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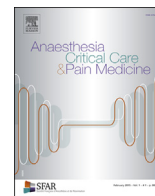
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## Original Article

# Implementation of an electronic checklist in the ICU: Association with improved outcomes



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## ABSTRACT

**Objective:** To assess the impact of an electronic checklist during the morning rounds on ventilator-associated pneumonia (VAP) in the intensive care unit (ICU).

**Patients and methods:** We conducted a retrospective, before/after study in a single ICU of a university hospital. A systematic electronic checklist focusing on guidelines adherence was introduced in January 2012. From January 2008 to June 2014, we screened patients with ICU stay durations of at least 48 hours. Propensity score-matched analysis with conditional logistic regression was used to compare the rate of VAP and number of days free of invasive devices before and after implementation of the electronic checklist.

**Results:** We analysed 1711 patients (before group,  $n = 761$ ; after group,  $n = 950$ ). The rates of VAP were 21% and 11% in the before and after groups, respectively ( $p < 0.001$ ). In propensity-score matched analysis ( $n = 742$  in each group), VAP occurred in 151 patients (21%) during the before period compared with 72 patients (10%) during the after period (odds ratio [OR] = 0.38; 95% confidence interval [CI] = 0.27–0.53). The after group showed increases in ICU-free days (OR = 1.05; 95% CI = 1.04–1.07) and mechanical ventilation-free days (OR = 1.03; 95% CI = 1.01–1.04).

**Conclusion:** In this matched before/after study, implementation of an electronic checklist was associated with positive effects on patient outcomes, especially on VAP. Further prospective studies are needed to confirm these observations.

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## 1. Introduction

Infectious complications remain a frequent issue in intensive care units (ICU), with the use of invasive devices representing the main risk factor [1,2]. Guidelines aim to improve practices, and thus reduce the risk of healthcare-related complications [3–6]. However, the adherence to guidelines is often suboptimal [7–9]. In a previous study, we observed a compliance rate of 24%, and it was greatly reduced in patients requiring more than three clinical recommendations [10].

A number of strategies have been implemented to improve guideline adherence. For this purpose, a systematic electronic

checklist was introduced in our ICU. Checklists are widely used in the operating room, and their implementation was reported to be associated with a reduced number of perioperative complications [11–14]. Some studies have reported encouraging findings regarding the impact of checklist implementation in the ICU [15–18]. In most studies, interventions target specific subgroups of patients or diseases [19–21], but their implementation results in improved adherence to guidelines [22,23].

Our hypothesis was that the implementation of an electronic checklist would reduce the rate of healthcare-related infections. The first goal of this study was to determine the effects of electronic checklist implementation on the rate of nosocomial ventilator-associated pneumonia (VAP). The secondary goals were to assess the durations of ICU stay, invasive mechanical ventilation, central venous catheterisation, and urinary catheterisation before and after checklist implementation. In another analysis of the

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completed checklist, we determined the compliance for each item to evaluate guideline adherence in our unit.

## 2. Material and methods

### 2.1. Checklist data collection

The electronic checklist combines the clinical recommendations initially extracted from our previous one-day survey [10] (Fig. 1). In the second step, a multi-professional group including physicians, certified registered nurse anesthetists (CRNA), nurses, and physiotherapists discussed each recommendation according to our local experience and challenges. The process required 3 months. Once the 14 recommendations had been defined, they were made available via an electronic program accessible to all ICU members via our intranet. After specific training using electronic tablets, four CRNAs (responsible for nursing care in our ICU) completed the electronic checklists for each patient at 07:00. The electronic checklists were immediately available to all of our staff via our intranet on computers, smartphones, and tablets, among others. During the morning rounds, the nurses, CRNAs, or residents reiterated the unresolved items from the electronic checklists.

The items on the electronic checklist covered invasive devices (central venous catheter, arterial catheter, peripheral venous line, urinary catheter) and their indications, VAP prevention (head-of-bed elevation, tube cuff pressure control, ventilation pressure < 30 cm H<sub>2</sub>O, daily sedation interruption), physical rehabilitation (enteral feeding, enteral route, transfer from bed to armchair), and miscellaneous care (contention, type of mattress, antithrombotic prophylaxis).

We used a four-grade classification for each invasive device: “present and needed,” “present and in excess,” “present and probably in excess,” or “none.” “Present and in excess” was reported by the CRNAs during the 07:00 round. “Present and likely

in excess” corresponded to an implemented device without any justification. The decision to attribute a grade for each item was left at the discretion of the CRNAs. Then, it was discussed with the staff, including physicians and nurses, or during ICU daily rounds. The usual recommendations were classified as: “done,” “not done,” or “not applicable.”

### 2.2. Patients

From January 2008 to December 2014, we conducted a retrospective, before/after study in a 15-bed ICU of a 968-bed university hospital (Hôpital Nord, Marseille, France). Our checklist was introduced on January 1, 2012. The before period ranged from January 1, 2008, to December 31, 2011. The after period ranged from January 1, 2012 to December 31, 2014.

### 2.3. Data collection

Demographic and clinical features, including gender, age, simplified acute physiology score 2 (SAPS2), reason for admission, use of antibiotics in the first 48 hours, and immunological status (neutropenia, immunosuppressive therapeutics), were collected from our electronic database. We also collected the types of invasive devices used (venous central catheter, urinary catheter, tracheal intubation). We recorded the duration of use of each invasive device during the ICU stay, the duration of invasive mechanical ventilation, and the duration of ICU stay. We noted the reintubation rate and the ICU mortality rate. The numbers of ICU-free days and invasive device-free days (mechanical ventilation, central venous catheter, urinary catheter) were reported from day of admission or of exposure to day 28 or the day of death, as applicable.

Nosocomial infections included VAP, catheter-related infections, bacteraemia, and urinary catheter-related infection, as

PART I. INVASIVE DEVICE					
Use of central venous catheter :	YES	<input type="checkbox"/>	NO <input type="checkbox"/>	USE IN EXCES <input type="checkbox"/>	
<input type="checkbox"/> Hemodynamic instability (use of catecholamine)					
<input type="checkbox"/> Use of venotoxic treatment					
<input type="checkbox"/> Impossible use of peripheral venous line					
<input type="checkbox"/> Use of parenteral feeding					
Use of arterial catheter :	YES	<input type="checkbox"/>	NO <input type="checkbox"/>	USE IN EXCES <input type="checkbox"/>	
<input type="checkbox"/> More than 3 blood samples					
<input type="checkbox"/> Daily blood sample					
Use of peripheral venous line :	YES	<input type="checkbox"/>	NO <input type="checkbox"/>	USE IN EXCES <input type="checkbox"/>	
<input type="checkbox"/> more than 3 days old					
Use of urinary catheter :	YES	<input type="checkbox"/>	NO <input type="checkbox"/>	USE IN EXCES <input type="checkbox"/>	
<input type="checkbox"/> Renal dysfunction					
<input type="checkbox"/> Anatomic issue					
<input type="checkbox"/> Woman					
PART II. RESPIRATORY CHECK					
Head of bed elevation :	DONE	<input type="checkbox"/>	NOT DONE <input type="checkbox"/>	NOT APPLICABLE <input type="checkbox"/>	
<input type="checkbox"/> Instable trauma rachis					
<input type="checkbox"/> Pelvis trauma					
Tube cuff pressure control:	DONE	<input type="checkbox"/>	NOT DONE <input type="checkbox"/>	NOT APPLICABLE <input type="checkbox"/>	
Ventilation pressure < 30cmH <sub>2</sub> O	DONE	<input type="checkbox"/>	NOT DONE <input type="checkbox"/>	NOT APPLICABLE <input type="checkbox"/>	
Tidal volume : _____ ml					
<input type="checkbox"/> Controled ventilation mode					
<input type="checkbox"/> Spontaneous assisted breathing mode					
<input type="checkbox"/> T Tube					
Use of sedative treatment	YES	<input type="checkbox"/>	NO <input type="checkbox"/>	USE IN EXCES <input type="checkbox"/>	
<input type="checkbox"/> Daily stop prescribed					
<input type="checkbox"/> Acute Distress Respiratory Syndrom					
<input type="checkbox"/> Intra cranial hypertension					
PART III. NURSING					
Physical contention	YES	<input type="checkbox"/>	NO <input type="checkbox"/>	NO BUT NEEDED <input type="checkbox"/>	USE IN EXCES <input type="checkbox"/>
<input type="checkbox"/> Physical contention prescribed					
<input type="checkbox"/> Use of a pharmacological treatment					
Use of therapeutic mattress	YES	<input type="checkbox"/>	NO <input type="checkbox"/>	NO BUT NEEDED <input type="checkbox"/>	USE IN EXCES <input type="checkbox"/>
<input type="checkbox"/> ICU stay < 3 days					
Use of Thrombophylaxis	YES	<input type="checkbox"/>	NO <input type="checkbox"/>	NO BUT NEEDED <input type="checkbox"/>	USE IN EXCES <input type="checkbox"/>
<input type="checkbox"/> Active bleeding					
<input type="checkbox"/> Use of mechanical compression system					
<input type="checkbox"/> Use of compression stocking					
PART IV. REHABILITATION					
Transfert from bed to arm-chair	DONE	<input type="checkbox"/>	NOT DONE <input type="checkbox"/>	NOT APPLICABLE <input type="checkbox"/>	
<input type="checkbox"/> Transfert prescribed					
<input type="checkbox"/> Traumatic anatomic issue					
<input type="checkbox"/> Muscular hypotonia					
<input type="checkbox"/> Bedsore preventing sitting					
Enteral feeding	DONE	<input type="checkbox"/>	NOT DONE <input type="checkbox"/>	NOT APPLICABLE <input type="checkbox"/>	
<input type="checkbox"/> Upper digestive surgery					
<input type="checkbox"/> Extubation form less than 48h					
<input type="checkbox"/> Other counter indication					
Oral route used	DONE	<input type="checkbox"/>	NOT DONE <input type="checkbox"/>	NOT APPLICABLE <input type="checkbox"/>	

Fig. 1. Checklist used during study.

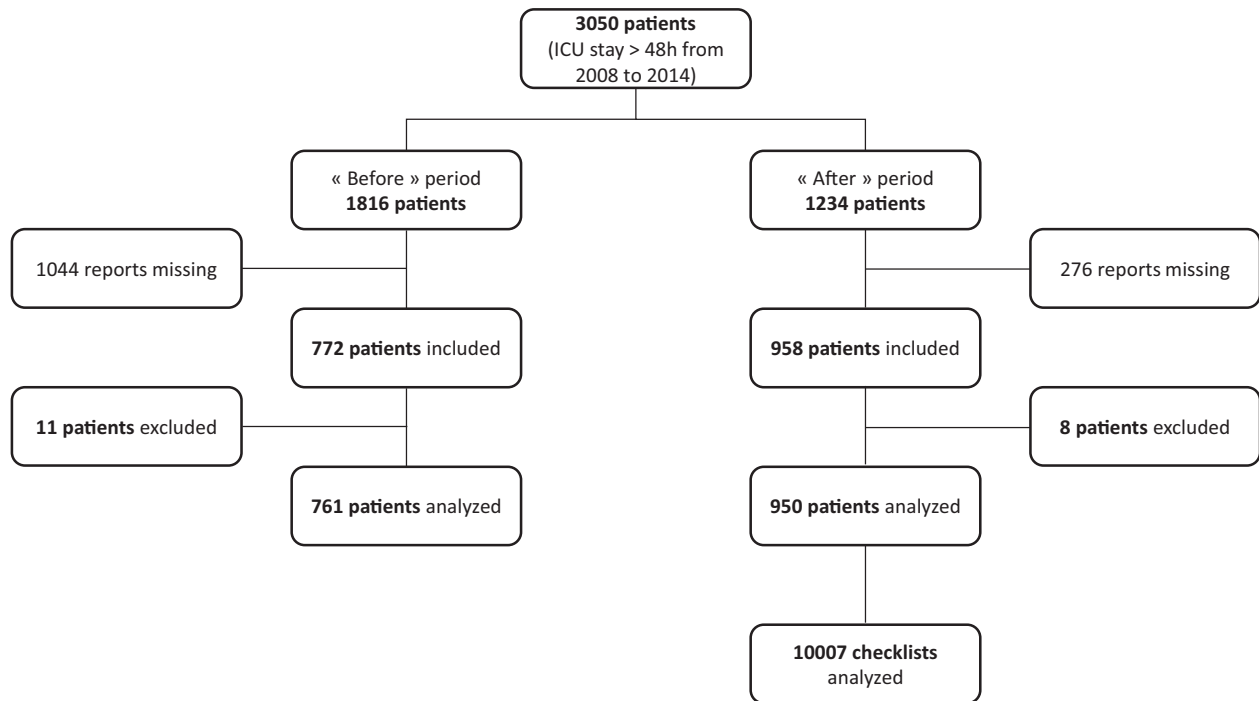


Fig. 2. Flowchart. ICU: intensive care unit.

defined according to international definitions [24] (Appendix A). Only episodes with microbiological identification were reported. We used our local data extracted from a regional database in which all patients admitted to our ICU for more than 48 hours were registered, and each of the previous nosocomial infections prospectively reported. The patients with data missing were excluded from the analysis (Fig. 2).

#### 2.4. Statistical analysis

Statistical analyses were performed using IBM SPSS V24.0 (IBM Corp., Armonk, NY). The first analysis included all of the patients during each period. Continuous data are expressed as means and standard deviations or medians with interquartiles. Qualitative data are expressed as absolute numbers and percentages. Comparisons between the continuous data periods were performed using Student's *t* test or Wilcoxon's test according to their distribution and with the chi-square test for categorical variables. A propensity score-based approach was used to match patients between the periods. Propensity score was derived with the following covariates: age, SAPS2, reason for admission (trauma, medical, scheduled or emergent surgery), sex, and immunological status. A 1:1 matching algorithm without replacement was used with a maximum range of standard deviation of 20% (Appendix B). Outcomes were compared between 1444 matched patients (722 in each group) using conditional logistic regression. Results are presented as odds ratios (OR) with 95% confidence intervals (95% CI). All comparisons were two-tailed and  $P < 0.05$  was required to exclude the null hypothesis. To reduce the effect of early death, we computed the numbers of ICU-free days and device (tracheal intubation, central line, urinary catheter)-free days (from inclusion to day 28).

As this was an observational retrospective study, according to French legislation (articles L. 1121-1 paragraph 1 and R. 1121-2, Public Health Code), neither informed consent nor approval from the ethics committee was needed to use routine data at the time of the analysis. Patients or their families were informed that data

could be used during their ICU stay. Data were stocked and treated according CNIL authorisation number 588909v1.

### 3. Results

During the entire study period, 3050 patients were admitted to our ICU for more than 48 hours, including 1816 patients in the before group and 1234 patients in the after group. Among these patients, 1730 reports were available in the regional database on nosocomial infections (Regional Surveillance Network of Health-care-acquired Infections, C-CLIN Sud-Est). Unavailable data were explained by incomplete reports during the study period. Of the 1730 available reports, 19 patients were excluded due to missing data (incomplete or erroneous forms). Finally, 761 and 950 patients were respectively included in the before and after groups, (Fig. 2). We also analysed 10,007 electronic checklists of the 950 patients in the after group. Central venous catheter, arterial catheter, and urinary catheter uses were reported as definitely in excess or probably in excess (no clear indication) in 16%, 7.6%, and 27% of our patients, respectively. Among the patients eligible for each guideline, head-of-bed elevation, daily interruption of sedation, armchair transfer, and enteral feeding non-compliance were found in 1.2%, 32%, 28%, and 21% of the electronic checklists, respectively.

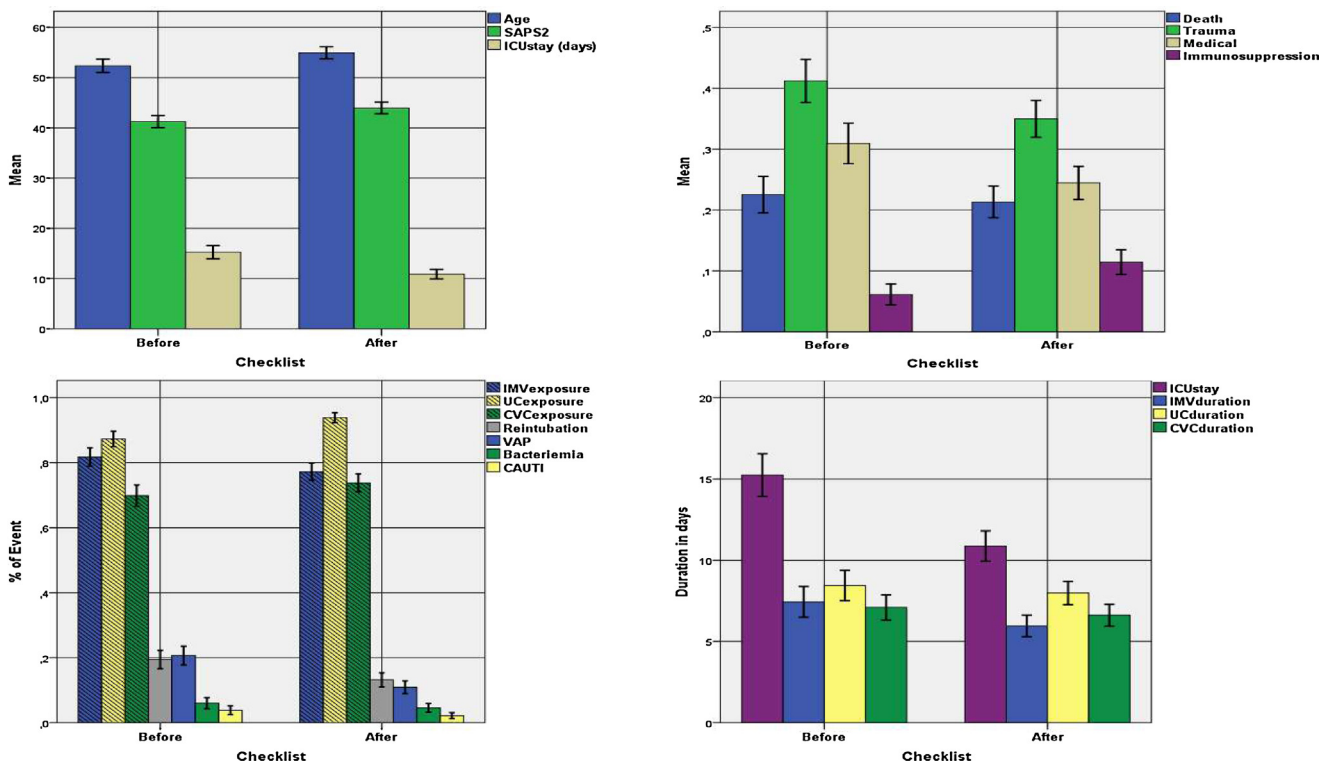
Univariate analysis showed imbalances between the two groups (Table 1, Fig. 3). The patients in the after group were older and had higher severity scores than those in the before group. Immunosuppression was more frequent in the after group. The case mix differed between the two periods. The rates of patients requiring emergency and scheduled surgery increased in the after period, whereas the rates of medical and trauma patients decreased (Table 1). There were no significant differences between analysed patients and patients with missing reports in terms of demographic characteristics, case mix, or death (Table 1). Data regarding the duration of ICU stay of the patients who were not analysed were missing from the before period. We did not have access to specific ICU duration data as the institution's computer program saved only total length of hospitalisation stay for this

**Table 1**

Comparison of patients characteristics according to the period group.

Variables	"Before period"		"After period"		P
	All patients (n = 1816)	Analysed group (n = 750)	All patients (n = 1234)	Analysed group (n = 961)	
Age (years) (median [Q25–Q75])	55 [39–67]	54 [39–67]	56 [37–68]	58 [42–69]	0.005
Death occurring (%)	360 (20)	169 (23)	257 (21)	205 (21)	0.6
SAPS2 at admission	40 [29–53]	40 [15–65]	41 [30–52]	41 [19–63]	< 0.001
Males (%)	1323 (73)	532 (71)	856 (69.3)	655 (68)	0.23
Immunosuppression (%)	–	46 (6.1)	–	110 (11)	< 0.001
Trauma patients (%)	726 (40)	309 (41)	432 (35)	336 (35)	0.009
Medical patients (%)	544 (30)	232 (31)	296 (24)	235 (24)	0.003
Emergent surgery patients (%)	327 (18)	126 (17)	284 (23)	213 (22)	0.006
Scheduled surgery patients (%)	236 (13)	90 (12)	210 (17)	177 (18)	< 0.001
Duration of ICU stay (days)	–	15 ± 18	11 ± 8	11 ± 15	0.005
Invasive mechanical ventilation (%)	–	613 (82)	–	742 (77)	0.026
Re-intubation (%)	–	146 (20)	–	127 (13)	< 0.001
Central venous catheter exposure (%)	–	524 (70)	–	709 (74)	0.082
Urinary catheter exposure (%)	–	655 (87)	–	902 (94)	< 0.001

SAPS2: simplified acute physiology score 2; ICU: intensive care unit; VAP: ventilator-associated pneumonia; IMV: invasive mechanical ventilation; CVC: central venous catheter; CAUTI: catheter-associated urinary tract infection.



**Fig. 3.** Comparison of patients and outcome according to the period. SAPS2: simplified acute physiology score; ICU: intensive care unit; IMV: invasive mechanical ventilation; CVC: central venous catheter; UC: urinary catheter; VAP: ventilator associated pneumonia; CAUTI: catheter associated urinary tract infection.

period. Exposure to mechanical ventilation decreased during the after period, which was due to patients admitted after emergency surgery. In contrast, exposure to urinary catheter use increased during the after period. The rates of reintubation were 20% in the before group and 13% in the after group ( $P < 0.001$ ) (Table 1, Fig. 3).

The durations of use of each invasive device are shown in Fig. 3. The duration of ICU stay was significantly reduced in the after group ( $15 \pm 18$  days vs.  $11 \pm 15$  days in the before group,  $P = 0.005$ ) (Fig. 3). The duration of invasive mechanical ventilation decreased from  $7.4 \pm 13$  days in the before group to  $6.0 \pm 10$  days ( $P = 0.01$ ) in the after group (Fig. 3). The durations of exposure to urinary catheter and central venous catheter use were similar between the two groups (Fig. 3, Table 2).

The rates of VAP were 21% and 11% in the before and after groups, respectively ( $P < 0.001$ ). Central venous catheter-related infection, bacteremia, and catheter-related urinary tract infection rates did not differ between the two groups. The mortality rates were similar in the two groups (23% vs. 21%, respectively,  $P = 0.6$ ) (Table 1). The outcomes are shown according to the year in Table 3, Fig. 4, and Fig. 5.

In the propensity-based score, we matched 722 patients for each period (Table 3). Conditional logistic regression indicated a reduction in the risk of VAP associated with the checklist period (OR = 0.38; 95% CI = 0.27–0.53;  $P < 0.001$ ). Secondary outcome analysis showed increases in ICU-free days ( $16 \pm 8.5$  vs.  $19 \pm 7.5$ ;  $P < 0.001$ ) and ventilator-free days ( $21.5 \pm 7.8$  vs.  $23 \pm 6.6$ ;

**Table 2**  
Comparison of outcome depending of the year.

Year	Variables	Year	Variables
2008 n = 234	VAP (%)	2011 n = 230	VAP (%)
	CAUTI (%)		CAUTI (%)
	Bacteraemia (%)		Bacteraemia (%)
	Death (%)		Death (%)
	Duration ICU stay (days)		Duration ICU stay (days)
	IMV exposure (days)		IMV exposure (days)
	UC exposure (days)		UC exposure (days)
	CVC exposure (days)		CVC exposure (days)
2009 n = 139	VAP (%)	2012 n = 375	VAP (%)
	CAUTI (%)		CAUTI (%)
	Bacteraemia (%)		Bacteraemia (%)
	Death (%)		Death (%)
	Duration ICU stay (days)		Duration ICU stay (days)
	IMV exposure (days)		IMV exposure (days)
	UC exposure (days)		UC exposure (days)
	CVC exposure (days)		CVC exposure (days)
2010 n = 147	VAP (%)	2013 n = 398	VAP (%)
	CAUTI (%)		CAUTI (%)
	Bacteraemia (%)		Bacteraemia (%)
	Death (%)		Death (%)
	Duration ICU stay (days)		Duration ICU stay (days)
	IMV exposure (days)		IMV exposure (days)
	UC exposure (days)		UC exposure (days)
	CVC exposure (days)		CVC exposure (days)
2014 n = 188	VAP (%)		
	CAUTI (%)		
	Bacteraemia (%)		
	Death (%)		
	Duration ICU stay (days)		
	IMV exposure (days)		
	UC exposure (days)		
	CVC exposure (days)		

VAP: ventilator-associated pneumonia; CAUTI: catheter associated urinary tract infection; ICU: intensive care unit; IMV: invasive mechanical ventilation; UC: urinary catheter; CVC: central venous catheter.

**Table 3**  
Characteristics and outcomes of patients depending of matching.

Variables	Before matching		After matching	
	Before group (n = 750)	After group (n = 961)	Before group (n = 722)	After group (n = 722)
Age (years) (median [Q25–Q75])	54 [39–67]	58 [42–69]	55 [40–67]	58 [41–69]
Death occurring (%)	169 (23)	205 (21)	167 (23)	151 (21)
SAPS2 (at admission)	40 [15–65]	41 [19–63]	40 [29–54]	41 [31–52]
Males (%)	532 (71)	655 (68)	510 (71)	490 (68)
Immunosuppression (%)	46 (6.1)	110 (11)	46 (6.5)	44 (6.1)
Trauma patients (%)	309 (41)	336 (35)	296 (41)	279 (38.5)
Medical patients (%)	232 (31)	235 (24)	219 (30)	191 (26.5)
Emergent surgery patients (%)	126 (17)	213 (22)	126 (17.5)	135 (18.5)
Scheduled surgery patients (%)	90 (12)	177 (18)	81 (11)	117 (16)
ICU-free days	19 [10–23]	22 [17–24]	19 [10–23]	22 [17–24]
Invasive mechanical ventilation (%)	613 (82)	742 (77)	600 (83)	552 (76.5)
Ventilation-free days	25 [19–27]	26 [21–28]	25 [19–27]	26 [21–28]
Re-intubation (%)	146 (20)	127 (13)	143 (20)	95 (13)
Central venous catheter exposure (%)	524 (70)	709 (74)	514 (71)	528 (73)
CVC-free days	24 [19–28]	25 [21–28]	24 [19–28]	25 [21–28]
Urinary catheter exposure (%)	655 (87)	902 (94)	647 (89.5)	666 (92)
UC-free days	23 [18–26]	24 [19–26]	23 [18–26]	24 [19–26]

$P < 0.001$ ) during the checklist period. The occurrence rates of death, CVC infection, bacteraemia, and catheter-associated urinary tract infection (CAUTI) were different between periods (Table 4).

#### 4. Discussion

In our cohort, the implementation of an electronic checklist was associated with a significant reduction in the rate of VAP. The electronic checklist seemed to influence guideline adherence with regard to daily sedation interruption and head-of-bed elevation,

and improved the global management of invasive devices, resulting in lower nosocomial infection rates and shorter periods of invasive device exposure.

Adherence to guidelines is a crucial issue in the ICU. Application of care bundles was shown to be associated with improved performance [4,6,25–27]. However, most guidelines are based on targeted strategies with specific goals [1,28–31]. Routinely, we observed a low rate of compliance to guidelines in patients eligible for at least three clinical recommendations [10]. It seems that the more complex the care strategy, the more omissions occur. This is

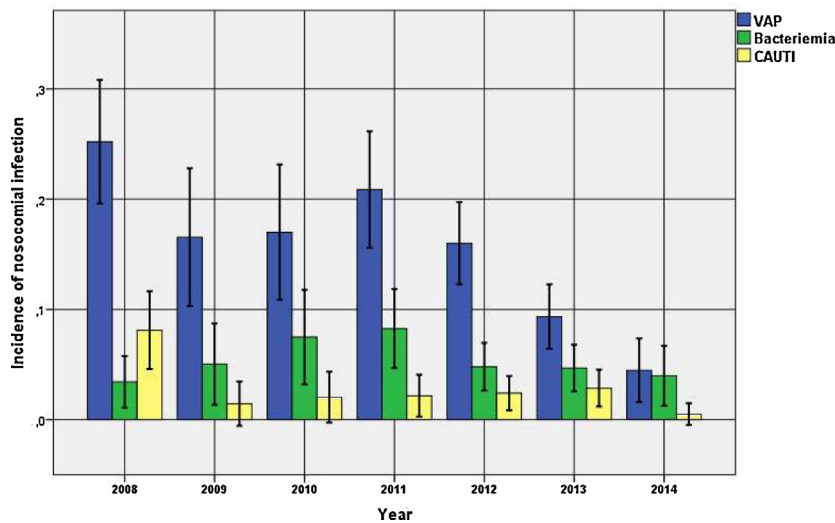


Fig. 4. Incidence of nosocomial infection according to the year. VAP: ventilator associated pneumonia; CAUTI: catheter associated urinary tract infection.

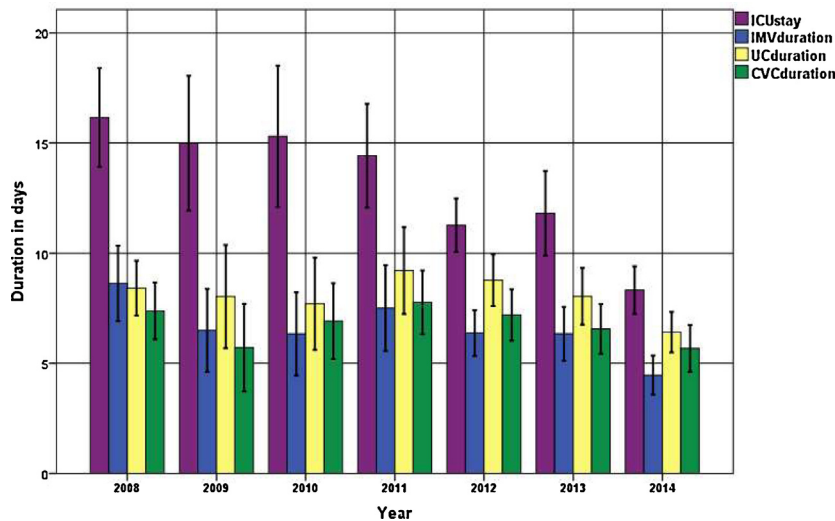


Fig. 5. Invasive device duration exposure according to the year. ICU: intensive care unit; IMV: invasive mechanical ventilation; CVC: central venous catheter; UC: urinary catheter.

**Table 4**  
Results of outcome analyses of matched cohort.

Outcome	"Before" group (n = 722)	"After" group (n = 722)	OR (95% CI)	P
Death (%)	167 (23)	151 (21)	0.93 [0.78–1.12]	0.47
VAP (%)	151 (21)	72 (10)	0.38 [0.27–0.53]	<0.001
CVC infection (%)	4 (0.5)	3 (0.3)	0.42 [0.09–2.73]	0.42
Bacteraemia (%)	45 (6.2)	32 (4.4)	0.69 [0.43–1.11]	0.13
CAUTI (%)	28 (3.9)	20 (2.8)	0.73 [0.39–1.26]	0.24
Re-intubation rate (%)	143 (20)	95 (13)	0.76 [0.61–0.95]	0.02
ICU-free days	16 (8.5)	19 (7.5)	1.05 [1.04–1.07]	0.001
Ventilator-free days	21.5 (7.8)	23 (6.6)	1.03 [1.01–1.04]	0.001
CVC-free days	21.5 (7.7)	22.3 (7)	1.01 [1.00–1.03]	0.03
UC-free days	20.5 (7.8)	21.3 (7)	1.01 [1.00–1.03]	0.06

VAP: ventilator-associated pneumonia; IMV: invasive mechanical ventilation; ICU: intensive care unit; CVC: central venous catheter; UC: urinary catheter; CAUTI: catheter-associated urinary tract infection. Continuous data are reported as mean (SD).

why our electronic checklist aimed to cover a wide spectrum of clinical areas.

Whereas the implementation of checklists indicated its efficiency in the operating room [11–13], its use in the ICU remains to be defined. Previous single-center studies showed improved guideline compliance and decreased use of invasive

devices after checklist implementation [15,16]. Conroy et al. reported a validation process using the Delphi method from a multidisciplinary workgroup of local experts [32,33]. This method served to select the most relevant items. In our institute, a multi-professional group including CRNAs, nurses, physicians, and therapists developed a global checklist. The rationale was based

on the results of a large one-day survey [10]. In all cases, the contents of checklists should generate discussion about the processes of care with all members of the care team [17,34].

In our opinion, checklists should be widely adopted. We used electronic support, which was easily accessible by the entire staff via our intranet. A previous study by Kastrop et al. showed that adherence to guidelines could be improved by using an electronic tool [35]. Weiss et al. showed that prompting checklist use during the morning rounds was associated with better compliance [18]. We did not assess the rate of daily use of our electronic checklist. However, our system collected more than 10,000 checklists during the study period, generating an efficient tool for assessing our practice.

The findings regarding use of the electronic checklist were encouraging. After its implementation, the incidence of VAP statistically decreased. As compared with other studies, this incidence seemed moderately high [1–3]. This could be explained by the inclusion of patients hospitalised for at least 48 hours, trauma patients with head injuries, and patients developing complications after chest surgery. Exposure to invasive mechanical ventilation may also have been decreased due to the increase in post-surgical patient admission. During the study period, there were no changes in rates of CAUTI, bloodstream infection, or catheter-related infection. As the severity status of our patients increased, the lack of increases in these specific infections may reflect improved practice. Moreover, CAUTI and catheter-related infection rates were already low in the before period, and any influence on the electronic checklist could be masked by a lack of study power. We conducted several previous studies regarding urinary catheter use in the field [36]. Thus, improvement was probably difficult because efforts had previously been made to reduce the duration of urinary catheterisation. These findings highlight a possible link between the local culture of the ICU and quality of care [37,38].

Analysis of the 10,007 checklists underlined that our practices can still be improved. The daily interruption of sedation, the route of feeding, or armchair transfer was applied in around 70–80% of our cases. Invasive devices were considered to be unjustified in 7.6% to 27% of cases. For example, as in a previous study, we found about 20% of urinary catheter use was in excess [33]. The physician in charge can justify or tolerate a process considered in excess by the CRNA during their morning rounds. It should be noted that the goal of the checklist was to introduce discussion regarding care quality. This discrepancy is representative of a disparity between routine practice and guidelines.

Our study had several limitations. First, its retrospective design led to the exclusion of several patients due to incomplete data, although demographic characteristics were the same between patients with missing reports and those included in the analyses. The large number of missing data can lead to selection bias. We compared some available demographic data and found no significant differences. VAP reduction could be induced by the Hawthorne effect, but the main goal of an electronic checklist was to improve guideline adherence, directly influencing physician practice, and prompting discussion with the medical team. However, with this retrospective study, the staffs were not influenced by the observer effect. Our results reflect real-life practice. Furthermore, analysing device-free days seems more accurate than the crude duration of exposure as it removes the effect of early death during an ICU stay. Second, the case mix evolved during the study period with the implementation of chest surgery in our hospital in June 2009 and the consequent increase in the number of post-surgical patients, but the propensity score-matched analysis should have reduced possible effects. Third, the management of patients probably differed between the onset and completion of the study considering the long period included.

## 5. Conclusion

In conclusion, the implementation of an electronic checklist seems associated with positive effects on the patients' outcome. The difference observed the two studied period suggest that use of a daily electronic checklist may have reduced nosocomial ventilator-associated pneumonia. These results require a prospective and multi-centered study in order to evaluate the impact of checklist use in ICU.

## Ethical statement

We further confirm that any aspect of the work covered in this manuscript that has involved either experimental animals or human patients has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript.

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## Disclosure of interest

The authors declare that they have no competing interest.

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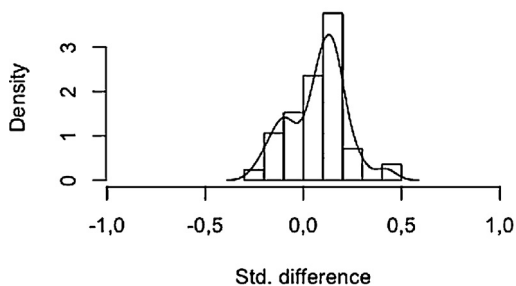
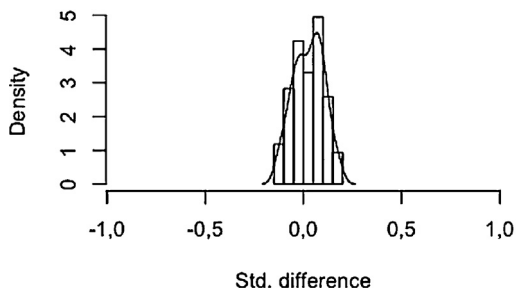
## Appendix A. Criteria for defining infections (based on international definitions) [24].

Site	Criteria for diagnosis
Catheter-associated urinary tract infection	Positive urine culture ( $> 10^4$ bacteria/ml, no more than two bacteria) AND Fever (body temperature $> 38^\circ\text{C}$ ) without any other suspected infection site
Bacteraemia	At least one positive blood culture collected during fever episode excepted for negative coagulase <i>Staphylococcus</i> , <i>Bacillus</i> sp., <i>Corynebacterium</i> sp., <i>Propionibacterium</i> sp., <i>Micrococcus</i> sp. For those micro-organisms, two positive blood cultures collected at different sites are required
Catheter-related infection	Positive blood culture (collected by a venous puncture) AND one of the following criteria: 1. Local infection AND identification of the same micro-organism in pus and peripheral blood 2. Positive culture of catheter AND identification of the same micro-organism in peripheral blood
Ventilator-associated pneumonia	Evolving radiological lung opacity AND identification of micro-organism in: 1. Tracheal aspirates through endotracheal tube with at least $10^6$ colonies forming unit/ml OR 2. Bronchial-alveolar lavage with at least $10^4$ colonies forming unit/ml OR 3. Protected brush with at least $10^3$ colonies forming unit/ml OR 4. Collection of abscess or pleural fluid
Intra-abdominal infection	Pus or abscess collected during surgery OR positive blood culture collected at the onset of disease



**Appendix A (Continued)**

Site	Criteria for diagnosis
Tissue or skin infection	Presence of at least two of the following signs: Local pain, tumefaction, local heat, sensibility, redness AND at least one of the following signs: 1. Positive culture of micro-organism collected at the suspected site 2. Micro-organism identified in blood culture

**Appendix B. Effect of matching on standardized difference.****Standardized differences before matching****Standardized differences after matching****References**

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