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ORIGINAL CONTRIBUTION

The Massachusetts Abscess Rule: A Clinical Decision Rule Using Ultrasound to Identify Methicillin-resistant *Staphylococcus aureus* in Skin Abscesses

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Abstract

Objectives: Treatment failure rates for incision and drainage (I&D) of skin abscesses have increased in recent years and may be attributable to an increased prevalence of community-acquired methicillin-resistant *Staphylococcus aureus* (CA-MRSA). Previous authors have described sonographic features of abscesses, such as the presence of interstitial fluid, characteristics of abscess debris, and depth of abscess cavity. It is possible that the sonographic features are associated with MRSA and can be used to predict the presence of MRSA. The authors describe a potential clinical decision rule (CDR) using sonographic images to predict the presence of CA-MRSA.

Methods: This was a pilot CDR derivation study using databases from two emergency departments (EDs) of patients presenting to the ED with uncomplicated skin abscesses who underwent I&D and culture of the abscess contents. Patients underwent ultrasound (US) imaging of the abscesses prior to I&D. Abscess contents were sent for culture and sensitivity. Two independent physicians experienced in soft tissue US blinded to the culture results and clinical data reviewed the images in a standardized fashion for the presence or absence of the predetermined image characteristics. In the instance of a disagreement between the initial two investigators, a third reviewer adjudicated the findings prior to analysis. The association between the primary outcome (presence of MRSA) and each sonographic feature was assessed using univariate and multivariate analysis. The reliability of each sonographic feature was measured by calculating the kappa (κ) coefficient of interobserver agreement. The decision tree model for the CDR was created with recursive partitioning using variables that were both reliable and strongly associated with MRSA.

Results: Of the total of 2,167 patients who presented with skin and soft tissue infections during the study period, 605 patients met inclusion criteria with US imaging and culture and sensitivity of purulence. Among the pathogenic organisms, MRSA was the most frequently isolated, representing 50.1% of all patients. Six of the sonographic features were associated with the presence of MRSA, but only four of these features were reliable using the kappa analysis. Recursive partitioning identified three independent variables that were both associated with MRSA and reliable: 1) the lack of a well-defined edge, 2) small volume, and 3) irregular or indistinct shape. This decision rule demonstrates a sensitivity of 89.2% (95% confidence interval [CI] = 84.7% to 92.7%), a specificity of 44.7% (95% CI = 40.9% to 47.8%), a positive predictive value of 57.9 (95% CI = 55.0 to 60.2), a negative predictive value of 82.9 (95% CI = 75.9 to 88.5), and an odds ratio (OR) of 7.0 (95% CI = 4.0 to 12.2).

Conclusions: According to our putative CDR, patients with skin abscesses that are small, irregularly shaped, or indistinct, with ill-defined edges, are seven times more likely to demonstrate MRSA on culture.

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The emergence of community-acquired methicillin-resistant *Staphylococcus aureus* (CA-MRSA) in the general population over the past two decades has changed therapy for cellulitis,[1,2] but treatment for skin and soft tissue abscesses has not changed substantially in over 30 years. Incision and drainage (I&D) remains the primary therapy for skin and soft tissue abscesses. However, the recently published failure rates following abscess I&D are high, with increased failure rates in patients with MRSA cultured from abscess purulence.[3]

There are a few previously published prediction rules for the presence of CA-MRSA or MRSA in patients with skin infections using clinical predictors, but these studies have been limited to inpatients[4] or include surveillance nasal cultures,[5] the results of which are not available immediately. Recently, a few studies have demonstrated the utility of bedside soft tissue ultrasound (US),[6–8] and it is possible that there are some features of soft tissue US that could be used to predict the presence of CA-MRSA. The benefit of using bedside US is that the findings are available immediately and can be used to direct initial patient care decisions.

The sonographic features of abscesses have been described previously,[7,9–12] and they include findings such as the presence of interstitial fluid, characteristics of abscess debris, and depth of abscess cavity. These sonographic findings represent visualization of physiologic changes such as increased subcutaneous edema, changes in viscosity of the abscess purulence, or extent of surrounding induration. During previous research in our group,[3] it was noted that abscesses that failed therapy tended to look somewhat more homogeneous than those that did not fail therapy. The finding that patients with CA-MRSA tended to fail therapy at a higher rate than those with non-MRSA led us to speculate that possibly the similarity of US characteristics was related to the presence of CA-MRSA.

The virulence of the CA-MRSA (USA 300 strain) appears to be multifactorial and is not linked to carriage of the methicillin resistance mecA gene but to other genetic factors. Preliminary evidence concerning virulence in USA 300 strains (both MRSA and methicillin-sensitive *S. aureus*) implicated other genetic factors to evasion from human leukocytes, such as Panton-Valentine leukocidin.[13,14] Cellular defense mechanisms of *S. aureus* involve mediators that influence the immune system of the host, using both proinflammatory and immunosuppressive compounds. For example, *S. aureus* produces proinflammatory compounds, phenol-soluble modulin-like peptides (PSM) that recruit polymorphonuclear leukocytes.[15] Proteins that suppress the immune system by impairing phagocytosis (protein A) have also been described.[16] Many of the mechanisms used by CA-MRSA to combat the human immune system have the potential to introduce changes visible by US.

Although speculative, the identification of CA-MRSA at the bedside may allow better treatment decisions, such as the aggressiveness of the I&D or follow-up decisions such as the timing for a clinical wound check. It is also possible that identification of CA-MRSA at the bedside could influence antibiotic decisions in patients with associated cellulitis or other clinical indications for antibiotics. In this study, our objective was to develop a putative decision rule for US images of abscesses to predict the presence of MRSA by microbiologic culture in preparation for a future prospective study to further develop and validate the clinical decision rule (CDR).

METHODS

Study Design

This was a multicenter pilot CDR derivation study from databases of patients who presented to one of two academic Level I trauma center emergency departments (EDs) with superficial skin and soft tissue abscesses. Patients included in this study were identified from databases at two separate acute care university hospitals in New England, the University of Massachusetts Memorial Medical Center, and Massachusetts General Hospital. The study was approved by the institutional review boards at both hospitals with a waiver of informed consent.

Study Setting and Population

The study was conducted at two urban hospital EDs with a combined annual census of 185,000 patient visits. Patients in the EDs at both centers who received US imaging for the suspicion of soft tissue abscesses were entered into a database. The attending physician caring for each patient determined whether US imaging should be obtained. Patients presenting between 2007 and 2011 were identified for possible inclusion. The diagnosis of a skin and soft tissue abscess was defined as sonographic imaging depicting an abscess cavity in a patient with signs and symptoms of an abscess (pain, localized swelling, or erythema). Only patients who met both of the following were included: 1) a soft tissue US of a soft tissue abscess was performed and digitally recorded and 2) abscess purulence was sent for culture and sensitivity. Exclusion criteria included animal bites, dental abscesses, genital abscesses, postsurgical abscesses, and patients with cultures that grew commensal organisms.[17] For example, abscesses that grew out organisms such as *S. epidermidis* and *Corynebacterium* sp. were excluded.

Patient data for all patients presenting to the ED with skin abscesses during the study period were also collected. These patients were identified from a computer tracking system used in the ED that includes the final diagnosis as written by the attending physician of record. The identification of patients for this study was based on free-texted final diagnosis as recorded in this database by the physician of record and not ICD 9 codes.

Study Protocol

A unified protocol was established for the collection of data and definition of the variables. Uniform definitions of standard sonographic image characteristics for soft tissue abscesses do not exist. In their absence, image characteristics were identified and defined by the senior author (RJG) based on previously published literature and personal experience.[6,12,18–20] Table 1 has complete

Table 1
Image Variables

Shape	
	• Round/compact—oval or round shape without extensions • Irregular—abscess cavity with extensions or lobulations • Indistinct—the shape of the abscess cavity cannot be determined
Size	
	• Height × width × depth × 1/6 × π
Number of cavities	
	• Single cavity • Multiple cavities
Cavity edge	
	• Edge visible between abscess and surrounding tissue visible • No edge visible—no clearly visible edge between abscess cavity and surrounding tissue or abscess edge haze or partially not visible
Surrounding tissue induration	
	• Induration—loss of all or some of the normal tissue planes proximal to abscess cavity • No induration—normal horizontal tissue planes extend to all abscess cavity edges
Surrounding tissue fluid	
	• Trace fluid in surrounding tissue—prominent small thin branching anechoic fluid collections surrounding abscess cavity • No trace fluid in surrounding tissue—no small thin branching anechoic fluid collections surrounding abscess cavity
Amount of debris	
	• Debris as a percentage of the abscess cavity, not including anechoic fluid
Echotexture	
	• Fine—contents of abscess uniform or nearly uniform in granularity • Coarse—contents of abscess with changes in texture or granularity
Echogenicity	
	• Anechoic—black • Hypoechoic—darker then surrounding tissue • Isoechoic—same echogenicity as surrounding tissue

Note: echogenicity is in reference to tissue adjacent but not deep to abscess cavity. This is to prevent confusion related to the artificial increase posterior to the abscess cavity related to posterior acoustic enhancement.

definitions. To ensure uniformity in how the definitions were applied, researchers standardized the definitions of each sonographic feature prior to initiating the image review.

Sonographic characteristics of the abscess cavity and surrounding tissue are described in Table 1. Figure 1 demonstrates the categorization of echogenicity. Figure 1A also demonstrates the measurement of the abscess cavity. Figures 2 and 3 demonstrate the shape variable and edge visibility, respectively. Figure 4 demonstrates an abscess cavity with incomplete filling of the cavity with debris to demonstrate how percentage of debris is measured. Figures 5 and 6 demonstrate findings in the surrounding soft tissue. Induration is depicted in Figure 5, and soft tissue fluid is depicted in Figure 6.

Each of the study images was blindly reviewed in a standardized fashion by two physicians (RJG, DB) experienced in soft tissue US for the presence or absence of the predetermined image characteristics. In the instance of a disagreement between the initial two investigators, a third reviewer (DP) adjudicated the findings prior to analysis. Adjudication was required in 16.5% of patients in the database. All reviewers were emergency physicians who had each performed and/or interpreted over 1000 soft tissue US. Digital images were reviewed (blinded to all patient information, culture results, and previous interpretations) for abscess size, and the presence or absence of the predetermined characteristics, with the results recorded in a computer database.

Data from the electronic medical record (demographic data and culture results) were abstracted from the patient records in a standardized format. Data definitions were defined prior to abstraction, and data were entered into an electronic database by an individual blinded to US findings.

Abscess Purulence Collection and Culture. The decision to obtain culture and sensitivity of the abscess purulence was made by the attending physician caring for the patient. Abscess cavity contents were obtained following I&D or spontaneous extrusion from the abscess cavity. Briefly, abscess contents were collected and inoculated into a single culture medium prior to transport to the hospital microbiology laboratory. Abscess cultures were processed as per hospital protocol using an automatic culture system. Patient cultures with nonpathogenic skin commensals and those that did not demonstrate any organism were excluded from the analysis. Based on previously published literature,

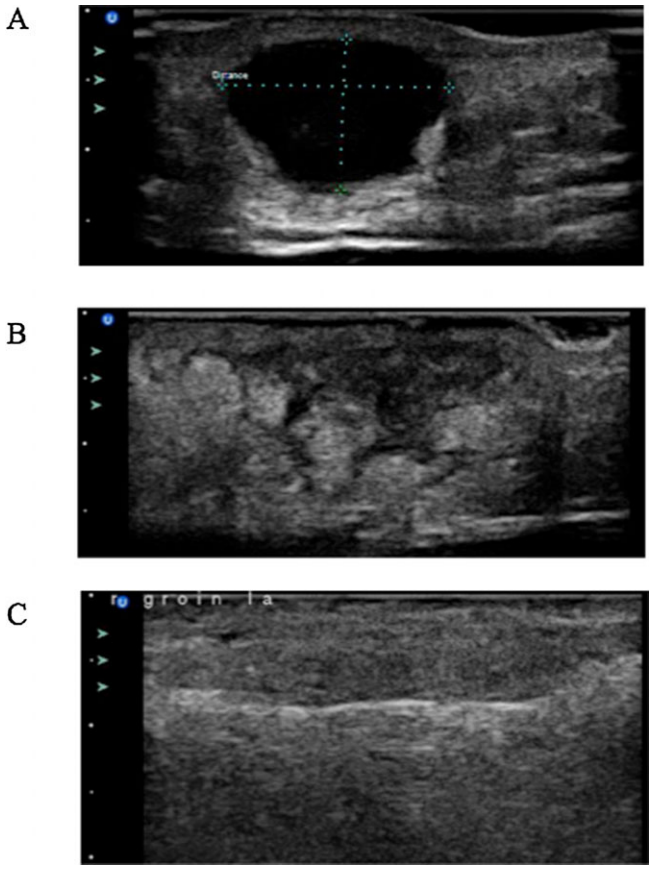

Figure 1. Echogenicity of abscess cavities. The figures demonstrate anechoic (**A**), hypoechoic (**B**), and isoechoic (**C**) abscesses. **A** also demonstrates the caliper measurements of the abscess cavity. Abscesses were characterized into one of these categories.

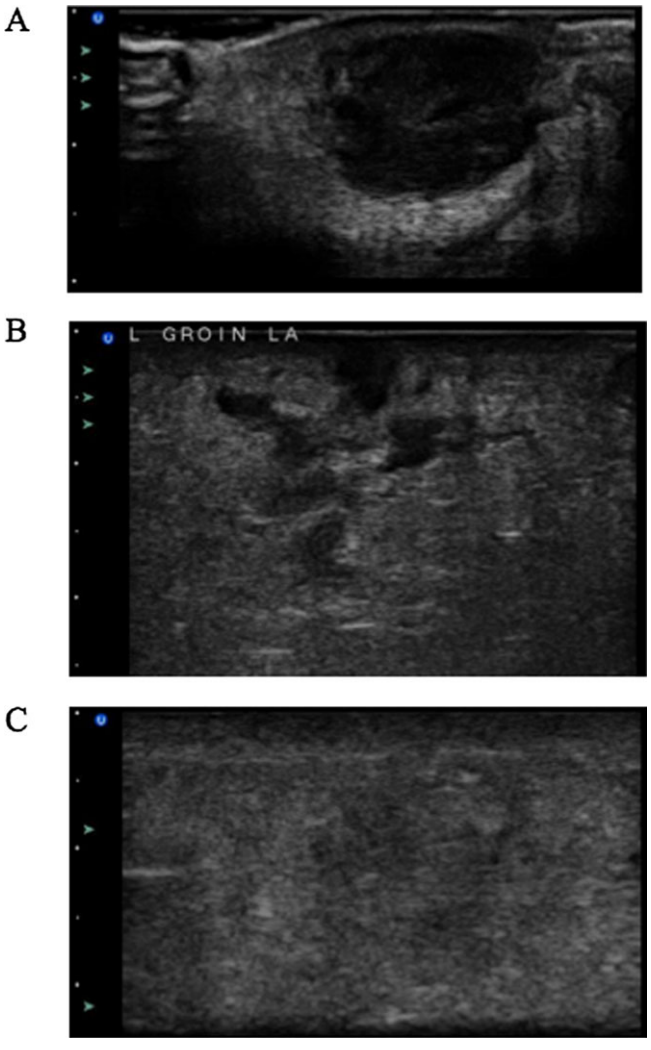

Figure 2. Abscess cavity shapes. The three types of abscess shapes are depicted. Round abscesses consist of a single abscess cavity (**A**). Lobular abscesses have many extensions that converge (**B**). Indistinct abscess cavities are difficult to visualize (**C**).

diphtheroids and cultures demonstrating mixed Gram-positive organisms with no predominant organism were considered to be skin commensals and/or nonpathogenic.[21] It is unclear if coagulase-negative *Staphylococcus* represents a pathogenic organism, so in this article we analyzed the data with and without these patients included in the analysis. Patients with mixed organisms or no predominant organism were excluded due to the possibility of inadequate sample being sent for culture or the possibility that the patient was taking antibiotics despite denying the use of antibiotics.

Data Analysis

Methodology for the derivation of the decision rule was based on previously published articles.[22,23] Data analysis was performed using SAS, version 9.3, and a web-based statistical program for creating decision rules (www.wessa.net). Initial univariate and multivariate analysis of the data was performed on the entire data set (n = 605). Chi-square recursive partitioning methods were then applied to derivation and validation data sets independently. Data were split by date into two groups, a derivation set (n = 183) and a validation set (n = 422), based on date of presentation (pre- and post-2010). The only criterion used to determine the date was to create a validation set that was large enough for validating the decision rule. For prediction rules for dichotomous outcomes, it has been estimated that the validation data must include at least 100 cases for each outcome.

The association between the primary outcome (presence of MRSA) and the sonographic features was assessed using the appropriate univariate analysis. Categorical data were analyzed using Fisher's exact test, and continuous variables were analyzed using a Wilcoxon two-sample test. To simplify the analysis in the multivariate analysis, continuous variables were categorized using the most discriminative cut points. Variables with $p \leq 0.1$ were then included in a multivariate logistic regression with MRSA/non-MRSA as the dependent variable. Variables present in less than 5% of all cases were excluded from the multivariate analysis. The reliability of each sonographic feature (except % debris) was measured by calculating the kappa (κ) coefficient of interobserver agreement. Agreement for percentage of debris was calculated using interclass correlation. These

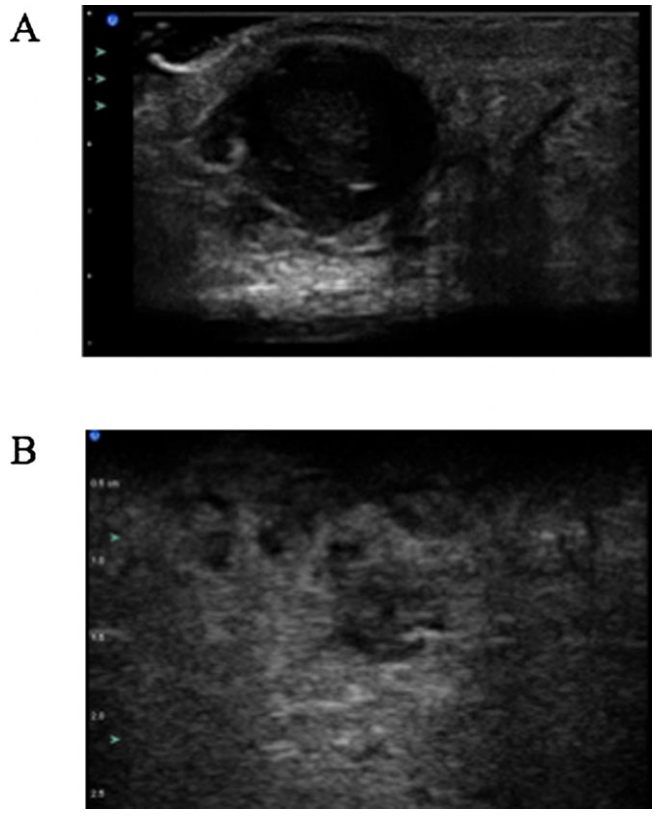

Figure 3. Abscess cavity edge visualization. (**A**) An abscess cavity with complete visualization of the edge of the abscess cavity. (**B**) An abscess cavity with partial visualization. Note that the inferior portion of the cavity has a distinct edge, but the superior portion does not.

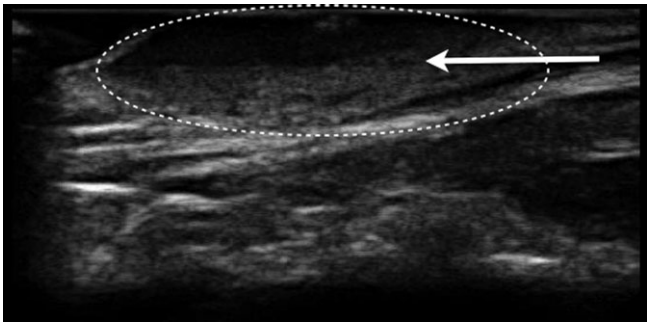

Figure 4. Abscess cavity debris percentage. The percentage of the abscess cavity filled with debris was measured by estimating the percentage of visualized debris relative to the entire cavity. In the example, the cavity is outlined in a *dotted white line* and the percentage of debris is roughly 50% (*white arrow*).

variables that were found to be both reliable ($\kappa > 0.6$) and associated with MRSA ($p < 0.1$) were analyzed by multivariate techniques. A kappa of >0.6 was chosen based on previously published literature as a variable with good agreement.[23]

Stepwise binary logistic regression was performed to determine which set of predictor variables were independently associated with CA-MRSA. Results of the multivariate analysis combined with chi-square recursive partitioning methods were used to develop models of best combinations of predictor variables for the presence of CA-MRSA. Receiver operating characteristic curve analysis was performed to assess the discriminatory properties of the decision rule. The overall fit of the model was measured using the Nagelkerke R^2 value. The reason we chose to use a statistical rather than a "clinical" approach to building this model was due to the lack of available information regarding sonographic features and CA-MRSA.

RESULTS

Study Patients

The study flow diagram describes overall study enrollment and exclusions (Figure 7). Table 2 shows the demographic and clinical characteristics of the 605 eligible patients and the 1,562 patients with skin and soft tissue abscesses who were not included. Patients with abscesses had a mean (±SD) age of 37.7 (±14.1) years with an overall admission rate of 16%. There were some differences between the patients included in the study and those not included. In general, the patients included in the study were more likely to be adult patients with abscesses above the belt line.

Abscess Culture Results

Pathogenic organisms were reported in 605 patients, and contaminants or lack of any growth was detected in 173. Among the pathogenic organisms, MRSA was the most frequently isolated, in 50.1% of patients. This was followed by methicillin-sensitive *S. aureus* found in 26.5% of patients.

Univariate and Multivariate Data Analysis

Table 3 shows the association between the primary outcome and sonographic features of the abscess. Some continuous variables were further categorized using discriminative cut points. Data are presented excluding patients with mixed Gram-positive organisms or no growth on culture. Analysis of the data including those patients demonstrated no significant differences. Overall, six of the sonographic features were associated with the presence of MRSA on culture. Interrater reliability of the sonographic features as measured using a kappa analysis or interclass correlation is also shown in Table 3. Three of the sonographic features were both reliable and associated with the presence of MRSA. The derivation data set was analyzed for multicollinearity using a correlation matrix and there was no significant multicollinearity (largest coefficient was 0.256).

Table 4 shows the multivariate logistic regression model that determined those features that were independently associated with MRSA. To perform the multivariate analysis, continuous variables were categorized into categorical variables using discriminatory cut points. The initial cut point for size (1 cm^3) was chosen based on clinical experience of one of the authors (RJG) to represent smaller abscesses that do not reliably provide fluid for culture following I&D. Small abscesses are defined as less than or equal to 1 cm^3, and larger abscesses are defined as greater than 1 cm^3. Multiple cut points for size were included during the receiver

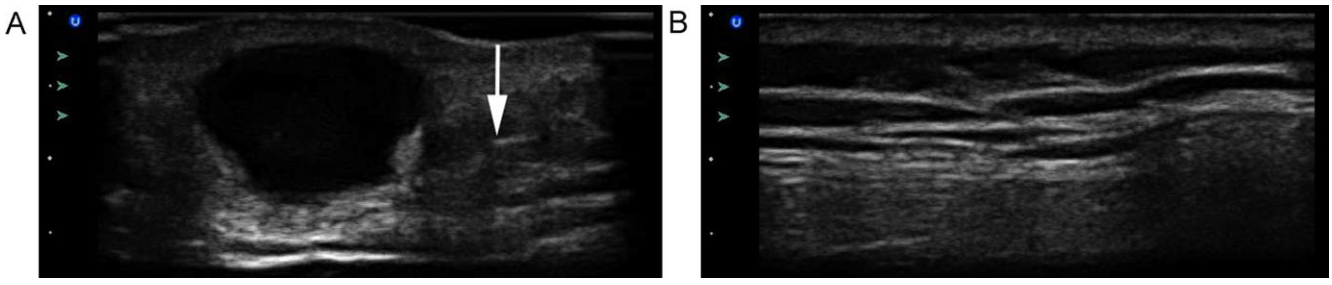

Figure 5. Soft tissue induration. There are two US images of an abscess cavity with surrounding induration (**A**) and images of the same patients contralateral normal soft tissue and no induration (**B**). Normal soft tissue is characterized by horizontal white lines parallel to the skin surface. The edge of induration can be visualized lateral (white arrow) and deep to the abscess cavity. US = ultrasound.

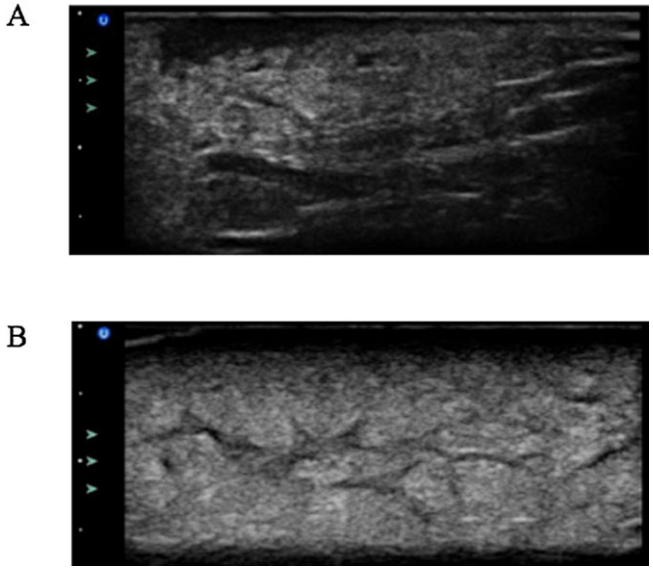

Figure 6. Soft tissue fluid. (**A**) An abscess cavity with no surrounding tissue fluid. The soft tissue demonstrates a relatively homogenous consistency. (**B**) Soft tissue fluid as hypoechoic or anechoic branching thin structures in the soft tissue.

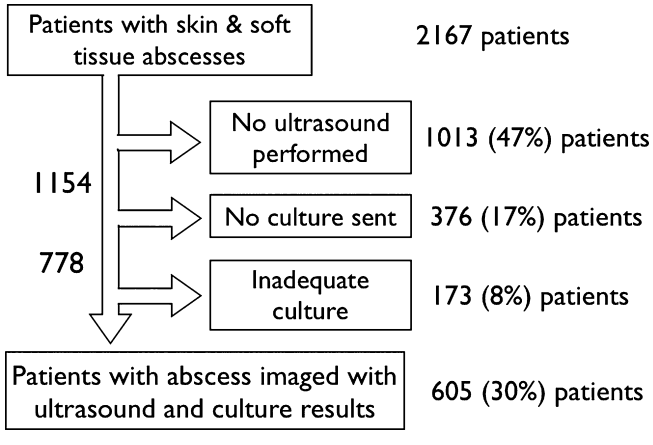

Figure 7. Study flow diagram.

operating characteristic analysis to determine the complete discriminatory ability of the decision rule. The cut point for debris was chosen based on an evaluation of the distribution of debris percentage for all patients to separate the data at a natural gap that discriminates between a smaller amount of debris and a larger amount of debris. All potential variables were initially included in the multivariate model. Only two of the variables remained significantly associated with MRSA (size and edge visibility), while also demonstrating good inter-observer agreement.

Results from the multivariate analysis were used to develop the CDR. The decision tree model for the rule was created with recursive partitioning analysis using an online calculator (www.wessa.net). The two independent variables that were associated with MRSA include the lack of a well-defined edge and irregular or indistinct shape. This model was developed on a subset of the data used for derivation of the prediction rule (n = 183) and then tested on the validation data set (n = 422). We refined the decision rule by adding "shape," as it was borderline for association in the multivariate analysis but was reproducible ($\kappa < 0.6$; Figure 8).

Receiver operating characteristic analysis demonstrates fair accuracy with an area under the curve of 0.75. The decision rule when applied to the validation cohort demonstrated a sensitivity of 89.2% (95% CI = 84.7% to 92.7%) and a specificity of 44.7% (95% CI = 40.9% to 47.8%; Table 5). The clinical rule demonstrates an odds ratio (OR) of 7.0 (95% CI = 4.0 to 12.2). In other words, a patient with a small, irregularly shaped abscess without a clear visible edge was 7.0 times more likely to have a MRSA infection. Using other cut points for size maximizes sensitivity at the expense of specificity. For example, defining small abscesses as ≤ 2 cm^3 results in a sensitivity of 94% (95% CI = 90% to 97%), but a specificity of 39% (95% CI = 36% to 41%).

DISCUSSION

The elements of our CDR were chosen by one of the investigators based on previous research and clinical experience, but their relevance is supported by biochemical and physiologic pathways related to infection. Magnetic resonance imaging of soft tissue infection demonstrates similar changes as those demonstrated by US, with soft tissue fluid, edema, and inflammatory changes in the surrounding tissue.[24] The increased inflammation or necrosis produced by CA-MRSA[15] supports our findings of an increase in soft tissue fluid in

Table 2
Patient Demographics

Variable	Derivation Cohort (*n* = 183)	Validation Cohort (*n* = 422)	Excluded (*n* = 1,562)
Demographic			
Age (yr), mean (±SD)	31.4 (±16.9)	34.7 (±16.7)	28.5 (±17.6)
Pediatric (age <18 yr)	19 (10.4)	41 (9.6)	*409 (26.2)
Age > 65 yr	9 (4.9)	12 (2.9)	44 (2.8)
Sex (male)	100 (54.6)	222 (51.1)	878 (56.2)
MRSA (% of cultured)	104 (57)	194 (46)	772 (49.4)
Disposition—admitted	27 (14.8)	482 (10.2)	145 (9.3)
Abscess location	*n* = 141	*n* = 396	*n* = 1,398
Axillary/groin	12 (7.0)	41 (10.3)	251 (17.0)*
Buttock	21 (12.3)	44 (11.1)	296 (20.0)*
Head/neck	26 (15.2)	55 (13.8)	198 (13.4)
Genital	0 (0)	0 (0)	21 (1.4)
Lower extremity	42 (24.6)	97 (24.4)	248 (16.8)*
Trunk	27 (15.8)	66 (16.7)	164 (11.1)
Upper extremity	43 (25.1)	93 (23.5)	211 (14.3)*
Unknown	0 (0)	0 (0)	83 (5.3)

Data are reported as *n* (%) unless otherwise noted. The patients who were not included represent all patients with superficial soft tissue abscesses who underwent incision and drainage during the study period but were not included in the study.
MRSA = methicillin-resistant *S. aureus*.
*Data points with differences between the validation cohort and those not included in the study (modified Wald technique).

Table 3
Univariate Comparisons and Kappa Values for MRSA and Sonographic Features

Variables	MRSA (*n* = 304)	Non-MRSA (*n* = 301)	p-value	Interrater Reliability, κ (95% CI)
Shape				0.61 (0.55–0.74)
Round	106 (35)	172 (57)	<0.01	
Irregular	118 (39)	89 (30)	<0.02	
Indistinct	80 (26)	40 (13)	<0.01	
Multiple cavities	80 (26)	55 (18)	<0.02	0.47 (0.30–0.64)
No well-defined edge	97 (32)	48 (16)	<0.01	0.65 (0.49–0.84)
Soft tissue induration	272 (89)	256 (85)	<0.14	0.83 (0.65–0.99)
Fluid in soft tissue	115 (38)	92 (31)	<0.05	0.53 (0.39–0.67)
Debris %	82.9	70.7	<0.05	0.50 (0.41–0.57)*
Echotexture			<0.87	0.37 (0.23–0.56)
Course	166 (55)	162 (54)		
Fine	138 (45)	138 (46)		
Echogenicity			<0.51	0.36 (0.11–0.64)
Hypoechoic	266 (88)	269 (89)		
Isoechoic	36 (12)	32 (11)		
Abscess volume			<0.01	0.83 (0.75–0.93)
Small	154 (51)	113 (38)		
Large	146 (48)	187 (62)		
Abscess not visible on ultrasound	7 (2)	4 (1)		

Data are presented as number of patients (percentage of total) unless otherwise indicated. The p-value represents a comparison between MRSA and non-MRSA. Agreement was determined using kappa analysis.
MRSA = methicillin-resistant *S. aureus*.
*Agreement was determined using interclass correlation.

patients infected with this organism. These same proinflammatory changes can also explain why CA-MRSA abscess cavities were smaller then non-MRSA. Patients with increased inflammation would present for treatment earlier due to increased symptoms related to increased inflammation.

We provide preliminary evidence for an association between sonographic features and the presence of MRSA, but the clinical role of our sonographic prediction rule is unclear. Many physicians treat abscesses in a similar fashion regardless of a consideration of the presence or absence of MRSA. It is not clear that this provides the best clinical care, as our failure rates following I&D are increasing, and researchers have demonstrated that MRSA infections respond differently to treatment than other organisms. A study by our research group demonstrated that CA-MRSA(+) abscesses were 10 times more likely to fail therapy following I&D and required additional therapy compared to CA-MRSA(–) abscesses.[3] Data on *S. aureus*

Table 4
Multivariate Analysis of Association between MRSA and Sonographic Features

Feature	Adjusted OR (95% CI)
Shape	
Round vs. irregular	2.72 (0.78–9.54)
Round vs. indistinct	1.67 (0.50–5.56)
Multiple cavities	2.25 (0.91–5.58)
No well-defined edge	4.95 (1.71–14.35)
Soft tissue induration	0.49 (0.21–1.15)
Fluid in soft tissue	1.35 (0.64–2.84)
Debris %	
Small (0%–20%) vs. medium (21%–79%)	0.67 (0.13–3.56)
Small (0%–20%) vs. large (80%–100%)	0.60 (0.12–3.00)
Echotexture—coarse	1.16 (0.55–2.44)
Echogenicity—hypoechoic	0.60 (0.16–2.85)
Abscess volume—large	0.24 (0.09–0.65)

MRSA = methicillin-resistant *S. aureus*.

bacteremia indicate that mortality rates are higher in patients with MRSA and CA-MRSA compared to those with methicillin-sensitive *S. aureus* even when both groups are treated with appropriate antibiotics.[25] Also, a review of the literature indicates that the recurrence rate is higher for CA-MRSA when compared to MSSA,[26] but the mechanism by which recurrence happens is unclear.

These preliminary data provide the initial steps in producing a CDR to help physicians determine if CA-MRSA is present in skin and soft tissue abscesses at presentation based on bedside US. Due to the limitations of using "secondary data," our study identifies possible variables for a future prospectively derived CDR. A prospective study can verify the inclusion of variables to form a CDR that would need to be evaluated and then validated. Once validated, clinical trials using this US decision rule to help guide therapy have the potential to decrease the current failure rate following I&D for skin and soft tissue infections.

LIMITATIONS

The most important limitation relates to the selection and source of our data. Patients were included if they were present in a database of soft tissue US and had culture results of the purulence. This results in both selection bias as well as ascertainment bias. It is not clear if the patients who underwent US and culture for their soft tissue abscesses had different characteristics from those who did not undergo US. The physicians who determined if patients received US and culture were not influenced by the research study, as the patients were entered into the database before the study was initiated. To eliminate this bias would require a prospective study.

Another limitation relates to the fact that the sonographic characteristics included in this study were identified and selected by the authors. Regardless of the experience level of the authors, it is possible that characteristics have been missed that should have been included. Future studies on these characteristics are warranted. In addition, during future studies, the

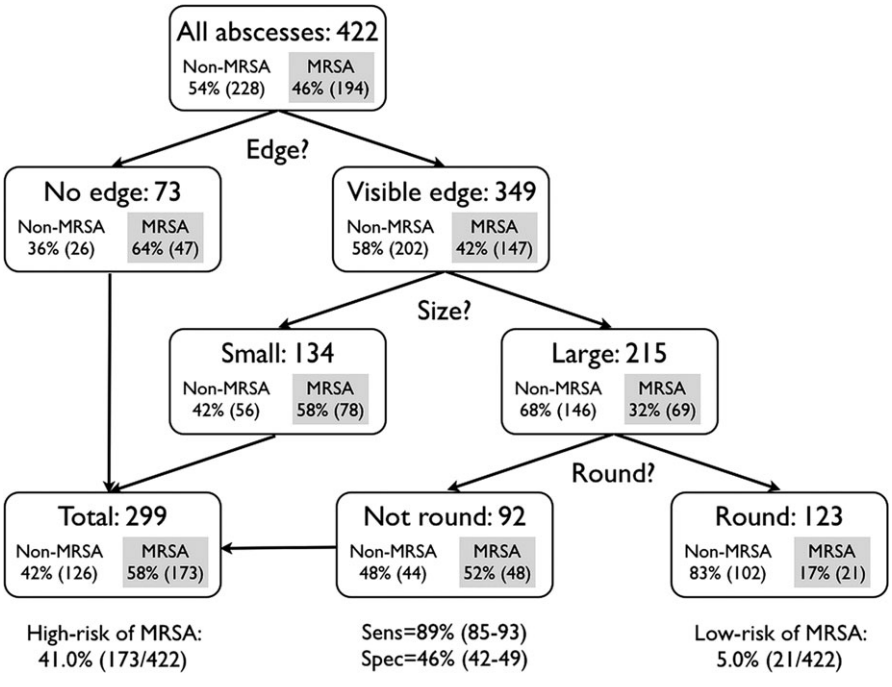

Figure 8. Decision tree for decision rule. Total patients and patients with MRSA are depicted for each node. Decision variables are indicated above *arrows* at each node. Patients at the *bottom right* represent those with a lower risk of MRSA and those at the *bottom left* represent those with a higher risk of MRSA. Overall sensitivity (95% CI) and specificity (95% CI) for this decision rule are 89% (85%–93^) and 46% (42%–49%), respectively. We measured the overall fit of the model using a multiple R-squared analog (Nagelkerke $R^2 = 0.18$). MRSA = methicillin-resistant *S. aureus.*

Table 5
2 × 2 Table for Decision Rule

	MRSA (+)	MRSA (–)
Decision rule (+)	173	126
Decision rule (–)	21	102

Sensitivity = 89.2 (95% CI = 84.7 to 92.7); specificity = 44.7 (95% CI = 40.9 to 47.8); positive predictive value = 57.9 (95% CI = 55.0 to 60.2); negative predictive value = 82.9 (95% CI = 75.9 to 88.5).
MRSA = methicillin-resistant *S. aureus*.

inclusion of an expert panel to review proposed characteristics could be helpful.

The retrospective nature of this study does present other limitations. It is possible that a prospective study would identify different sonographic characteristics (or none) as predictive of MRSA. For example, one or two views of the abscess may not visualize the small amount of fluid in the surrounding soft tissue because the sonographer obtaining the images did not recognize the importance of that finding. This same patient may demonstrate fluid in the surrounding soft tissue if imaged prospectively by a sonographer who is looking for this finding. It is also possible that the population of patients included in this study does not represent the general population. The demographic characteristics of the patients, approaches to care in the ED, and clinical features of soft tissue abscesses vary from site to site. These differences may affect our derived putative CDR. Future prospective studies in this area are warranted to address this limitation.

One final limitation relates to the methodology related to the building of our decision tree. We chose to use a statistical methodology due to the paucity of clinical information available to guide us using a "clinical" methodology. This methodology is not theory- or evidence-based and emphasizes statistical but not theoretical, clinical, or evidence-based relationships. Including theory in future models related to abscess treatment and resolution may help improve the CDR.

CONCLUSIONS

There are sonographic features visualized during soft tissue imaging that are associated with methicillin-resistant *S. aureus*. Patients with small, irregularly shaped abscesses with no clearly visible edges were more likely to have methicillin-resistant *S. aureus* infections.

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