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Age-standardisation of emergency department triage vital signs: does it improve discrimination of clinical outcomes?

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Age-standardisation of emergency department triage vital signs: does it improve discrimination of clinical outcomes?

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Abstract

Background: Vital signs are fundamental to emergency department (ED) triage; however, physiological values vary with age. We evaluated whether age-standardisation of routinely collected triage vital signs improves discrimination of in-hospital mortality, hospital admission, and intensive care unit (ICU) admission.

Methods: This retrospective cohort study included consecutive adult ED presentations to a tertiary referral hospital in Australia between March 2018 and March 2021. Generalised additive models were used to derive age-standardised Z-scores for heart rate, respiratory rate, systolic and diastolic blood pressure, pulse oximetry, and body temperature. Multivariable logistic regression models incorporating age-standardised or raw vital signs were compared using the area under the receiver operating characteristic curve (AUC) and DeLong's test.

Results: Among 116,781 ED presentations, 43,377 had complete data and were included in the complete-case analyses. Age-standardised vital signs were independently associated with in-hospital mortality, hospital admission, and ICU admission. Models incorporating physiological variables demonstrated better discrimination than models incorporating age and sex alone. However, Age-standardisation provided little incremental discriminatory value beyond raw vital signs. For mortality, the AUC was 0.853 for the age-standardised model versus 0.852 for the raw vital-sign model (DeLong P = .0004). Similar findings were observed for hospital admission (AUC, 0.686 vs. 0.686; P = .200) and ICU admission (AUC, 0.756 vs. 0.756; P = .758).

Conclusions: Age-standardised vital signs were independently associated with adverse clinical outcomes. Age-standardisation produced a statistically significant but very small improvement in discrimination for mortality, but did not improve discrimination for hospital or ICU admission. The magnitude of the mortality improvement was minimal, suggesting limited incremental discriminatory value beyond raw physiological measurements.

Keywords: emergency department; triage; vital signs; age-standardisation; mortality; hospital admission; intensive care unit.

Introduction

Emergency department (ED) triage aims to rapidly identify patients at risk of clinical deterioration and prioritise timely assessment and treatment. Initial triage decisions rely heavily on routinely recorded vital signs, including heart rate, respiratory rate, blood pressure, pulse oximetry, and body temperature, together with the presenting complaint. Abnormal vital signs have consistently been associated with adverse outcomes, including hospital admission, intensive care unit (ICU) admission, and mortality, making them fundamental components of early risk stratification in emergency care [1–5].

Several triage systems, including the Emergency Severity Index (ESI) [6], the Manchester Triage System (MTS) [7], and the Rapid Emergency Triage and Treatment System (RETTS) [8], incorporate vital signs into their assessment algorithms. However, these systems generally apply physiological thresholds across broad adult populations, with limited consideration of age-related physiological variation. Consequently, patients with identical vital sign measurements may have different baseline physiological states and clinical risk depending on their age [9].

Ageing is associated with progressive physiological changes affecting cardiovascular, respiratory, and autonomic function [10]. Resting heart rate, blood pressure, respiratory physiology, and oxygenation may vary across adulthood, independent of acute illness. Older adults may also present atypically with serious illness, increasing the potential for under-recognition when fixed physiological thresholds are applied [11,12]. Previous research has suggested that conventional triage systems may perform less effectively in older adults, highlighting the potential value of approaches that account for age-related physiological differences.

The prognostic value of individual vital signs may also vary according to patient age and clinical context. In haemorrhagic shock, for example, systolic blood pressure may remain within the normal range during the early stages because compensatory mechanisms, including increased heart rate and peripheral vasoconstriction, maintain perfusion despite substantial blood loss. Hypotension may therefore develop only after considerable blood volume loss, limiting the

sensitivity of conventional systolic blood pressure thresholds for early recognition of shock [13,14]. Similar limitations may contribute to the underestimation of illness severity in older adults with trauma or suspected infection. In addition, altered consciousness and reduced peripheral oxygen saturation have been identified as predictors of short-term mortality following ED presentation [15].

One potential approach is to interpret physiological measurements relative to the expected distribution for an individual's age rather than relying on absolute values alone. Age-standardisation provides a framework for expressing each vital sign as a deviation from its age-specific expected value, thereby accounting for age-related physiological variation while retaining information about clinically important abnormalities.

The aim of this study was to develop age-specific expected values for routinely measured ED triage vital signs and to evaluate whether age-standardised physiological measurements improve discrimination of in-hospital mortality, hospital admission, and ICU admission compared with raw, unadjusted vital signs.

METHODS

Study Design and Setting

This retrospective observational cohort study used routinely collected electronic health record data from the Emergency Department of Liverpool Hospital, a tertiary referral and teaching hospital in South Western Sydney, Australia. Consecutive eligible adult emergency department presentations between March 2018 and March 2021 were included. Data were extracted from the Cerner electronic medical record via the Comprehensive Epidemiological Dataset for Research, Innovation and Collaboration (CEDRIC) [16].

Consent to Participate

The requirement for individual informed consent was waived by the South Western Sydney Local Health District Human Research Ethics Committee, as the study involved the secondary analysis of routinely collected, de-identified electronic health record data.

Ethics

Ethics and governance approval were obtained from the South Western Sydney Local Health District Human Research Ethics Committee under the Low and Negligible Risk Pathway (LNR/17/LPOOL/234), approved on 15 January 2018. The study protocol was subsequently amended and approved by the Human Research Ethics Committee (LNR/17/LPOOL/432) and Site-Specific Assessment (LNRSSA/17/LPOOL/433) on 18 June 2019. As this study used routinely collected de-identified electronic health record data, the requirement for individual informed consent was waived. The study was conducted in accordance with the Declaration of Helsinki and applicable Australian ethical guidelines for human research.

Study Population

Eligible participants were adults (≥18 years) who presented to the Emergency Department between March 2018 and March 2021 and were assigned an Australasian Triage Scale (ATS) category of 2 or 3 with abnormal physiological findings. These categories were selected to capture patients with suspected time-critical illness while excluding immediate resuscitation cases (ATS 1) and lower-acuity presentations (ATS 4–5).

Patients were excluded if they were younger than 18 years, were not triaged or had an unknown triage category, required immediate ventilatory support or emergency surgery, were pregnant, or were deceased on arrival. Records with missing age or mortality data, implausible physiological measurements (systolic blood pressure >300 mmHg, diastolic blood pressure >200 mmHg, heart rate >300 beats/min, respiratory rate >80 breaths/min, or pulse oximetry >100%), or other data inconsistencies were excluded. Patients who could not be followed through the Australian population registry (e.g., non-permanent residents) were also excluded because outcome data were unavailable.

Of the eligible presentations, records with complete data for age, sex, and all six triage vital signs were included in the complete-case analytical cohort. Multivariable analyses were performed using complete-case analysis without imputation of missing values.

Data Source and Measurements

Data were retrospectively extracted from the Cerner electronic medical record via CEDRIC. The dataset included demographic characteristics, triage information, routinely recorded physiological measurements, and clinical outcomes. The six triage vital signs evaluated were heart rate, respiratory rate, systolic blood pressure, diastolic blood pressure, pulse oximetry, and body temperature.

Study Variables and Outcomes

Baseline variables included age and sex. Physiological variables comprised the six triage vital signs: heart rate, respiratory rate, systolic blood pressure, diastolic blood pressure, pulse oximetry, and body temperature. The prespecified clinical outcomes were in-hospital mortality, hospital admission, and intensive care unit (ICU) admission.

Age-standardisation of Vital Signs

Generalised additive models (GAMs) were fitted separately for each of the six vital signs, with age specified as the predictor. Age-specific expected values were obtained from the fitted models. For each vital sign, residuals were calculated as the difference between the observed measurement and its age-specific expected value. Residuals were then standardised using the residual standard deviation to generate age-standardised Z-scores (AgeZ). Positive and negative AgeZ values represented measurements above and below the age-specific expected value, respectively.

Statistical Analysis

Continuous variables were summarised using means and standard deviations or medians and interquartile ranges, as appropriate, and categorical variables using frequencies and percentages. Multivariable analyses were restricted to presentations with complete data for age, sex, and all six triage vital signs. No imputation was performed for missing values.

Three multivariable logistic regression models were constructed separately for each prespecified outcome: in-hospital mortality, hospital admission, and ICU admission. The baseline model included age and sex. The raw vital-sign model included age, sex, and the six raw triage vital signs. The age-standardised model included age, sex, and the six corresponding AgeZ variables.

Adjusted odds ratios (ORs) with 95% confidence intervals (CIs) were calculated to quantify associations between model variables and each outcome. Model discrimination was assessed using the area under the receiver operating characteristic curve (AUC), with 95% CIs. Correlated AUCs were compared using DeLong's test. Comparisons were performed between the baseline and raw vital-sign models and between the raw and age-standardised models. A two-sided p value <0.05 was considered statistically significant.

All statistical analyses were performed using R version 4.5.1 (R Foundation for Statistical Computing, Vienna, Austria) [17]. Analyses used the tidyverse, mgcv, pROC, gtsummary, rms, caret, and flextable packages.

Potential sources of bias included selection bias arising from incomplete physiological measurements and the use of complete-case analysis. Measurement-related bias was addressed by applying prespecified physiological plausibility thresholds consistently across the study population. Potential confounding was addressed by including age and sex in all multivariable models.

Reporting Guideline

This study was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [18].

No external funding was received for this study, and no funder had a role in the study design, data analysis, interpretation of results, manuscript preparation, or decision to submit the manuscript.

RESULTS

Study Population

A total of 116,781 emergency department presentations met the eligibility criteria. Complete measurements for all six vital signs were available for 43,384 presentations (37.2%). Seven of these presentations had missing sex information and were therefore excluded from the multivariable analyses, resulting in a final complete-case analytical cohort of 43,377 presentations (37.1%). Characteristics of the overall eligible cohort are presented in Table 1, and characteristics of the complete-case analytical cohort are presented in Supplementary Table S2.

Table 1. Characteristics of the overall eligible emergency department cohort (N = 116,781).

Characteristic	Value
Demographic characteristics	
Age, years	48 (32–63)
Female	57,353 (49.1%)
Male	59,417 (50.9%)
Triage vital signs	
Systolic blood pressure, mmHg	133 (120–148)
Diastolic blood pressure, mmHg	80 (72–88)
Heart rate, beats/min	87 (76–100)
Respiratory rate, breaths/min	18 (17–20)
Pulse oximetry, %	98 (97–99)
Temperature, °C	36.7 (36.4–37.0)
Arrival mode	
Walk-in	112,254 (96.1%)

Other	4,442 (3.8%)
Study outcomes	
Hospital admission	50,643 (43.4%)
ICU admission	726 (0.6%)
In-hospital mortality	7,323 (6.3%)
Clinical characteristics	
Charlson comorbidity present	16,824 (14.4%)
Presentation during COVID-19 period	61,962 (53.1%)
Trauma presentation	1,138 (1.0%)

Abbreviations: ICU, intensive care unit. Data are presented as median (interquartile range) for continuous variables and as counts (percentages) for categorical variables. Missing data were present for sex (n = 11), arrival mode (n = 85), systolic blood pressure (n = 48,693), diastolic blood pressure (n = 45,292), heart rate (n = 39,348), respiratory rate (n = 51,771), pulse oximetry (n = 39,663), and temperature (n = 56,452). Characteristics of the complete-case analytical cohort (n = 43,377) are presented in Supplementary Table S2.

Age-standardisation of Vital Signs

Generalised additive models were fitted separately for heart rate, respiratory rate, systolic blood pressure, diastolic blood pressure, pulse oximetry, and body temperature. Age-specific expected values and age-standardised Z-scores were generated for each physiological variable (Figure 1).

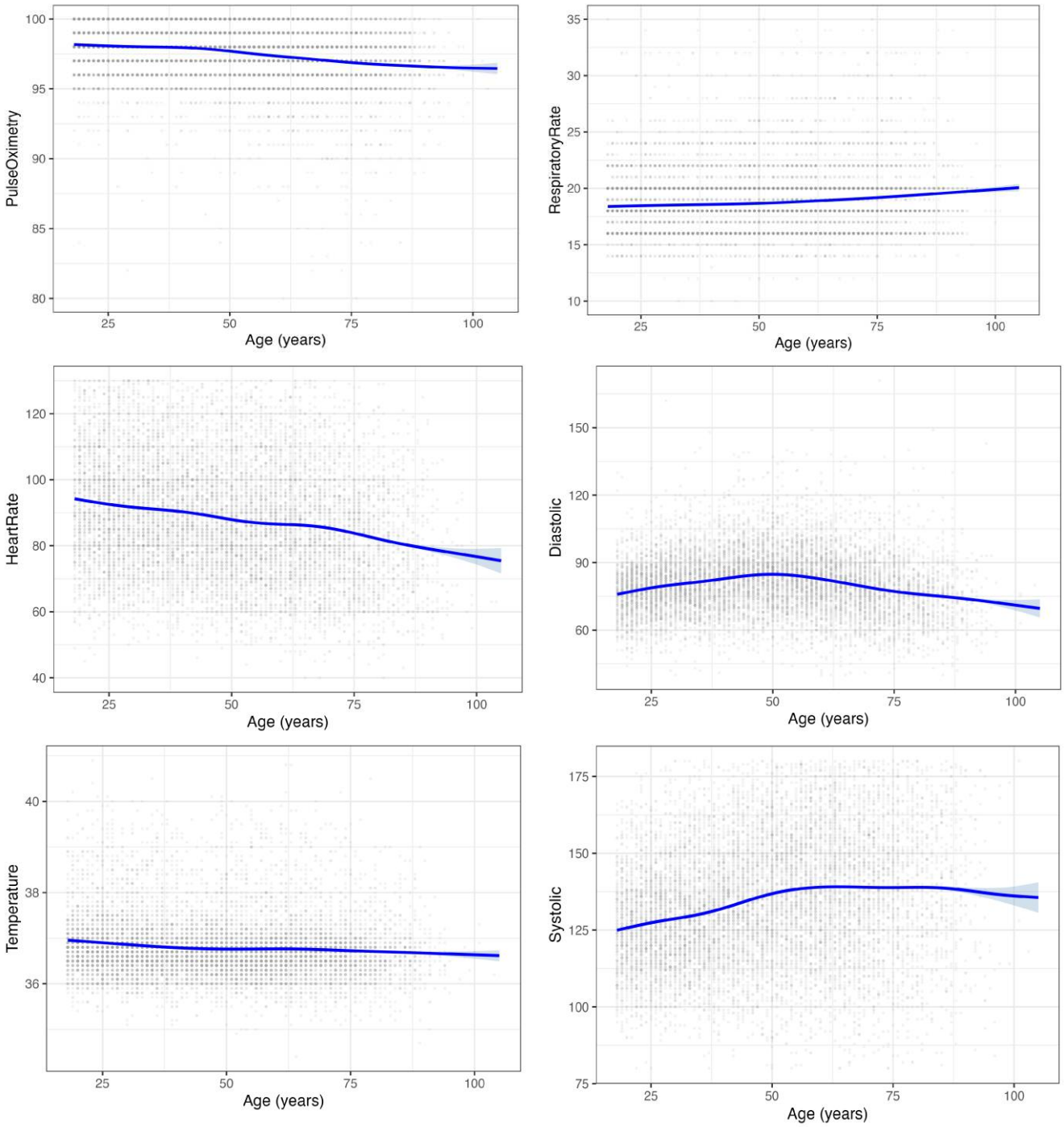


Figure 1: Generalised additive model (GAM) curves showing the age-specific expected values for heart rate, respiratory rate, systolic blood pressure, diastolic blood pressure, pulse oximetry, and body temperature. These fitted curves were used to derive age-standardised Z-scores for each physiological variable.

Multivariable Logistic Regression

Separate multivariable logistic regression models were fitted for mortality, hospital admission, and ICU admission. Adjusted odds ratios (ORs) with 95% confidence intervals (CIs) are presented in Tables 2–4.

Table 2. Multivariable logistic regression model for in-hospital mortality using age-standardised vital signs.

Characteristic	OR	95% CI	p-value
Age (per year)	1.07	1.07–1.07	<0.001
Sex			
Female (reference)	—	—	
Male	1.20	1.09–1.31	<0.001
Heart rate (AgeZ)	1.45	1.38–1.52	<0.001
Respiratory rate (AgeZ)	1.21	1.16–1.26	<0.001
Systolic blood pressure (AgeZ)	0.76	0.73–0.80	<0.001
Diastolic blood pressure (AgeZ)	0.72	0.67–0.77	<0.001
Pulse oximetry (AgeZ)	0.95	0.91–0.99	0.007
Temperature (AgeZ)	0.94	0.90–0.98	0.010

Abbreviations: OR, odds ratio; CI, confidence interval; AgeZ, age-standardised Z-score. ORs represent the change in odds of in-hospital mortality associated with a one-unit increase in the corresponding predictor.

Table 3: Multivariable logistic regression model for hospital admission using age-standardised vital signs

Characteristic	OR	95% CI	p-value
Age (per year)	1.03	1.03–1.03	<0.001
Sex			
Female (reference)	—	—	

Male	1.13	1.08–1.18	<0.001
Heart rate (AgeZ)	1.22	1.19–1.25	<0.001
Respiratory rate (AgeZ)	1.17	1.15–1.20	<0.001
Systolic blood pressure (AgeZ)	0.91	0.88–0.93	<0.001
Diastolic blood pressure (AgeZ)	0.92	0.89–0.94	<0.001
Pulse oximetry (AgeZ)	0.98	0.96–1.00	0.039
Temperature (AgeZ)	1.16	1.13–1.18	<0.001

224 Abbreviations: OR, odds ratio; CI, confidence interval; AgeZ, age-standardised Z-score.

225 Table 4: Multivariable logistic regression model for ICU admission using age-standardised vital signs

Characteristic	OR	95% CI	p-value
Age (per year)	1.02	1.01–1.03	<0.001
Sex			
Female (reference)	—	—	
Male	1.42	1.07–1.91	0.016
Heart rate (AgeZ)	1.32	1.14–1.53	<0.001
Respiratory rate (AgeZ)	1.28	1.14–1.43	<0.001
Systolic blood pressure (AgeZ)	0.62	0.52–0.74	<0.001
Diastolic blood pressure (AgeZ)	0.72	0.59–0.90	0.003
Pulse oximetry (AgeZ)	0.84	0.76–0.94	0.001
Temperature (AgeZ)	1.08	0.95–1.22	0.200

226 Abbreviations: OR, odds ratio; CI, confidence interval; AgeZ, age-standardised Z-score.

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Model Discrimination

The discrimination of the baseline, raw vital-sign, and age-standardised vital-sign models for each outcome is summarised in Table 5.

For in-hospital mortality, the baseline model had an AUC of 0.814 (95% CI, 0.807–0.821). The raw vital-sign model had an AUC of 0.852 (95% CI, 0.845–0.859), while the age-standardised model had an AUC of 0.853 (95% CI, 0.846–0.860).

For hospital admission, the baseline, raw vital-sign, and age-standardised models had AUCs of 0.660 (95% CI, 0.655–0.665), 0.686 (95% CI, 0.681–0.691), and 0.686 (95% CI, 0.681–0.691), respectively. For ICU admission, the baseline model had an AUC of 0.653 (95% CI, 0.617–0.689). The raw vital-sign model had an AUC of 0.756 (95% CI, 0.717–0.794), while the age-standardised model had an AUC of 0.756 (95% CI, 0.718–0.795).

Compared with the baseline model containing age and sex, incorporation of raw vital signs significantly improved discrimination for all three outcomes (all $P < 0.001$). The age-standardised model demonstrated a statistically significant but very small improvement in discrimination compared with the raw vital-sign model for in-hospital mortality (AUC, 0.853 vs. 0.852; DeLong $P = .0004$), whereas no significant improvement was observed for hospital admission ($P = .200$) or ICU admission ($P = .758$). Pairwise comparisons of ROC curves using DeLong's test are presented in Table 5. Receiver operating characteristic curves for all three outcomes are shown in Figure 2.

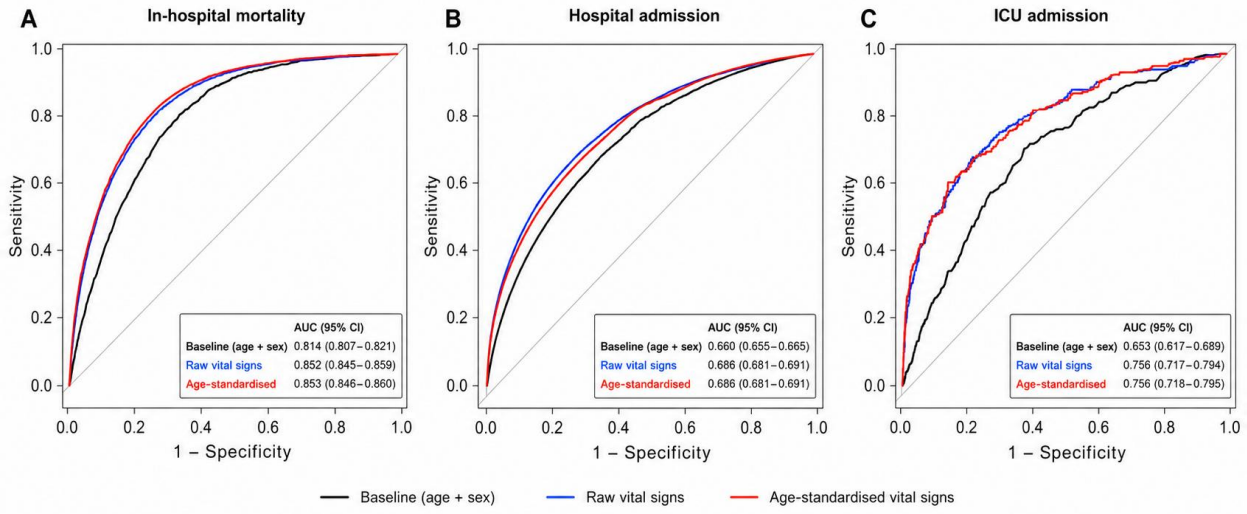
Table 5: Discriminative performance of baseline, raw vital sign and age-standardised vital sign models.

Outcome	Model	AUC (95% CI)	DeLong p-value*
Mortality	Baseline	0.814 (0.807–0.821)	—
	Raw	0.852 (0.845–0.859)	<0.001†
	Age-standardised	0.853 (0.846–0.860)	0.0004‡
Hospital admission	Baseline	0.660 (0.655–0.665)	—
	Raw	0.686 (0.681–0.691)	<0.001†

	Age-standardised	0.686 (0.681–0.691)	0.200
ICU admission	Baseline	0.653 (0.617–0.689)	—
	Raw	0.756 (0.717–0.794)	<0.001†
	Age-standardised	0.756 (0.718–0.795)	0.758‡

* DeLong's test compares correlated ROC curves., † Comparison of the raw vital sign model with the baseline model., ‡ Comparison of the age-standardised model with the raw vital sign model.

Figure 2. Receiver operating characteristic curves comparing baseline, raw vital-sign, and age-standardised vital-sign models.



ROC, receiver operating characteristic; AUC, area under the curve; CI, confidence interval; ICU, intensive care unit.
AUCs were compared using DeLong's test for correlated ROC curves.

Figure 2: Receiver operating characteristic (ROC) curves comparing baseline, raw vital-sign, and age-standardised vital-sign models for in-hospital mortality, hospital admission, and ICU admission.

Discussion

This study evaluated whether age-standardising routinely collected emergency department vital signs improves discrimination of in-hospital mortality, hospital admission, and intensive care unit (ICU) admission. In this large retrospective cohort of 116,781 emergency department presentations, models incorporating physiological variables demonstrated substantially better discrimination than models containing age and sex alone. Age-standardisation provided little incremental discriminatory value beyond raw vital signs. Although the age-standardised model demonstrated a statistically significant improvement in discrimination for mortality, the absolute difference in AUC was extremely small. No significant improvement was observed for hospital admission or ICU admission.

The rationale for age-standardising vital signs is based on the well-established observation that physiological values vary across adulthood [5,19–21]. Ageing is associated with progressive alterations in cardiovascular, respiratory, autonomic, and thermoregulatory function that may reduce physiological reserve and modify responses to acute illness [22–27]. Consequently, identical vital-sign measurements may represent different physiological states and levels of clinical risk in younger and older adults [9]. By expressing each physiological measurement relative to its age-specific expected value, we hypothesised that age-standardisation would improve identification of abnormal physiology and, consequently, discrimination of adverse clinical outcomes.

Contrary to our hypothesis, age-standardisation provided minimal incremental discrimination beyond models using raw vital signs. For mortality, the age-standardised model had an AUC of 0.853 compared with 0.852 for the raw vital-sign model. Although this difference was statistically significant (DeLong P = .0004), the absolute increase in AUC was only 0.0008. For hospital admission and ICU admission, the corresponding AUCs were essentially identical and the differences were not statistically significant. These findings suggest that routinely collected vital signs already capture most of the outcome-related discriminatory information represented by the age-standardised measurements and that transformation into age-standardised Z-scores provides limited additional discriminatory value in this cohort.

Although age-standardisation did not improve overall model discrimination, the age-standardised physiological variables remained independently associated with all three clinical outcomes after adjustment for age and sex. Heart rate, respiratory rate, systolic blood pressure, diastolic blood pressure, and pulse oximetry were associated with mortality, hospital admission, and ICU admission, while body temperature was associated with mortality and hospital admission but not ICU admission. These findings indicate that age-standardised physiological measurements retain associations with adverse outcomes; however, the lack of improvement in AUC suggests that these transformed measurements do not provide meaningful incremental discrimination beyond the corresponding raw measurements in this cohort.

Age remained independently associated with all three outcomes, consistent with previous studies demonstrating associations between increasing age and mortality, hospital admission, and critical illness among emergency department patients [28,29]. Older adults experience reduced physiological reserve, increased frailty, and a greater burden of chronic disease, all of which may contribute to poorer outcomes following acute illness [22–25]. Age-related physiological changes may also influence the interpretation of vital signs, as older patients can exhibit attenuated cardiovascular and respiratory responses to physiological stress. In addition, older adults are more likely to have multiple comorbidities and use medications that modify physiological responses, further complicating interpretation of vital signs [26]. Consequently, clinically important illness may not always be accompanied by marked abnormalities in conventional physiological measurements, potentially contributing to under-triage among older adults.

Several emergency triage systems, including the Emergency Severity Index (ESI), Canadian Triage and Acuity Scale (CTAS), Australasian Triage Scale (ATS), and Manchester Triage System (MTS), incorporate age either directly or indirectly when assessing patient risk [6,30–32]. Previous studies have reported that age adjustment of triage systems may modestly improve discrimination or prediction of mortality and hospital admission among older adults [33,34], although improvements for ICU admission have been less consistent [34]. Our findings provide a complementary perspective: although age-standardised physiological variables were independently associated with adverse outcomes, accounting for age-related physiological

variation in the vital signs themselves did not improve overall model discrimination compared with conventional vital signs. This suggests that the relationship between age and adverse outcomes is unlikely to be fully captured by physiological measurements alone and may also reflect factors such as frailty, multimorbidity, functional status, and pre-existing chronic disease.

Our findings should not be interpreted as evidence that age-standardisation has no potential clinical value. Rather, they indicate that, in this cohort, age-standardised vital signs performed similarly to raw physiological measurements in terms of discrimination. Age-standardisation may nevertheless provide an alternative framework for representing physiological abnormalities across age groups. Whether this representation offers advantages in other applications, such as clinical decision-support systems or externally validated prediction models, remains uncertain. Future studies should determine whether age-standardisation provides additional value in specific patient populations, different healthcare settings, or models incorporating broader clinical information, including frailty and comorbidity measures.

This study has several strengths, including its large sample size, use of routinely collected emergency department data, and application of generalised additive models to derive age-specific expected physiological values. Model performance was evaluated using multivariable logistic regression, ROC analysis, AUCs, and DeLong's test, allowing direct comparison of discrimination between raw and age-standardised approaches.

Several limitations should be acknowledged. First, this was a retrospective single-centre study, which may limit the generalisability of the findings to other emergency departments and healthcare systems. Second, complete-case analysis was used for the multivariable models, resulting in the exclusion of presentations with incomplete data. The extent of missing data and characteristics of complete and incomplete cases are presented in Supplementary Tables S1 and S2. Third, external validation was not performed; therefore, the findings should be confirmed in independent emergency department populations before conclusions about broader clinical applicability are drawn.

Conclusion

In this large retrospective cohort of emergency department patients, age-standardised vital signs were independently associated with in-hospital mortality, hospital admission, and ICU admission. Models incorporating physiological variables demonstrated substantially better discrimination than models containing age and sex alone. Age-standardisation produced a statistically significant but very small improvement in discrimination for mortality, while providing no significant improvement for hospital or ICU admission. Overall, age-standardisation offered limited incremental discriminatory value beyond raw triage vital signs in this setting.

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