

High Early Mortality in Patients With *Staphylococcus aureus* Bloodstream Infection: A Call for Action

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Abstract

Objectives: More than half of all deaths within one month of identification of *Staphylococcus aureus* bloodstream infection (SABI) occur within seven days of the first positive culture. However, there has not been a specific evaluation of studies of early mortality in patients with SABI. The objectives were to analyze studies that reported the seven-day all-cause mortality rate in patients with SABI and risk factors for this outcome. We also hypothesized that studies of gram-negative bloodstream infection (GNBI) or all episodes of BI (gram-negative and gram-positive, including fungemia) that reported seven-day all-cause mortality might provide other methods for predicting this outcome.

Methods: Early mortality was defined as death within seven days following the first day blood cultures were positive. Of 751 studies of SABI reviewed, 23 reported seven-day all-cause mortality rates. Studies were categorized into three groups: those reporting data on all SABI, methicillin-susceptible SABI, or methicillin-resistant SABI alone. Four studies of SABI evaluated risk factors for early mortality. Of 545 studies of GNBI or all episodes of BI, six evaluated factors predictive of seven-day all-cause mortality.

Results: There was a significant difference in the mean seven-day all-cause mortality rate between the three groups with SABI. However, there was no significant difference between the three groups when the metric was the proportion of all deaths within the first 30 days following the first positive blood culture that occurred within the first seven days (early death proportion). Overall, the median early death proportion for 23 studies was 53% (interquartile range 49–57). Four studies reported risk factors for early mortality, but all had methodological limitations. Analysis of six studies of GNBI or all BI revealed that an acute severity of illness model (bloodstream infection mortality risk score) by itself accurately predicted seven-day all-cause mortality.

Conclusions: Concordance in the early death proportion in 23 studies suggests a distinct group of patients with SABI is at risk for early mortality. However, methodologically sound studies are needed to identify all factors (clinical, diagnostic, and pathogen) associated with early mortality to evaluate methods to potentially reduce mortality in this group. Acute severity of illness models should be evaluated for predicting early mortality in patients with SABI.

Introduction

In a systematic review and meta-analysis of studies of mortality due to *Staphylococcus aureus* bloodstream infection (SABI), half of all deaths within one month of identification of SABI occurred within seven days of the first positive culture.¹ Apart from the direct effect on patients, patients with early mortality due to SABI have had an impact on randomized controlled treatment trials of this infection because they have been excluded from these trials. This exclusion has resulted in lower mortality rates in treatment trials compared to observational studies of SABI that do not exclude the early mortality group.² The lower mortality rate in treatment trials may overestimate the treatment effect on mortality and influence how clinicians manage patients with SABI.²

Despite the high proportion of deaths in the first month following identification of SABI that occurs within seven days of the first positive blood culture,¹ there has not been a specific analysis of studies reporting early mortality and risk factors for this outcome. Therefore, the objective of this manuscript is to emphasize the high early mortality of *S. aureus* bloodstream infection by (a) identifying and analyzing studies of SABI that report data on early mortality and (b) evaluating those studies that specifically analyzed for factors associated with early mortality that may enable identification of those at risk for SABI at presentation and result in interventions to reduce early mortality.

Methods

There is no consensus regarding the definition of early mortality in patients with bloodstream infection. Based on the findings of Bai et al.,¹ the definition of early mortality for this study is mortality occurring within seven days of the date the first positive blood culture is obtained. References of two recent studies that, in combination, had 751 reports of SABI were reviewed to identify those that provided data on early mortality.^{1,3} Only studies that reported data on all episodes of SABI (methicillin-susceptible *S. aureus* [MSSA] plus methicillin-resistant *S. aureus* [MRSA]), MSSA BI alone, or MRSA BI alone and provided data on all-cause mortality at seven days or less and 30 days after the first positive blood culture were included in this review. Studies of SABI reporting mortality within seven days were excluded if they had fewer than 100 cases of SABI, only reported attributable mortality, were case-control studies or randomized controlled trials, evaluated specific treatment regimens for SABI, evaluated only selected patients with SABI (e.g., patients with intravenous catheter-associated SABI or pneumonia), included other organisms with SABI (polymicrobial infection), or were studies conducted during an outbreak of staphylococcal infection. Details of 27 excluded studies and reason for exclusion are listed in **Online Supplement Appendix S1**.

For studies included in this report the following information was extracted: last name of the first author, year of publication, study design, study years, country where the study was conducted, study objective, and mortality rates. For comparison purposes, studies were categorized into three groups: studies that evaluated all SABI, MSSA BI alone, or MRSA BI alone. Metrics for comparison of the three groups were the mean percentage of deaths in the study population that occurred within seven days of the first positive blood culture and the mean proportion of deaths within 30 days of the first positive blood culture that occurred in the first seven days

(referred to as the “early death proportion” in the remainder of this paper). Mean values were assessed using the Kruskal–Wallis test with a significance level of ≤ 0.05 . In the remainder of this paper the term “mortality” indicates all-cause mortality.

We hypothesized that studies of gram-negative bloodstream infection (GNBI) or all episodes of BI combined (gram-positive plus gram-negative BI) may also have evaluated risk factors for early mortality and might provide models useful in patients with SABI. We reviewed 545 studies of GNBI with or without gram-positive BI published between January 2000 and March 2021 utilized in a prior study³ to identify those that evaluated risk factors or models for seven-day all-cause mortality.

Results

Review of 751 studies of SABI identified 31 (4.1%) that met inclusion criteria and reported mortality rates between one and seven days after the first positive blood culture: two-day (N=5), three-day (N=3), and seven-day (N=23) mortality. The focus of this paper is the 23 studies reporting seven-day mortality rates. Information regarding studies reporting two-day and three-day mortality rates is provided in **Online Supplement Appendix S2**.

Studies of SABI that reported mortality rates within seven days of the first positive blood culture

Twenty-three studies reported seven-day mortality rates for SABI (**Online Supplement Appendix S3**).^{4,5,6,7-26} Two studies^{18,19} evaluated the same patient population, and only data from one of these studies¹⁸ is included in the remainder of the analysis of seven-day mortality rates. Fourteen studies evaluated all SABI,^{6,7,9-11,13,15,16,19,21-24,26} five evaluated MSSA BI alone,^{5,8,17,20,25} and three evaluated MRSA BI alone.^{4,12,14} Four studies of all SABI provided seven-day mortality data separately for MSSA and MRSA BI,^{7,9,13,18} and these data were added to the MSSA BI alone and MRSA BI alone groups in the statistical analysis below.

A comparison of the mean seven-day mortality rates and mean early death proportion for all SABI, MSSA BI only, and MRSA BI only is shown in **Table 1**. When the mean seven-day mortality rates for all three study groups were compared, there was a significant difference in the mean rates. The mean seven-day mortality rate for all SABI was significantly higher than for MSSA BI only and approached significance compared to MRSA BI only. The mean seven-day mortality rate for MRSA BI only was significantly higher than for MSSA BI only. However, for the metric mean early death proportion there was no significant difference in any of the group comparisons. The overall median early death proportion was 53% (interquartile range 49–57).

Studies of risk factors for seven-day mortality in patients with S. aureus bloodstream infection

Four studies reported risk factors for seven-day mortality in patients with SABI,^{14,18,19,26} and the results of the multivariate analyses are listed in **Table 2**. In the population-based study of MRSA BI, female sex was a risk factor for seven-day mortality and age was a strong predictor of seven-day mortality.¹⁴ The risk of death at seven days was almost fourfold higher in those 85 and older compared to the reference group (age 35–44). A major limitation of this study is the absence of clinical information for

Table 1. Mean Seven-Day All-Cause Mortality Rates and Early Death Proportion^a in Patients With *S. aureus* Bloodstream Infection (SABI) by Organism Group

	MSSA and MRSA	MSSA Alone ^b	MRSA Alone ^b
No. of studies	14	9	7
Mean 7-day mortality rate ± SD	10.3 ± 2.4	7.7 ± 2.1	14.3 ± 6.4
Mean early death proportion ± SD	53.3 ± 5.4	49 ± 9	55.7 ± 11.3

MSSA=methicillin-susceptible *S. aureus*; MRSA=methicillin-resistant *S. aureus*; SD=standard deviation; IQR=interquartile range
^aEarly death proportion=proportion of all deaths within 30 days of the first positive blood culture that occurred in the first seven days.
^bFour studies of all SABI (MSSA plus MRSA)^{8,10,14,18} provided data separately for MSSA and MRSA BI and were added to the data for MSSA Alone and MRSA Alone.

Statistical analysis (Kruskal–Wallis test):	
Mean 7-day mortality rate:	
MSSA and MRSA vs MSSA alone vs MRSA alone	(H[2]=9.39, p=0.009)
MSSA and MRSA vs MSSA alone	(H[1]=5.88, p=0.02)
MSSA and MRSA vs MRSA alone	(H[1]=3.62, p=0.06)
MSSA alone vs MRSA alone	(H[1]=5.18, p=0.02)
Mean early death proportion:	
MSSA and MRSA vs MSSA alone vs MRSA alone	(H[2]=3.11, p=0.21)
MSSA and MRSA vs MSSA alone	(H[1]=2.19, p=0.14)
MSSA and MRSA vs MRSA alone	(H[1]=1.70, p=0.19)
MSSA alone vs MRSA alone	(H[1]=2.87, p=0.09)

the study population. In the study by Bassetti et al.¹⁸ there were only 44 deaths within seven days of the first positive blood culture. However, because of the small number of deaths, the confidence intervals of the odds ratio for some of the significant factors are wide, making the validity of the multivariate analysis questionable.

In the second study by Bassetti et al.,¹⁹ utilizing the same study population as the initial study,¹⁸ there was a significant difference in seven-day mortality when the study population was stratified by age: <75 (N=219; 20 deaths (9.2%) vs ≥75 (N=118; 24 (20.3%); *p*=0.004). In the multivariate analysis, only two factors were predictive of seven-day mortality: cirrhosis and septic shock; adequate initial antibiotic therapy was associated with a decreased risk of mortality. This analysis is also of questionable validity because of the small sample size (N=118) and small number of deaths at seven days (N=24).

Kaasch et al.²⁶ conducted a pooled analysis of five prospective studies of SABI involving 3,395 patients in 20 tertiary hospitals in Germany, Spain, United Kingdom, and United States. The authors identified significant variation in the percentage of patients with diabetes, MRSA BI, hospital-associated infection, and infection foci between the five studies. There were also significant limitations of individual studies, including the inability to identify community onset, healthcare-associated SABI; inconsistent information on antibiotic treatment and surgical management; and lack of information regarding use of computer tomography or magnetic resonance imaging in some studies.

The overall seven-day mortality was 9.4% (range 7.3%–12.5%) in the 20 studies. Univariate predictors of seven-day mortality were age, MRSA BI, endocarditis, pneumonia, “other focus” (other than an intravenous catheter, osteoarticular infection, pneumonia, skin/soft tissue infection, and endocarditis), and unknown focus. All the univariate predictors except “other focus” were significant in the multivariate analysis, whereas male gender was associated with a significantly lower risk of seven-day mortality. However, the multivariate model explained only a small percentage of

the variation in the seven-day mortality rate between study facilities (*R*²=0.074).

Studies that evaluated risk factors for seven-day all-cause mortality in patients with GNBI or all BI combined

Six studies were identified that utilized published models or multivariate analysis to evaluate factors predictive of seven-day all-cause mortality (**Table 3**).^{27–32} Design, study period, country, study size, and organisms studied varied between these six studies. However, the seven-day all-cause mortality rate in these six studies was like that observed in the SABI studies. In particular, two studies utilized published severity of illness models to predict early mortality, the bloodstream infection mortality risk score (BSIMRS; **Online Supplement Appendix S4**)²⁷ or Pitt bacteremia score (PBS; **Online Supplement Appendix S5**).²⁵ Four studies used multivariate analysis to identify risk factors for seven-day all-cause mortality;^{28–31} and two of these studies included the PBS as an independent variable in the analysis.^{30,31}

Analysis of these six studies revealed several important findings. First, older age was a significant risk factor in three studies,^{28,30,32} as it was in studies of SABI.^{14,26} Secondly, severity of illness models used alone accurately predicted seven-day all-cause mortality in two studies.^{27,31} Al-Hasan et al.,²⁷ using receiver operating characteristics analysis, found that the BSIMRS had an area under the curve of 0.85, indicating high discrimination for predicting seven-day all-cause mortality in the study population. A model to predict seven-day all-cause mortality was derived in 625 patients with BI initially evaluated in the emergency department of a university hospital in China from 2003–2016 referred to as the ED bacteremia mortality model, or ED-BM.³² The ED-BM model was compared to the PBS and BSIMRS for predicting early mortality in a separate validation cohort. Using receiver operating characteristic curve analysis, the area under the curve of the ED-BM model (0.903) was significantly better than the PBS (0.848) or the BSIMRS (0.885).

Table 2. Multivariate Analysis of Risk Factors for Seven-Day All-Cause Mortality in Four Studies of *S. aureus* Bloodstream Infection (SABI)

Reference Acquisition	Organism Studied; Acquisition	No. of Cases	No. of Deaths Within 7 Days	Multivariate Risk Factors for 7-Day All-Cause Mortality				
Lamagni ^{14,a}	MRSA (acquisition not determined)	9,001	1,825		Total Cases	% 7-d Deaths	OR	95% CI of OR
				Female sex	3,422	22%	1.16	1.04–1.29
				Age:				
				45–54	696	14%	1.54	1.05–2.26
				55–64	1,189	16%	1.92	1.35–2.74
				65–74	1,900	19%	2.34	1.57–3.28
				75–84	2,738	25%	3.4	2.45–4.73
				≥85	1,513	28%	3.83	2.73–4.36
Bassetti ^{18,b}	MSSA and MRSA (CO, CO-HCA, HO)	337	44				OR	95% CI of OR
				Comorbidity score			130%	1.1–1.5
				Endocarditis			4.5	1.4–14.6
				Septic shock			320%	5.4–36.4
				ID consultation			0.1	0.05–0.4
				De-escalation therapy			0.2	0.1–0.7
Bassetti ^{19,c}	MSSA and MRSA (CO, CO-HCA, HO)	118	24		Total Cases	% 7-d Deaths	OR	95% CI of OR
				Cirrhosis	9	67%	8.4	1.3–74.6
				Septic shock	20	60%	8.8	2.7–32
				Adeq abx init	72	14%	0.3	0.1–0.9
Kaasch ^{26,d}	MSSA and MRSA (CO and HO) ^e	3,395	317		Total Cases		OR	95% CI of OR
				Age			1.03	1.02–1.04
				Male gender		2,167	0.77	0.62–0.97
				Injection drug use		189	2.12	1.16–3.89
				MRSA		698	1.35	1.03–1.75
				Endocarditis		282	1.91	1.11–3.31
				Pneumonia		178	5.22	3.23–8.45
				Unknown focus		641	4.13	2.73–6.26

Abbreviations: MRSA=methicillin-resistant *S. aureus*; OR=odds ratio; CI=confidence interval; MSSA=methicillin-susceptible *S. aureus*; CO=community-onset; CO-HCA =community-onset, healthcare-associated; HO=hospital-onset; Adeq abx init=adequate antibiotic initially

^aPopulation-based study of MRSA bloodstream infection in England 2004–2005; no data on site of acquisition, comorbidities, source of infection, or treatment.

^bRetrospective study of SABI in two university hospitals in Italy, 2011–2014; there was no protocol for infectious diseases consultation during the study period.

^cThis study included only patients age 75 and older from reference 23.

^dThis was a pooled analysis of five prospective studies of SABI conducted in 20 tertiary hospitals in Germany, Spain, United Kingdom, and United States.

^eThere were only two categories of SABI: nosocomial or hospital-onset (blood cultures first positive more than 48 hours after admission) and the remainder were considered community-onset; identification of healthcare-associated, community onset SABI could not be accurately defined retrospectively in all study centers and, therefore, were included in the community-onset group.

Table 3. Studies of Gram-Negative Bloodstream Infection or All Episodes of Bloodstream Infection That Evaluated Risk Factors for Seven-Day All-Cause Mortality

Study	Design	Study Period Country # Cases	Organisms Studied	7-Day Mortality ^a	Factors Associated With 7-Day Mortality ^a																								
Al-Hasan ²⁷	Population-based	1998–2007 U.S. N=424	<i>E. coli</i> and <i>Ps. aeruginosa</i>	6%	BSIMRS ^b predicted 7-day mortality with AUC=0.85																								
Fitzpatrick ²⁸	Prospective	Oct 2013–Mar 2014 U.K. N=679	All GNBI at 10 hospitals	8%	Factors associated with 7-day mortality by MV analysis: ^c Older age, severity of illness score, CRP level, and neutropenic sepsis																								
Leistner ²⁹	Retrospective	2008–2011 Germany N=1,690	<i>E. coli</i> and <i>K. pneumoniae</i> In 1 hospital	8.7%	Factors associated with 7-day mortality by MV analysis: ^d Heart disease, liver disease, renal disease, and cancer/ immunological disease																								
Del Arco ³⁰	Prospective	2 years Spain N=773	All episodes of BI (including fungemia)	8.4%	Bivariate predictors of 7-day mortality: Age, no source of infection, no treatment modification, McCabe–Jackson classification,^e Pitt bacteremia score, and Charlson comorbidity index^f 3 logistic regression models were constructed varying the comorbidity factors (McCabe, PBS, or Charlson score); data are relative risk of death <table><thead><tr><th></th><th>Model 1</th><th>Model 2</th><th>Model 3</th></tr></thead><tbody><tr><td>Age</td><td>1.026</td><td>1.028</td><td>1.029</td></tr><tr><td>No source</td><td>2.889</td><td>2.761</td><td>2.440</td></tr><tr><td>No Rx change</td><td>2.316</td><td>2.442</td><td>2.487</td></tr><tr><td>McCade UF</td><td>5.30</td><td>PBS 7.014</td><td>Charlson sc 2.678</td></tr><tr><td>RF</td><td>7.62</td><td></td><td>Noso infec1.868</td></tr></tbody></table>		Model 1	Model 2	Model 3	Age	1.026	1.028	1.029	No source	2.889	2.761	2.440	No Rx change	2.316	2.442	2.487	McCade UF	5.30	PBS 7.014	Charlson sc 2.678	RF	7.62		Noso infec1.868
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Santoro ³¹	Retrospective	Nov 2015–June 2017 Italy N=1,049	All episodes of BI (excluding fungemia) at 1 hospital	12.1%	Factors associated with 7-day mortality by Cox proportional hazards model:^g <table><thead><tr><th>Variable</th><th>Hazard Ratio</th></tr></thead><tbody><tr><td>PBS 2–5</td><td>4.80</td></tr><tr><td>PBS >6</td><td>11.30</td></tr><tr><td>Abdominal source</td><td>5.67</td></tr><tr><td>Pulmonary source</td><td>4.95</td></tr><tr><td>Psuedomonas with resistance</td><td>6.72</td></tr><tr><td>Approp rx after 2 days</td><td>0.18</td></tr><tr><td>Inappropriate rx</td><td>3.24</td></tr></tbody></table>	Variable	Hazard Ratio	PBS 2–5	4.80	PBS >6	11.30	Abdominal source	5.67	Pulmonary source	4.95	Psuedomonas with resistance	6.72	Approp rx after 2 days	0.18	Inappropriate rx	3.24								
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Chiang ³²	Retrospective	2003–2016 China N=14,625	All patients who had positive blood cultures drawn in ED of 1 hospital	8.4%	Compared PBS and BSIMRS with a model developed by the authors called the ED bacteremia mortality model (ED-BM) for predicting 7-day mortality, which utilized 16 independent variables. Using ROC analysis, the ED-BM had a significantly higher AUC (95% CI) than either PBS or BSIMRS for predicting 7-day mortality: <table><tbody><tr><td>PBS</td><td>AUC=0.850 (0.835–0.865)</td></tr><tr><td>BSIMRS</td><td>AUC=0.883 (0.871–0.895)</td></tr><tr><td>ED-BM</td><td>AUC=0.909 (0.900–0.919)</td></tr></tbody></table>	PBS	AUC=0.850 (0.835–0.865)	BSIMRS	AUC=0.883 (0.871–0.895)	ED-BM	AUC=0.909 (0.900–0.919)																		
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AUC=area under the receiver operating characteristics curve; U.K.=United Kingdom; GNBI = gram-negative bloodstream infection; MV=multivariate; CRP=c-reactive protein; BI=bloodstream infection; ED=emergency department; PBS=Pitt bacteremia score; ROC=receiver operating characteristics; CI=confidence interval; Charlson sc=Charlson score; Noso infec=nosocomial infection

^aIndicates 7-day all-cause mortality.

^bBSIMRS=bloodstream infection mortality risk score; this prediction model was developed by Al-Hasan and colleagues (*Clin Microbiol Infect* 2013;19:948–954) for predicting mortality in patients with gram-negative bloodstream infection. The BSIMRS is a prediction model that incorporates the Pitt bacteremia score (PBS). The PBS was developed in the 1990s as a model to predict mortality in patients with bloodstream infection. The PBS underwent several iterations and is an empiric model, i.e., the model components were chosen by the authors and each component was given a weight or score with no statistical analysis. On the other hand, the BSIMRS was a predictive model with the components and scoring system based on a statistical analysis. A detailed analysis of the PBS and BSIMRS can be found in reference 3.

^cControlling for gender, creatinine level, age-adjusted comorbidity score, neutrophil count, platelet count, acquisition, days of symptoms, and empiric inappropriate therapy.

^dControlling for polymicrobial BI, age, comorbidity score, cardiovascular disease, and gastrointestinal disease.

^eMcCabe–Jackson classification was developed in the early 1960s to assess the impact of underlying disease on mortality in patients with gram-negative BI. This method classifies underlying disease into three categories of risk: nonfatal, ultimately fatal, and rapidly fatal underlying disease. This classification scheme continues to be utilized with no revisions. (McCabe WR, Jackson GG. Gram-negative bacteremia: I. Etiology and ecology. *Arch Intern Med*. 1962;110:847–855.

^fCharlson Comorbidity Index is a method to aggregate the presence of underlying diseases in a patient as a way to determine the burden of disease as it relates to outcome. (Charlson ME, Pompei P, Ales KL, MacKenzie CR. A New Method of Classifying Prognostic Comorbidity in Longitudinal Studies: Development and Validation. *J Chron Dis*. 1987;40(5):373–383)

^gControlling for age, hospital-acquired bloodstream infection, central venous catheter, urinary catheter, comorbidity score, urinary source, biliary tract source, skin/soft tissue infection, methicillin-resistant *S. aureus* bloodstream infection, appropriate treatment within two days of onset of bacteremia.

Discussion

Twenty-three studies of SABI were identified that reported early all-cause mortality defined as death within seven days of the first day blood cultures were positive. After stratifying these studies into three groups based on the organisms studied, there was a significant difference in the mean percent seven-day all-cause mortality between the groups. However, when the analysis was done using the mean early death proportion, there was no significant difference in this metric between these groups. The early death proportion consistently ranged from 50%–60% in the 23 studies despite heterogeneity in terms of the characteristics of the study populations. The narrow range of the early death proportion in the studies of SABI in this report provides support for defining early mortality as all deaths within seven days of the first positive blood culture. The narrow range of the early death proportion also suggests that patients with SABI who die within seven days of the first positive blood culture may represent a distinct group based on shared clinical and diagnostic characteristics that could be identified early in their hospital course.

To address the question of a specific group of patients with SABI at risk for early mortality, four studies were identified that evaluated factors associated with seven-day all-cause mortality using multivariate analysis (**Table 2**).^{14,18,19,26} However, none of the four studies provided a valid analysis, either due to a small number of patients with early mortality^{18,19} or a lack of data on several factors that may be associated with early mortality.^{14,26} These factors include severity of illness at the time of initial evaluation;³ duration of illness prior to blood cultures being obtained, especially in patients with community-onset SABI;³³ source control;³⁴ evidence of metastatic infection at the time blood cultures are performed; pathogen factors;³⁵ host factors;³⁵ host-pathogen interactions;³⁶ and treatment factors.³⁷

A recent study of SABI was published online that analyzed factors associated with early mortality defined as attributable mortality within seven days of the first day blood cultures were positive.³⁸ This was a retrospective study of electronic records of 464 patients with SABI at three teaching hospitals in the United Kingdom between December 2019 and August 2022. Of the 464 episodes, there were 67 (14.4%) deaths attributable to SABI (early death=37 patients and late death=30 patients [more than seven days after the index blood culture]). Factors associated with early death included age, comorbidity score, acute severity of illness, and positive follow-up blood cultures, which was similar to some findings of studies in the present report (**Table 2**).^{14,18,26} The authors point out that it is unlikely that new approaches to antimicrobial therapy alone will decrease the rate of early mortality given that age and comorbidities are important factors in this regard. They suggested that interventions to improve host response (e.g., reducing the risk of sepsis) and stabilizing comorbid disease should be studied to reduce early mortality.

However, a major limitation of this study is the small number of patients with early mortality, as was the case in studies in the present report (**Table 2**), as well as no information on source control or treatment. Nevertheless, Russell et al.³⁸ found that complications of SABI (i.e., early mortality, metastatic infection, and endocarditis) are each associated with different factors and need to be considered as separate and distinct clinical outcomes in future studies of this infection. Before an attempt is made to develop interventions to potentially reduce early mortality, a valid

evaluation of all potential factors associated with early mortality in patients with SABI must be completed and will require large prospective studies. The ongoing *Staphylococcus aureus* Network Adaptive Platform (SNAP) trial represents one such effort that could provide detailed information on early mortality related to SABI.³⁹

Six studies of GNBI or all BI were identified that evaluated factors associated with seven-day all-cause mortality that might be useful for evaluation in patients with SABI. Two of these studies found that acute severity of illness models accurately identified patients at risk for early mortality, which may be useful in patients with SABI.^{27,31} However, these studies did not consider factors that may be important in early mortality of patients with SABI noted above that may affect the predictive capability of these models. In addition, the ED-BM model includes a large number of variables (**Online Supplement Appendix S6**) and there are no weights or scores assigned to each variable in the ED-BM to allow for a simplified method to apply the model. In contrast, data to complete the BSIMRS is readily available early on in the hospital course of a patient with suspected BI, validation of the model has been done,³ and excellent discrimination for predicting early mortality has been demonstrated.^{27,32} Therefore, severity of illness models, such as the BSIMRS,²⁷ should be evaluated for identifying early mortality in patients with SABI.

Even if one can rapidly and accurately identify patients with SABI at risk for early mortality, will it be possible to reduce mortality given the short time interval (seven days) over which mortality is highest? Since all studies that reported risk factors for early mortality related to SABI have significant methodological limitations,^{14,18,19,26,38} this question can only be answered by designing prospective studies to identify all factors associated with early mortality. Only then can it be determined if there are feasible interventions that may mitigate the risk for early mortality in a short time interval. Conversely, even if there is an accurate model for identifying patients at risk for early mortality, it may not be possible to impact the early mortality rate of SABI given the short timeline to intervene.

As suggested recently,³⁸ and verified in the present study, several factors associated with early mortality (e.g., age, underlying disease) are not modifiable. In this situation one might consider vaccination to reduce mortality related to SABI. However, despite several decades of research, an effective staphylococcal vaccine has yet to be developed.⁴⁰ Recently the focus has changed from studying vaccines that target a single surface antigen of *S. aureus* to antitoxin monoclonal antibodies for treatment to reduce severity of infection, and vaccines containing multiple targets, including surface antigens and toxins, for prevention.⁴¹ It remains to be determined if these latest efforts will reduce severity of SABI and decrease mortality or prevent infection.

The present study has several limitations. First, the overall number of studies that reported seven-day mortality rates were small and only four studies performed an analysis of risk factors for early mortality. Several studies of SABI that reported seven-day all-cause mortality were excluded as noted in **Online Supplement Appendix S1**. This was not a systematic literature review and additional studies reporting seven-day mortality may have been missed. However, overall, 751 studies of SABI were carefully reviewed and the number that were missed is likely to be low. Second, there was considerable heterogeneity among studies included in this report, including variation in organism studied, design, size of the study population, and number of cases with early mortality.

Conclusions

In conclusion, despite the limitations noted above, consistently, 50%–60% of all deaths within one month of identification of SABI occur within seven days of the first positive blood cultures. This finding supports standardizing the definition of early mortality of SABI as all-cause mortality within seven days of the first positive blood culture. Standardization of the definition of early mortality is important to ensure that future studies utilize the same outcome. Despite the high early mortality in patients with SABI, there has been a lack of methodologically sound studies to identify factors associated with early mortality. There is an urgent need for well-designed studies focusing on this group of patients. Decreasing the high early mortality rate in patients with SABI should be an important component of the continuing effort to reduce the 30-day all-cause mortality rate of this infection.

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Note: References 42–76 are cited across the appendices and tables in the **Online Supplement**

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