as 90% of antibiotics for CAP are administered in the ED [35], rapid diagnosis is a challenge for prescribers. Another advantage of CT over chest radiography is a reasoned prescription of antibiotics to reduce antibiotic consumption and bacterial resistance [14, 15].

Concerning mortality, our results revealed a lower 60-day mortality rate in the ULD chest CT group (2.1% vs. 7.2%, $p = 0.023$). However, given the small sample size of the ULD group, this difference could be due to chance rather than an effect of imaging choice. Also, it is possible that the most severe patients did not benefit from CT scan, as their clinical condition did not allow the examination to be carried out lying down, whereas radiography does not require the patient to lie down with signs of respiratory distress. We cannot therefore conclude from our results on the impact of imaging on mortality.

Limitations and strengths

Data completeness and quality remain the main limit due to retrospective nature of this study. Indeed, factors other than the strategy applied for the diagnostic workup could explain the differences between the groups. Emergency physicians and radiologists chose whether to perform ULD CT or radiography according to various factors that we were unable to identify precisely, such as clinical condition, patient age and previous history. But we performed inverse probability weighting using propensity scores to reduce heterogeneity between groups. However, other factors such as imaging availability could have influenced this allocation and were not taken into account in this retrospective study.

Our cost calculations considered ED costs and subsequent hospital costs during a 60-day follow-up period, without outpatient costs, because hospitalization accounted for the majority of strategy-related costs. In addition, rehospitalization could not be comprehensively recovered.

Finally, our measure of efficacy did not take into account diagnostic accuracy and the patient's state of health, which could be discussed. However, the superiority of CT over chest radiography was already known and no longer needs to be evaluated, as shown by the numerous studies cited. In fact, we wanted to propose a real-life study of the management of pneumonia in the emergency department. The impact of our strategy was assessed in terms of organizational impact, which is an essential criterion of effectiveness in an emergency department. The objective of changing the imaging strategy in the emergency department was in fact linked to the need for efficient triage to optimize patient flow. As such, this criterion is an essential element to be taken into account by decision-makers when choosing between different investment strategies in the emergency department. Time spent in the ED therefore seems to be the best outcome in terms of performance.

To our knowledge, this is the first study to provide real-world data on the cost-effectiveness of imaging strategies performed in the ED for the diagnostic workup of patients with CAP. These results provide important data for healthcare payers. In this study, imaging access time was longer for CT in the ED, suggesting that priority should be given to reducing imaging access times through specific pathways between EDs and radiology departments to further improve organizational performance. In addition, greater improvement in ED LOS for CT might be expected with more experienced radiologists and emergency physicians. Indeed, the care pathway needs to be evaluated when the actors have experience with the new strategy, which could have an impact on the imaging access time. However, because of the Covid outbreak, we have not had the opportunity to evaluate the implementation of ULD CT in the ED for the management of CAP over a longer period of time. An ongoing multicenter, non-inferiority randomized controlled trial (OPTIMACT) will evaluate the replacement of chest radiography by ULD chest CT in the diagnostic workup of ED patients with suspected nontraumatic lung disease, with a cost-utility analysis [35, 36]. This study will complement our results by providing information on patient-related costs and health outcomes.

Despite this analysis is based on the perspective of the French healthcare system and costs differ by country, the consequences of imaging on patient care and consumption are potentially the same, although the precise financial valuation is not possible with the results of this single study. To account for these differences between healthcare systems, we performed a deterministic sensitivity analysis. When we varied costs to reflect health costs in different countries, ULD chest CT remained cost-effective across broad settings.

Taking into account the results of previous studies revealing the superior diagnostic performance of CT compared with radiography for the diagnosis of pneumonia and our results, it would therefore be desirable for ULD CT to become the first-line examination for the diagnosis of pneumonia in emergency departments in the future, taking into account the organizational impact, while contributing to cost reduction.

Conclusions

Our study showed that a diagnostic workup with ULD chest CT for CAP in the ED did not significantly reduce ED length of stay (12 min reduction per patient) but did reduce costs, with an average cost reduction of €94 per patient compared to chest radiography. Our results confirm that this strategy is a viable alternative to improve the diagnostic management of patients with respiratory symptoms in the ED. Indeed, in addition to a better diagnostic accuracy, this strategy improves the organization of the care pathways and significantly reduces the delay between the examination and the discharge from the ED.

Abbreviations

ULD	Ultra-low-dose
CAP	Community-acquired pneumonia
CT	Tomography
ED	Emergency departments
COPD	Chronic obstructive pulmonary disease
HBP	High blood pressure
ICER	Incremental cost effectiveness ratio

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Author contributions

SK, MO, and IZD conceived the idea of the study. SK, KZ, MO, IZD and PB formed the working group that wrote the study protocol. SK, MO, LH, CH, PLB, FS and JM conducted acquisition of the data. SK, KZ and IZD provided

statistical advice on study design and analyzed the data. All coauthors have approved the protocol and will participate in the study.

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Data availability
The datasets analysed during the current study are not available in accordance with French law.

Declarations

Ethics approval and consent to participate
Institutional Review Board approval was obtained. The study was approved by the Ethics Comitte (CE 2021-50). A declaration of conformity was obtained from the Commission nationale de l'informatique et des libertés (CNIL) (agreement number 2208067v0).). This study was registered with the Clinical Trials Registry (NCT05140408). In accordance with French legislation, formal written informed consent was not required for this type of study because data were entirely retrospectively studied.

Consent for publication
Not applicable.

Competing interests
No author declared competing interests concerning this study.

Author details
[1]Emergency Department, Hôpitaux Universitaires de Strasbourg, 1 place de l'hôpital, CHRU of Strasbourg, Strasbourg 67091, France
[2]ICUBE UMR 7357 CNRS, équipe IMAGeS, 300 Bd Sébastien Brant, Illkirch-Graffenstaden 67400, France
[3]Groupe Méthodes en Recherche Clinique (GMRC), Hôpitaux Universitaires de Strasbourg, 1 place de l'hôpital, Strasbourg 67091, France
[4]URCEco, Hôtel Dieu, AP-HP, 1 Place du Parvis Notre Dame, Paris 75004, France
[5]Radiology Department, Nouvel Hôpital Civil, Hôpitaux Universitaires de Strasbourg, 1 place de l'hôpital, Strasbourg 67091, France
[6]Emergency Department, Hôpital Emile Muller, 20 rue du Dr Laennec, Mulhouse 68100, France
[7]UMR 1260, INSERM / Université de Strasbourg CRBS, 1 rue Eugene Boeckel, Strasbourg 67000, France
[8]Public Health Unit, Hôpitaux Universitaires de Strasbourg, CHRU of Strasbourg, 1 place de l'hôpital, Strasbourg 67091, France
[9]Univ Paris Est Creteil (UPEC), Université de Paris, CRESS, INSERM, INRA, 74 rue Marcel Cachin, Bobigny 93017, France

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