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ORIGINAL ARTICLE

24-hour limit: development of a calculator to estimate mortality attributable to delayed admission from the emergency department in patients older than 75 years

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Objectives. Prolonged waiting time for hospital admission from emergency departments (boarding) has been consistently associated with increased in-hospital mortality, particularly among older patients. However, translating this increase in relative risk into a specific population-level clinical impact remains limited, hindering its incorporation into organizational decision-making.

Objective. To develop a clinical impact calculator aimed at estimating the number of potentially preventable in-hospital deaths associated with reducing emergency department stays exceeding 24 hours in patients aged 75 years or older.

Methods. We developed a conceptual model based on hospital structural and health care delivery data and risk estimates derived from the scientific literature. Exposure was defined as waiting > 24 hours for hospital admission. Impact was estimated by calculating the attributable fraction among exposed individuals, applying different exposure-reduction scenarios and performing sensitivity analyses.

Results. The calculator enables transformation of relative risks derived from observational studies and meta-analyses into absolute estimates of potentially preventable deaths, expressed as monthly or annual periods. The estimated number of potentially preventable deaths was approximately 124 annual cases in the baseline scenario (RR, 1.3), reaching approximately 239 cases in higher-vulnerability scenarios (RR, 1.8). Although based on aggregated real-world data, these figures should be interpreted as population-level estimates derived from a model and do not constitute causal clinical validation. The model allows estimation of the impact of reducing the proportion of patients remaining in emergency departments for more than 24 hours on in-hospital mortality.

Conclusions. Reducing prolonged waiting times for hospital admission from emergency departments could prevent a substantial number of in-hospital deaths among older patients. The developed tool facilitates consideration of the 24-hour limit as a patient safety standard and supports implementation of organizational strategies aimed at minimizing boarding.

Keywords: Emergency departments. Boarding. In-hospital mortality. Patient safety. Older patients. Healthcare management.

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Límite 24 horas: desarrollo de una calculadora que estima la mortalidad atribuible al retraso para ingresar desde urgencias en pacientes de 75 años o más

Objetivo. La espera prolongada para el ingreso hospitalario desde los servicios de urgencias *(boarding)* se asocia con un aumento de la mortalidad intrahospitalaria, especialmente en pacientes de edad avanzada. Sin embargo, su impacto clínico poblacional se desconoce, lo que dificulta su incorporación en la toma de decisiones organizativas. Se desarrolla una calculadora de impacto clínico destinada a estimar el número de muertes intrahospitalarias potencialmente evitables asociadas a la reducción de estancias en urgencias superiores a 24 horas en pacientes de 75 años o más.

Métodos. Se desarrolló un modelo conceptual basado en datos estructurales y asistenciales del hospital y en estimaciones de riesgo procedentes de la literatura científica. La exposición se definió como la espera para ingreso hospitalario superior a 24 horas. El impacto se estimó mediante el cálculo de la fracción atribuible en expuestos, aplicando distintos escenarios de reducción de la exposición y realizando análisis de sensibilidad.

Resultados. La calculadora permite transformar riesgos relativos procedentes de estudios observacionales y metanálisis en estimaciones absolutas de muertes potencialmente evitables, expresadas en periodos mensuales o anuales. Esta estimación se situó en torno a 124 casos anuales en el escenario base (RR 1,3) y a 239 casos en escenarios de mayor vulnerabilidad (RR 1,8). Estas cifras, aunque basadas en datos reales agregados, deben interpretarse como estimaciones poblacionales derivadas de un modelo y no constituyen una validación clínica causal. El modelo permite estimar el impacto de reducir las estancias superiores a 24 horas en urgencias sobre la mortalidad intrahospitalaria.

Conclusiones. La reducción de la espera prolongada de ingreso hospitalario desde los servicios de urgencias podría

evitar un número significativo de muertes intrahospitalarias en pacientes de edad avanzada. La herramienta desarrollada facilita considerar el límite de 24 horas como un estándar de seguridad del paciente y apoya la adopción de estrategias organizativas orientadas a minimizar el *boarding*.

Palabras clave: Urgencias hospitalarias. *Boarding.* Mortalidad intrahospitalaria. Seguridad del paciente. Pacientes ancianos. Gestión sanitaria.

Introduction

The sustained increase in health care demand in emergency departments (EDs) has turned overload and overcrowding into a structural phenomenon. One of its most relevant signs is prolonged waiting for hospital admission (boarding, or prolonged stay in the ED), which in Spain can frequently exceed 24 hours. This situation not only affects quality of care and patient experience, but has consistently been associated with increased morbidity and in-hospital mortality.[1-7]

Despite the abundant available evidence, a gap persists between the identification of increased relative risk in population-based studies and the ability to estimate its actual clinical impact in terms of potentially avoidable adverse events. This difficulty in quantifying the effect of boarding limits the use of scientific evidence in organisational decision-making and contributes to the problem being perceived as an issue of efficiency rather than one of patient safety.[8-11] The absence of clear time standards for the maximum permissible waiting time in the ED, such as a 24-hour limit, contributes to this situation.[12-14]

The objective of this study was to develop and conceptually validate a clinical impact calculator designed to estimate the number of potentially avoidable in-hospital deaths associated with reducing the waiting time for hospital admission from the ED. By translating epidemiological evidence into metrics that are understandable and applicable to operational decision-making, the aim is to facilitate data-driven decision-making and reinforce the recognition of prolonged waiting as a relevant determinant of patient safety.[15-19] This is a conceptual modelling study, without the use of individual patient data, aimed at translating published relative risks into absolute estimates applicable to health care planning. The final tool developed is freely available for use and adaptation at the following link: https://med-calc-interactive.lovable.app/ (Figure 1).

Methods

We conducted a theoretical estimation modelling study; that is, a theoretical simulation estimating how many deaths would have been avoided if the exposure (waiting > 24 hours) had not occurred, while keeping all other care conditions constant. The model, applicable to general hospitals within the Spanish National Health System, uses routinely available health care variables and translates the relative risk described in the literature into a quantifiable population impact, expressed as potentially avoidable deaths. Exposure was defined as prolonged waiting for hospital admission from the ED (boarding), distinguishing patients according to whether they exceeded 24 hours from the decision to admit.[1-6,15]

The estimated number of potentially attributable deaths was calculated using the following expression: Attributable deaths = N exposed × Observed mortality × AFE, where AFE = (RR – 1) / RR and N exposed corresponds to the number of patients aged 75 years or older with an ED stay > 24 hours.

For application of the model, real aggregated data were used from patients aged 75 years or older with an indication for hospital admission from the ED of a tertiary referral center over a 1-year period. The cohort included a total of 8,439 patients, of whom 4,064 remained in the ED for more than 24 hours awaiting a bed. Because mortality stratified according to exposure was unavailable, the overall mortality observed in the cohort (13.2%) was used as a conservative approximation. These estimates should be interpreted as attributable at the population level and not as causal relationships at the individual level.

The model integrates structural and health care-related hospital data, local clinical parameters, and effect estimates derived from the international scientific literature, a detailed description of which is provided in Table 1. Hospital data include information routinely available in institutional reports and clinical information systems, whereas effect parameters are based on adjusted relative risks or odds ratios describing the association between prolonged ED waiting and in-hospital mortality. The relative risks incorporated were derived from adjusted observational studies and meta-analyses published between 2011 and 2025, prioritising older populations, critically ill patients, or cohorts with multivariable analyses of in-hospital mortality.[1-7] (Table 1). Different risk scenarios were defined, using a relative risk in the range of 1.3-1.4 as the baseline scenario and values close to 1.8 as the higher-vulnerability scenario used for sensitivity analyses. Impact was estimated by calculating the attributable fraction among exposed patients,[20-22] applied to the observed mortality in patients with prolonged waiting, modelling different degrees of exposure reduction. Finally, sensitivity analyses were performed by varying the main model parameters and presenting the results as estimates of potential impact.

The model does not incorporate formal probabilistic simulation or complete mathematical propagation of uncertainty; therefore, the estimates should be interpreted as indicative ranges dependent on the selected relative risks. These could vary between more conserva-

CLINICAL IMPACT CALCULATOR IN PATIENTS AGED ≥ 75 YEARS

A. ACTUAL HOSPITAL DATA (COHORT)		
Patients aged ≥ 75 years with an indication for admission/year 8,439	Patients aged ≥ 75 years with a stay > 24 h 4,064	Deceased patients aged ≥ 75 years 1,113
Relative risk (RR): 1.3		
B. ORGANISATIONAL SCENARIO		
Reduction in exposure (> 24 h): 50%		
C. RESULTS OF THE MODEL APPLIED TO ACTUAL DATA		
Patients aged ≥ 75 years/year 8,439	Exposed patients (> 24 h) 4,064	Observed mortality 13.19%
Deaths among exposed patients/year 536.0	Attributable fraction among exposed patients (AFe) 23.1%	Attributable deaths/year 123.7
Potentially avoidable deaths/year: 61.8		
D. MODEL FORMULAS		
AFe = (RR – 1)/RR	Attributable deaths = N exposed × Observed mortality × AFe	Avoidable deaths = Attributable deaths × Reduction in exposure

Figure 1. Clinical impact calculator «24-hour Limit». Conceptual model estimating potentially avoidable in-hospital deaths by reducing ED stays > 24 hours in patients aged ≥ 75 years, integrating health care and epidemiological data to simulate the effect of organisational improvements. Example of the entry of real data from a tertiary-care hospital. The selected relative risk values were based on the consistency of the included studies, prioritising recent meta-analyses and adjusted observational cohorts involving older or critically ill populations. The baseline scenario (RR, 1.3-1.4) was defined on the basis of the predominant literature, whereas the higher-vulnerability scenario (RR, approximately 1.8) was reserved for sensitivity analyses and situations of high clinical frailty.

tive scenarios and higher-risk scenarios, while remaining within clinically relevant margins. No individual data were used, and no direct comparisons were made between exposed and unexposed patients at the individual level.

Because this was a conceptual development without the use of individual patient data, and following consultation with the Ethics Committee, approval by the Committee was not required.

Results

The clinical impact calculator was conceptually designed to generate an estimate of the number of potentially avoidable in-hospital deaths. This estimate was obtained by projecting a reduction in waiting times for hospital admission from the ED below the 24-hour threshold, based on data from each hospital using the tool and on epidemiological evidence regarding relative risk.[12-16]

When the model was applied to a real cohort of patients aged 75 years or older with an indication for hospital admission from the ED (n = 8,439), of whom 4,064 remained for more than 24 hours awaiting a bed, and using an observed overall mortality rate of 13.2% as a conservative approximation, the estimated number of potentially avoidable deaths was 124 in the baseline scenario with an RR of 1.3, 153 with an RR of 1.4, and 239 in the higher-vulnerability scenario (RR, 1.8).

The main output of the calculator is a figure quantifying the impact in terms of potentially avoidable deaths over a given period (eg, per month or per year) if the proportion of patients waiting more than 24 hours for admission could be reduced. This result is presented intuitively, transforming abstract relative risks, which are often difficult for non-epidemiologists to interpret, into a specific number of events with a direct and understandable impact on the population served by the hospital. Under exposure-reduction scenarios of 25%, 50%, and 75%, the estimated impact showed a progressive and relatively proportional reduction in potentially avoidable deaths, with values ranging from 31 to 124 for an RR of 1.3, from 38 to 153 for an RR of 1.4, and from 60 to 239 for an RR of 1.8, reinforcing the practical usefulness of the tool in organisational planning (Table 3).

The tool enables relative risks to be translated into absolute estimates of potentially avoidable deaths, thereby facilitating their clinical interpretation and application to health care planning.

Table 1. Parameters used in the modelling

Parameter	Bibliographic source	Baseline value	Interpretation/Scenario
Relative risk (RR) of mortality with boarding > 24 h	Lauque D *et al.*, J Clin Med 2022[1]	1.22 (0.85-1.74)	Overall meta-analysis
Relative increase in mortality with stay ≥ 12 h	Miró Ò, EUSEM 2025[24]	+19% (1-42%)	Recent European estimate
Increase with prolonged boarding (> 8 h)	Huang KW *et al.*, Postgrad Med J 2023[5]	+21% (10-33%)	Critically ill patients
Exposed population (waiting > 24 h)	Local hospital data	10-40%	Adjustable parameter
Observed mortality	Local hospital data	5-15%	Baseline parameter
Attributable fraction among exposed patients	Rockhill B, 1998; Benichou J, 2001[21,22]	Calculated	Estimate of potentially avoidable deaths

Discussion

Reducing waiting time for hospital admission from the ED, particularly when it exceeds 24 hours, could have a clinically relevant impact on in-hospital mortality, especially among older patients.[3-7,12,23] Even under conservative assumptions, the results highlight that time spent in the ED after the decision to admit constitutes a relevant determinant of patient safety. The literature appears to indicate that a clear time limit, such as 24 hours, can be interpreted as a patient-safety standard.[15,22]

The proposed model allows the increase in relative risk described in the literature to be translated into a quantifiable population impact, facilitating its application to organisational decision-making. Applying the model to real aggregated data reinforces its practical usefulness and provides an approximation of the magnitude of the problem within a specific health care context, while preserving the population-level nature of the estimates.

The greater estimated impact in vulnerability scenarios is consistent with previous evidence identifying patients older than 75 years as particularly susceptible to prolonged waiting for hospital admission.[3,7,17] In line with the review presented by Miró *et al.* at the European Congress of Emergency Medicine (EUSEM 2025, Vienna, Austria),[21] the results support the hypothesis that the relationship between waiting time and mortality may not be linear.

The main value of this study is the development of an adaptable tool that translates epidemiological evidence into a metric applicable to operational decision-making, supporting the consideration of boarding as a determinant of patient safety.[15,22] Nevertheless, this is a theoretical model based on risk estimates derived from heterogeneous literature, and the results should therefore be interpreted as population-level estimates rather than individual predictions.

Among the limitations, the absence of mortality stratified according to exposure necessitated the use of overall mortality as a conservative approximation, reinforcing the indicative nature of the estimates. The possibility of publication or selection bias in the source studies should also be considered, as this could influence the estimated impact. Finally, the adaptability of the model allows its application across different hospital settings, facilitating health care planning. However, data from only a single centre are presented. Future prospective studies will be required to assess the actual effect of these strategies.

In conclusion, prolonged waiting for hospital admission from the ED is associated with an increased risk of in-hospital mortality, particularly among older patients. The modelling presented indicates that reducing this waiting time through a policy of admission within 24 hours could prevent a clinically relevant number of deaths, even under conservative assumptions. These results support consideration of the 24-hour limit as a patient-safety standard rather than merely an organisa-

Table 2. Definition and meaning of the parameters of the "24-hour Limit" calculator

Field/Parameter	Description (explanatory legend)	Type/Range of values
Beds	Total number of available hospital beds.	Integer (> 0).
Occupancy (0-1)	Mean proportion of occupied beds (0 = empty, 1 = 100%).	Decimal (0-1).
Mean length of stay (days)	Mean number of hospitalisation days per episode.	Integer or decimal (> 0).
% admissions from the ED (0-1)	Proportion of hospital admissions originating from the emergency department.	Decimal (0-1).
% aged ≥ 75 among admissions from the ED (0-1)	Proportion of patients aged ≥ 75 years among admissions originating from the ED.	Decimal (0-1).
% currently exposed (> 24 h in the ED) (0-1)	Proportion of patients aged ≥ 75 years who currently remain > 24 h in the ED before admission.	Decimal (0-1).
In-hospital mortality among exposed patients (0-1)	Proportion of deaths among exposed patients (> 24 h in the ED).	Decimal (0-1).
RR of mortality associated with exposure	RR of in-hospital mortality in exposed vs unexposed patients, according to the literature.	Decimal (> 1 if there is increased risk).
% reduction in exposure (0-1)	Expected proportion of reduction in exposure after implementation of an organisational measure.	Decimal (0-1).
Results (avoidable deaths/year, month)	Estimates derived from the model according to the parameters entered.	Calculated output.
AFE (attributable fraction among exposed patients)	Proportion of risk in the exposed group attributable to the exposure (> 24 h).	Calculated: (RR – 1)/RR.
What do RR and "attributable deaths" mean?	Explanatory text in the lower help panel.	—

RR: relative risk.

Table 3. Scenarios of reduced exposure to stays > 24 hours and potentially avoidable deaths (PADs) in patients aged ≥ 75 years

Scenario	PADs	Deaths avoided according to reduction in boarding			
		–25%	–50%	–75%	–100%
RR 1.3	124	31	62	93	124
RR 1.4	153	38	77	115	153
RR 1.8	239	60	120	179	239

tional target and reinforce the need for structural strategies aimed at minimising boarding in EDs. The calculator should be interpreted as a tool to support population-level planning and quality-improvement projects, without direct causal or individual applicability, and future multicentre validation will be required before it can be adopted as a formal standard.

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