The Emergency Department Occupancy Rate: A Simple Measure of Emergency Department Crowding?

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Study objective: We examine the validity of the emergency department (ED) occupancy rate as a measure of crowding by comparing it to the Emergency Department Work Index Score (EDWIN), a previously validated scale.

Methods: A multicenter validation study was conducted according to ED visit data from 6 academic EDs for a 3-month period in 2005. Hourly ED occupancy rate (ie, total number of patients in ED divided by total number of licensed beds) and EDWIN scores were calculated. The correlation between the scales was determined and their validity evaluated by their ability to discriminate between hours when 1 or more patients left without being seen and hours when the ED was on ambulance diversion, using area under the curve (AUC) statistics estimated from the bootstrap method.

Results: We calculated the ED occupancy rate and EDWIN for 2,208 consecutive hours at each of the 6 EDs. The overall correlation between the 2 scales was 0.58 (95% confidence interval [CI] 0.56 to 0.60). The ED occupancy rate (AUC=0.73; 95% CI 0.65 to 0.80) and the EDWIN (AUC=0.65; 95% CI 0.58 to 0.72) did not differ significantly in correctly identifying hours when patients left without being seen. The ED occupancy rate (AUC=0.78; 95% CI 0.75 to 0.80) and the EDWIN (AUC=0.70; 95% CI 0.59 to 0.81) performed similarly for ED diversion hours.

Conclusion: The ED occupancy rate and the EDWIN classified leaving without being seen and ambulance diversion hours with moderate accuracy. Although the ED occupancy rate is not ideal, its simplicity makes real-time assessment of crowding feasible for more EDs nationwide. [Ann Emerg Med. 2008;51:15-24.]

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INTRODUCTION

A recent report by the Institute of Medicine's Committee on the Future of Emergency Care described hospital emergency departments (EDs) as "at the breaking point."[1] Reduced inpatient capacity, increased volume, and other factors such as an aging population, escalating standards of care, and limited primary care resources in the community have resulted in significant crowding in EDs nationwide.[2-12] ED crowding is a serious problem because it is associated with adverse outcomes such as higher rates of leaving without being seen,[13-16] more frequent periods of ambulance diversion,[3,12,17,18] and longer lengths of stay in the ED.[19,20] More recently, evidence suggests that ED crowding may also negatively affect patient care.[21-24]

Despite the prevalence and chronicity of ED crowding, there is no accepted operational definition. A number of instruments have recently been developed to measure crowding

Editor's Capsule Summary

What is already known on this topic

Emergency department (ED) crowding can alter care and outcomes. A standard measure of crowding and its effect on outcome does not exist.

What question this study addressed

Can an ED crowding score, the Emergency Department Work Index (EDWIN), offer better assessment of crowding outcomes than simple occupancy rates?

What this study adds to our knowledge

In an analysis of 2,200 consecutive hours and 93,840 patients at 6 academic sites, ED occupancy rate and EDWIN each modestly predicted diversion intervals and patients leaving without care. The correlation of the 2 measures varied greatly among sites, with the more complex EDWIN achieving no apparent advantage.

How this might change clinical practice

A simple tool to assess ED crowding is lacking, and neither of the measures tested here was particularly robust across sites, underscoring the site-specific nature of the crowding problem.

quantitatively and objectively.[25-29] All the instruments are multidimensional and yield a crowding score that is based on a number of operational factors, including ED staffing, ED treatment spaces, patient volume, patient acuity, and hospital occupancy. These instruments advance the measurement of ED crowding by quantifying crowding reproducibly. For many EDs, however, the instruments cannot be used for real-time monitoring of crowding, because the EDs do not have electronic patient tracking systems that routinely capture the data elements needed to compute these scores.[30,31]

To quantify how crowded a hospital is, the most common measure used is hospital occupancy.[32] The hospital occupancy rate is the ratio between the total number of inpatients in the hospital and the total number of hospital beds during a given period. A logical question is, can we use the ED occupancy rate to measure ED crowding? The ED occupancy rate is the ratio of the total number of patients in the ED to the total number of ED treatment bays per hour. Most EDs across the country can calculate their occupancy rate in real time because they track patient registrations and discharges electronically and the number of treatment bays is known.

The purpose of this study was to examine the validity of using the ED occupancy rate to measure ED crowding by comparing it to a previously validated ED crowding measure, the Emergency Department Work Index (EDWIN). The EDWIN was chosen for comparison over other ED crowding scales because all the participating study sites routinely capture the data elements needed to calculate the EDWIN. In addition, in previous single-site comparisons of the EDWIN and other instruments, the EDWIN has demonstrated adequate discriminatory power in predicting ED crowding compared with other instruments.[33-35]

In this study, we determine the correlation between the ED occupancy rate and the EDWIN and compare the validity of the 2 instruments according to how well they discriminate between hours when patients left without being seen and when EDs were on ambulance diversion. We hypothesized that the 2 instruments would be moderately correlated and would not differ significantly in discriminatory ability by these crowding indicators.

MATERIALS AND METHODS

Study Design

The study was based on the input-throughput-output model of ED crowding proposed by Asplin et al.[36] From this conceptual model, we examined the relationship between the ED occupancy rate and the EDWIN and 2 input measures of crowding: leaving without being seen and ambulance diversion.[37] A multicenter validation study was conducted according to ED visit data from 6 academic EDs for a 3-month period in 2005. A separate data coordinating center analyzed the data from the 6 EDs.

Setting and Selection of Participants

The 6 academic EDs are geographically dispersed, and all have implemented electronic clinical information systems to support patient care activities (4 have commercial systems and 2 are homemade). Five of the 6 study sites are Level I trauma centers. In addition to the main ED treatment area, all the study sites had a fast-track area and 3 had an observation unit. The operational hours of the fast-track area varied among the EDs and ranged from 8 to 24 hours per day. The annual census of the different EDs ranged from 55,000 to 99,000 visits for 2005. The institutional review boards of all of the study sites and the data coordinating center approved this research project.

Data Collection and Processing

The unit of analysis was hourly measures of crowding during a 3-month period at the 6 hospital EDs. The principal investigator from each site sampled all relevant patient and ED data during each 24-hour period for each day between August 1, 2005, and October 31, 2005. The following data elements were extracted from the clinical information system for each registered patient: date and time of ED arrival, date and time of ED discharge, date and time of hospital admission decision, discharge disposition, and triage level. Five sites used the Emergency Severity Index[38] to assess patient acuity and 1 site had its own 4-level system.

In addition to the patient data, each site supplied the following ED information for the entire study period: total number of attending physicians working hourly, total number of treatment bays as defined by the ED's original blueprint, total

number of treatment bays open and staffed hourly, and all episodes of ED ambulance diversion (ie, start and end date and time). Four of the 6 sites used ambulance diversion to alleviate ED crowding and 2 did not.

Methods of Measurement

For each study site, we calculated hourly ED occupancy rates and EDWIN scores for each of the 2,208 hours in the study period. The ED occupancy rate was defined as the ratio of the total number of ED patients to the total number of licensed treatment bays per hour. The numerator included all patients in the ED at any point during each study hour, regardless of ED location (ie, including in the waiting room, boarding, hallway location). The denominator included the total number of licensed treatment bays as defined according to the ED's original blueprint but excluded hallway locations. Treatment bays that were part of fast track or an observation unit were included in the denominator. Regardless of whether a specific treatment area was staffed during particular hours or days of the week, the treatment bays were counted in the denominator. Thus, the denominator did not vary by study hour. An ED occupancy rate above 1.0 indicates there are more patients in the ED than treatment bays. The higher the occupancy rate, the more crowded the ED.

The EDWIN is calculated as follows: $\Sigma n_i t_i / N_a (B_T - B_A)$. The numerator of the EDWIN is the sum of the Emergency Severity Index triage categories (t_i) of all active patients (n_i) in the ED. ED patients who are admitted are counted as a hold and removed from the numerator. The EDWIN denominator is the cross-product of the number of treatment bays (B_T) minus the number of admitted patients (holds) (B_A) multiplied by the number of attending physicians (N_a) working each hour.[26] The triage scale was reversed so that level 5 represented the most acute and level 1 the least sick patients. As specified by Bernstein et al,[26] the number of treatment bays was defined according to the ED's original blueprint and was identical to the calculation of the ED occupancy rate. The EDWIN may be interpreted as "patient triage units per attending physician per available bed." A higher EDWIN score indicates a more crowded ED.

Outcome Measures

The main outcome variables were the 2 indicators of ED crowding: leaving without being seen and ambulance diversion. We classified each hour according to whether patients left without being seen or the ED was on ambulance diversion for each site. If a patient arrived during a particular hour and left without being seen, the arrival hour of the patient was classified as positive for having patients who left without being seen. If the facility was on ambulance diversion during any part of that hour, then that study hour was classified as positive for being on diversion.

Primary Data Analysis

All the analyses were completed using Statistical Analysis Software (SAS) version 9.0 (SAS Institute, Inc., Cary, NC). The data analysis was conducted in 4 phases. First, we imputed missing values for 2,946 visits (3.2%) that were missing one of the data elements needed to calculate the EDWIN. Of the 93,840 ED visits included in the study, 1,388 were missing their triage level (1.5%), 1,000 (1.1%) were missing the time to admit decision, and 558 (0.6%) were missing both. Triage level was imputed by calculating the mean triage score by ED disposition for each site separately and assigning each subject with a missing triage level the mean triage score for that site according to the ED disposition. The time of ED disposition was used as the admission decision time for subjects missing the hospital admission decision time. For the one site that did not use the Emergency Severity Index, we used the 4-level scale rather than trying to convert it into 5 levels.

Second, we measured the association between the ED occupancy rate and the EDWIN by using the average Spearman correlation coefficient obtained from bootstrapping 500 replications. The Spearman correlation coefficient ranges between –1 and 1, and the closer the values are to –1 or 1, the stronger the association between the 2 crowding measures. We used the bootstrap method to obtain standard errors for the Spearman correlation between the 2 measures.[39] The bootstrap method takes appropriate account of the autocorrelation among the hourly observations of each measure over time. For each site, we obtained 500 bootstrap samples by randomly sampling with replacement 92 (total number of study days) 24-hour periods. For each bootstrap replicate, we estimated the correlation coefficient and the 95% confidence interval (CI), which includes 95% of the bootstrapped values.

We also used the bootstrap samples to compare the discriminatory validity of the ED occupancy rate and the EDWIN by calculating the average sensitivity, specificity, and area under the receiver operating characteristic curve (AUC) statistic and corresponding 95% CIs with logistic regression modeling. Sensitivity is defined as the ability of the ED occupancy rate or EDWIN to correctly identify study hours that are positive for leaving without being seen or ambulance diversion. Specificity is the ability of the crowding instrument to correctly identify study hours that are negative for leaving without being seen or ambulance diversion. An AUC statistic reflects how accurately a measure is able to discriminate between 2 outcomes.[40] A score of 1.0 means the measure always selects the correct outcome. In contrast, a score of 0.5 implies the scale is no better than chance at predicting the correct outcome. For each site, we used the 500 bootstrap replications to calculate the average sensitivity, specificity, AUC statistic, and 95% CIs for discriminating between periods when patients left without being seen versus when they did not and between periods when the ED was on ambulance diversion versus not. For the ambulance diversion analysis, only the 4 sites that use ambulance diversion were included. The discriminant validity of the 2 instruments

Table 1. Description of study centers.

Characteristic	Overall	Site A	Site B	Site C	Site D	Site E	Site F
Total ED visits	93,840	14,620	13,350	24,184	13,591	14,853	13,242
Total ED beds	268	35	33	68	39	48	45
Admitted patients (%)	23	20	20	16	31	28	29
Left without being seen (%)	4	4	5	2	3	6	3
Time on ambulance diversion (%)	8	12	N/A	4	2	N/A	14
Median length of stay, h (IQ range)	4.3 (2.5–6.9)	4.2 (2.7–6.5)	4.0 (2.1–6.5)	3.8 (2.4–5.8)	4.7 (2.60–7.8)	5.4 (3.1–8.6)	4.3 (2.3–7.0)
Median EDWIN score* (IQ range)	1.5 (1.1–2.1)	2.1 (1.6–2.7)	1.8 (1.3–2.3)	1.3 (1.1–1.6)	1.4 (1.1–1.9)	1.5 (1.1–1.9)	1.2 (0.9–1.5)
Median occupancy rate* (IQ range)	1.0 (0.7–1.2)	1.1 (0.8–1.4)	1.1 (0.8–1.4)	0.9 (0.7–1.1)	1.1 (0.7–1.4)	1.0 (0.8–1.2)	0.8 (0.6–1.0)
Median acuity level* (IQ range)	3.0† (2.7–3.3)	3.6 (3.3–3.9)	2.7‡ (2.4–3.0)	2.8 (2.6–3.0)	3.1 (2.9–3.3)	2.9 (2.7–3.0)	2.6 (2.4–2.8)
Median number of boarding patients* (IQ range)	7 (5–11)	6 (4–9)	6 (4–9)	7 (5–10)	9 (6–14)	8 (6–12)	7 (5–10)
Median number of attending physicians working* (IQ range)	2 (2–3)	1 (1–2)	2 (2–3)	3 (1–3)	2 (1–4)	3 (2–3)	2 (2–3)

N/A, Not applicable because site does not use ambulance diversion; *IQ,* interquartile range (25% to 75%).
*Calculated hourly.
†Does not include 1 site that does not use the Emergency Severity Index.
‡Site B uses a 4-level triage scale; all other sites use the 5-level Emergency Severity Index.

was considered statistically significantly different when the 95% CIs did not overlap.

Third, to adjust for the nesting of hourly observations within each ED, we used a random intercept model to estimate the pooled mean and variance for the sensitivity, specificity, and AUC for all 6 sites. The mean and variance of the sensitivity, specificity, and AUC for each site from the bootstrap method was entered into the random intercept model. The random intercept model provides a pooled estimate of the sensitivity, specificity, and AUC and variance that is weighted by the variance of each ED.[41]

Sensitivity Analyses

Finally, we conducted a sensitivity analysis to determine whether our results would vary by the following factors: excluding data from the site that did not use the Emergency Severity Index to determine the effect on the EDWIN scores, excluding subjects with missing data instead of using the imputed values, and calculating the ED occupancy rate and the EDWIN according to whether the treatment bays were open and staffed versus closed and unstaffed to allow the number of treatment bays to vary hourly. For example, if one ED closed and did not staff the fast-track area during certain hours of the day, then the fast-track beds were subtracted from the total number of treatment bays available during those hours.

RESULTS

During the 3-month study period, there were a total of 94,028 ED visits across the 6 study sites. We excluded 188 visits (0.2%) because time of ED discharge was missing from the electronic record. Thus, the 2,208 hourly measures that require patient data are based on data from the remaining 93,840 visits.

Table 1 presents operational characteristics of the 6 study sites. During the 3-month study period, an average of 145 to 263 patients presented daily to one of the 6 study sites (overall mean of 170 patients). The median ED length of stay (range 3.8 to 5.4 hours) and the hospital admission rate (range 16% to 31%) differed across the sites. Across the 6 sites, at least 1 patient was more likely to leave without being seen during the afternoon and evening hours (ie, from 12 PM to 9 PM) compared with the early morning hours (Figure 1). Among the 4 sites that used ambulance diversion, the EDs were least likely to be on diversion at 7 AM and most frequently on diversion at 4 PM (Figure 1). Across all 6 sites, the median number of boarding patients was lowest between 5 AM and 10 AM (median number 5) and highest in the evening at 6 PM and 8 PM (median number 11) (Figure 2). The median number of attending physicians working was highest (median=3) between 10 AM and 8 PM and lowest (median=1) between 4 AM and 7 AM.

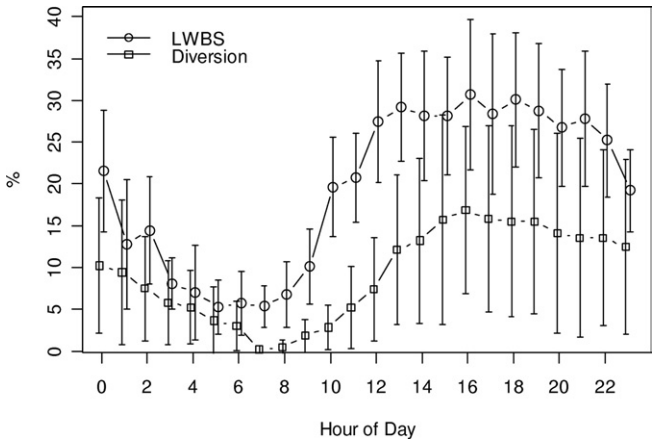

Figure 1. Proportion of hours that at least 1 patient left without being seen across all study sites and proportion of hours ED was on ambulance diversion across all 4 sites that use diversion by hour of the day. The error bars represent the 95% CI. *LWBS,* Leave without being seen.

Overall, the median hourly ED occupancy rate and EDWIN score were highest on Tuesday (occupancy rate=1.1 and

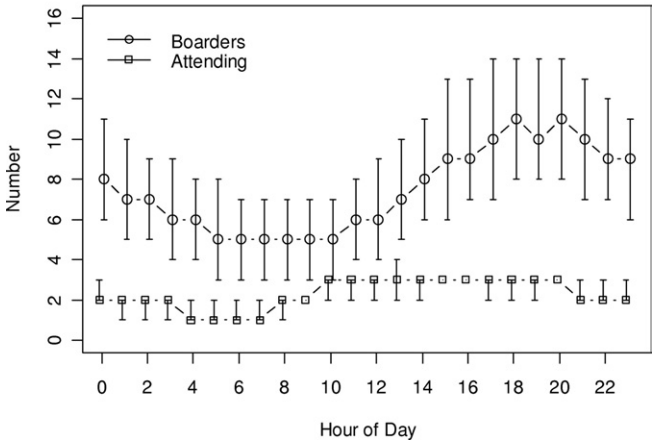

Figure 2. Median number of patients boarding and attending physicians working across all 6 study sites by hour of the day. The error bars represent the interquartile range.

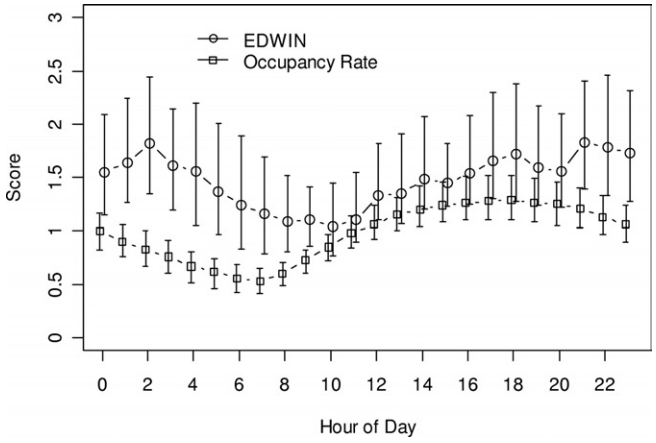

Figure 3. Median EDWIN score and ED occupancy rate across all 6 study sites by hour of the day. The error bars represent the interquartile range.

EDWIN=1.5) and lowest on Sunday (occupancy rate=0.9 and EDWIN=1.4). The median hourly ED occupancy rate was highest at 6 PM (median=1.3) and lowest at 7 AM (median=0.5) (Figure 3). In contrast, the median hourly EDWIN was highest at 9 PM and 2 AM (median=1.8) and lowest at 9 AM (median=1.2).

The overall correlation between the hourly ED occupancy rate and the EDWIN was 0.58 (95% CI 0.56 to 0.60) across all sites (see Figure 4 for all sites combined and Figure 5 for site-specific displays). Site-specific correlations ranged from 0.03 to 0.89 (Table 2). The EDs with the lowest correlations between the EDWIN and the ED occupancy rate were sites that had high EDWIN scores in the late evening and early morning as a result of reduced staffing and low ED occupancy rates at those times. To assess the influence of staffing on the relationship between the 2 measures, we eliminated staffing from the EDWIN calculation and found that the correlation between the

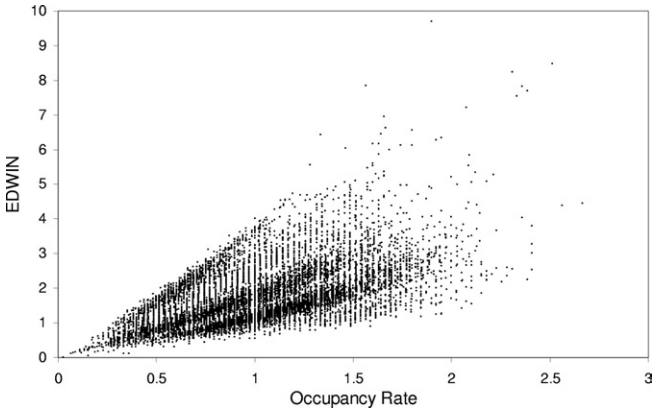

Figure 4. Scatterplot of the EDWIN score and the ED occupancy rate for each study hour and study site (N=13,248 total hours).

modified EDWIN and the ED occupancy rate improved substantially; site-specific correlations ranged from 0.90 to 0.93. Similarly, we eliminated triage level and boarding separately from the EDWIN calculation and found that neither factor improved the correlation (Table 2).

Table 3 displays the results of the discriminant validity analysis. Across all sites, there was no significant difference in the ability of the ED occupancy rate (AUC=0.73; 95% CI 0.65 to 0.80) and the EDWIN (AUC=0.65; 95% CI 0.58 to 0.72) to differentiate between periods of leaving without being seen (Figure 6). However, within each site and across all sites, the ED occupancy rate consistently performed slightly better. For 4 of the 6 sites, the AUC for the ED occupancy rate was significantly higher than for the EDWIN. For example, the ED occupancy rate performed the best at site F, where the AUC was 0.83 (95% CI 0.80 to 0.85) compared with 0.75 for the EDWIN (95% CI 0.72 to 0.78).

At a threshold value of 2.0 (cut point suggested by the EDWIN developers),[26] the overall sensitivity and specificity of the EDWIN was 45% (95% CI 21% to 68%) and 70% (95% CI 53% to 86%), respectively Table E1, available online at http://www.annemergmed.com). The overall sensitivity and specificity of the ED occupancy rate for leaving without being seen at a threshold value of 1.2 was 53% (95% CI 31% to 76%) and 72% (95% CI 59% to 85%) (Table E2, available online at http://www.annemergmed.com). For both scales, a higher threshold value reduced the sensitivity but improved the specificity (Tables E1 and E2 available online at http://www.annemergmed.com). Furthermore, the sensitivity and specificity at different threshold values varied significantly among the sites for both scales.

For ambulance diversion periods, the discriminant validity of the ED occupancy rate was equal or slightly better than the EDWIN (Figure 7). At one site (site C), the AUC of the ED occupancy rate was significantly higher, 0.74 (95% CI 0.67 to 0.81) compared with the AUC of the EDWIN, 0.52 (95% CI 0.45 to 0.59). The sensitivity of the 2 scales for ambulance

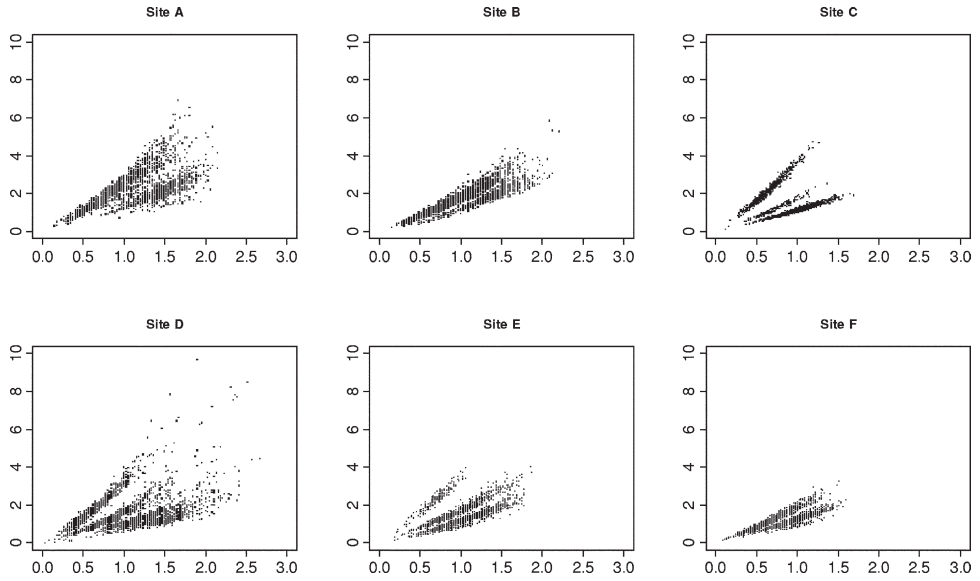

Figure 5. Scatterplots of EDWIN score (Y) and ED occupancy rate (X) for each study hour by site.

Table 2. Spearman correlations (95% CI) of the ED occupancy rate and the EDWIN.

Sites	Normal EDWIN Formula	Staffing Omitted	Triage Level Omitted	Boarding Omitted
Overall	0.58 (0.56 to 0.60)	0.88 (0.88 to 0.89)	0.58 (0.56 to 0.60)	0.41 (0.39 to 0.44)
Site A	0.62 (0.58 to 0.66)	0.90 (0.90 to 0.91)	0.61 (0.57 to 0.64)	0.41 (0.36 to 0.45)
Site B	0.89 (0.87 to 0.90)	0.91 (0.90 to 0.92)	0.90 (0.89 to 0.92)	0.74 (0.71 to 0.78)
Site C	0.03 (–0.04 to 0.11)	0.90 (0.89 to 0.92)	0.07 (0.00 to 0.15)	0.00 (–0.08 to 0.06)
Site D	0.40 (0.33 to 0.47)	0.93 (0.92 to 0.93)	0.42 (0.35 to 0.48)	0.01 (–0.06 to 0.07)
Site E	0.54 (0.49 to 0.60)	0.93 (0.92 to 0.93)	0.57 (0.52 to 0.62)	0.46 (0.40 to 0.51)
Site F	0.78 (0.56 to 0.60)	0.91 (0.90 to 0.92)	0.82 (0.80 to 0.85)	0.65 (0.61 to 0.69)

Table 3. AUC statistics (95% CI) for leaving without being seen and ambulance diversion.

Outcome	Overall	Site A	Site B	Site C	Site D	Site E	Site F
Left without being seen							
EDWIN	0.65 (0.58–0.72)	0.61 (0.58–0.64)	0.72 (0.70–0.75)	0.52 (0.49–0.56)	0.61 (0.57–0.64)	0.68 (0.65–0.70)	0.75 (0.72–0.78)
Occupancy rate	0.73 (0.65–0.80)	0.69 (0.66–0.71)	0.77 (0.75–0.79)	0.55 (0.52–0.58)	0.71 (0.68–0.75)	0.80 (0.78–0.83)	0.83 (0.80–0.85)
Ambulance diversion							
EDWIN	0.70 (0.59–0.81)	0.68 (0.63–0.73)	N/A*	0.52 (0.45–0.59)	0.74 (0.56–0.92)	N/A*	0.81 (0.74–0.88)
Occupancy rate	0.78 (0.75–0.80)	0.72 (0.67–0.76)	N/A*	0.74 (0.67–0.81)	0.78 (0.62–0.94)	N/A*	0.81 (0.74–0.89)

*Site data excluded from the ambulance diversion analysis.

diversion decreased with higher threshold values, but the specificity improved (Tables E1 and E2 available online at http://www.annemergmed.com). There was also significant variation in sensitivity and specificity by site across all threshold values.

The sensitivity analyses did not change the primary findings. When the site that did not use the Emergency Severity Index was excluded, the EDWIN AUC statistics for leaving without being seen (AUC=0.63; 95% CI 0.57 to 0.70) and ambulance diversion (AUC=0.72; 95% CI 0.64 to 0.79) did not change significantly across the sites. When the imputed data were excluded, the overall AUC statistics for the EDWIN and the ED occupancy rate were still not significantly different from each other for leaving without being seen or ambulance diversion (Table E3, available online at http://www.annemergmed.com). When missing data were excluded, the discriminatory power of the EDWIN improved for leaving without being seen at several sites, but the EDWIN AUC statistics were still not significantly higher than the ED occupancy rate AUC statistics at these sites. Finally, when the number of treatment bays included only open and staffed rather than total number of licensed treatment bays, the discriminatory power of the 2 instruments did not change substantially (Table E4, available online at http://www.annemergmed.com).

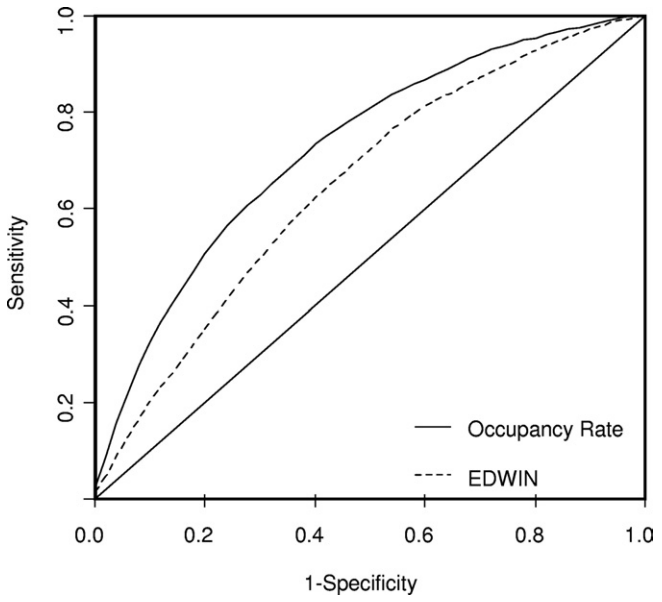

Figure 6. Overall receiver operating characteristic curves of the EDWIN and the ED occupancy rate across all study sites for leaving without being seen.

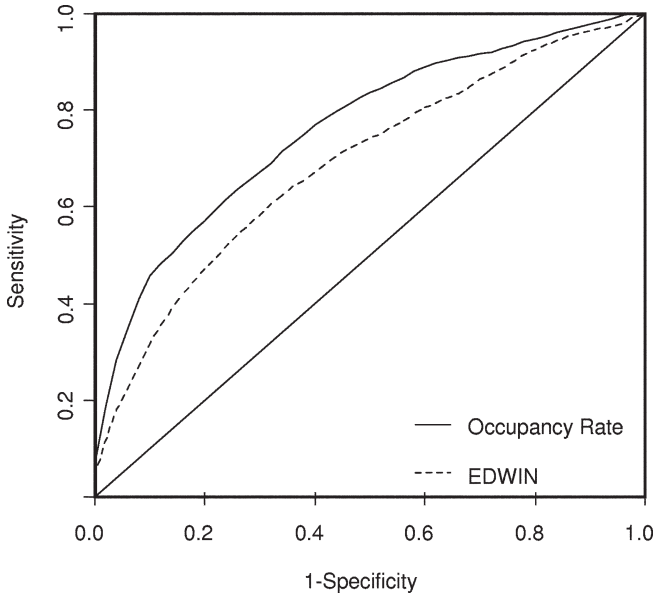

Figure 7. Overall receiver operating characteristic curves of the EDWIN and the ED occupancy rate across 4 study sites for ambulance diversion.

LIMITATIONS

The results of this study must be interpreted in the context of the following limitations. First, we did not compare the ED occupancy rate to other ED crowding instruments, because the clinical information systems of the study sites did not routinely capture the data needed for some instruments (ie, the National Emergency Department Overcrowding Scale or the Real-time Emergency Analysis of Demand Indicators) or the instrument was not published at the time of the study (ie, ED Work Score). Future studies should compare the ED occupancy rate to other crowding scales. Second, the generalizability of this study may be limited to academic EDs and to summer or fall season. Although these instruments should be evaluated in other types of ED settings and seasons, we expect the results will be similar. Third, we classified an hour of leaving without being seen and a diversion hour as positive if 1 patient left without being seen or the ED was on diversion for at least 1 minute during that hour, rather than choosing more stringent criteria such as 2 or more patients must leave without being seen or the ED must be on diversion at least 30 minutes during the hour. Finally, we evaluated the validity of the ED occupancy rate and the EDWIN by using leaving without being seen and ambulance diversion as our crowding criteria; others have validated crowding instruments by perceived ED crowding. Again, future studies should examine the validity of the ED occupancy rate with other crowding indicators because there is no criterion standard. The more consistent the results are across multiple indicators and sites, the more evidence we will have of the validity of our crowding instruments.

DISCUSSION

ED crowding shows no signs of mitigation nationally or internationally. However, the lack of well-validated, objective measures of ED crowding continue to hinder research related to the impact of ED crowding on patient care. A first step to addressing ED crowding is measuring it in a reliable and valid way. The results of this study suggest that the ED occupancy rate can serve as a valid measure of ED crowding. When compared with the EDWIN, a previously validated ED crowding scale, the ED occupancy rate performed as well at discriminating between hours when patients left without being seen and hours when the ED was on ambulance diversion. Neither scale was perfect. However, this may have as much to do with the reference standard against which the crowding scales were evaluated (ie, left without being seen and ambulance diversion). However, others have used both leaving without being seen and ambulance diversion as surrogate indicators of ED crowding.[12,27,29,35,42-44]

The correlation between the 2 crowding scales was modest. In general, as the EDWIN increased, so did the ED occupancy rate. The EDs with the lowest correlations between the 2 instruments were sites that demonstrated high EDWIN scores at night and in the early morning hours, when the ED occupancy rates were low. It is most likely that high EDWIN scores at these hours reflect a reduction in staffing rather than increased crowding. Because the EDWIN is a work index score, it is highly sensitive to the number of attending physicians working. Holding other factors constant, the EDWIN will increase as the number of attending physicians working decreases. When we eliminated staffing from the EDWIN formula, the 2 instruments were highly correlated at all sites.

The correlation between the ED occupancy rate and the EDWIN may also have been modest because boarding influences the EDWIN score differently, depending on the

occupancy rate. If all other factors are held constant, when the occupancy rate is equal to 1 (ie, number of ED patients equals the number of ED treatment areas), the EDWIN score remains constant even if the number of boarding patients increases. When the occupancy rate is greater than 1, the EDWIN score will increase if the number of boarding patients increases, other factors being held constant. However, if the occupancy rate is less than 1, the EDWIN score will decrease if the number of boarding patients increases, other factors being held constant. Given that research suggests that boarding is a surrogate for reduced inpatient capacity and contributes to ED crowding, the EDWIN may underestimate ED crowding when there are boarding patients in the ED.[32,45]

In this study, we defined the denominator of the ED occupancy rate as the number of licensed treatment bays regardless of whether they were open and staffed or type of bed they were (ie, fast-track or observation bed). The discriminatory power of the ED occupancy rate did not improve when we allowed the number of treatment bays to vary by availability and staffing. Future research is needed to determine whether it is optimal to define the denominator of the ED occupancy rate as licensed versus staffed beds, as well as whether to compute separate occupancy rates for each major ED venue. More research is also needed to determine the optimal threshold values for the ED occupancy rate and why there is substantial variation in the ability of the ED occupancy rate to predict leaving without being seen and ambulance diversion among different EDs.

To date, there have been several investigations of the validity of various ED crowding instruments. One study sampled 214 2-hour periods during a 17-day period and found a relatively strong correlation between the NEDOCS and the left without being seen rate (0.66) and the ambulance diversion rate (0.73) at their facility.[44] However, these correlations may be overestimated because the researchers did not account for the autocorrelation present in the time series data. Another study compared the discriminant validity of the EDWIN and the NEDOCS between periods when the staff perceived the ED was crowded versus not crowded. The investigators found that during 130 sampled times, the 2 instruments were relatively equivalent. The AUC for the EDWIN was 0.80 (95% CI 0.73 to 0.88) and the AUC for the NEDOCS was 0.83 (95% CI 0.75 to 0.90).[33] The single site study involved a small sampling period and did not control for the autocorrelation in the hourly data.

A study by Jones et al[34] also examined the discriminatory validity of 4 ED crowding instruments to detect perceived ED crowding by staff members' perceptions at a single institution during 135 sampling instances. The 2 scales that best discriminated perceived crowding were the NEDOCS (AUC=0.92; 95% CI 0.85 to 0.97) and the Bed Ratio (AUC=0.86; 95% CI 0.78 to 0.93), which is one of the components of the READI scale. However, the investigators observed that all the scales examined lacked scalability and that the published thresholds established for the different instruments may not be valid at sites where ED crowding is not prevalent.[34] Finally, Hoot et al[35] compared the ability of 4 crowding scales and the ED occupancy rate to predict future ambulance diversion at a single institution during a 2-month period. They found that the ED occupancy rate predicted future ambulance diversion episodes as well or better than any of the ED crowding scales.

All the validation studies conducted to date begin to provide evidence and insight into the measurement of ED crowding. This study contributes to existing knowledge in 3 important ways. First, this is the first multicenter validation study to address the external validity of ED crowding scales. Second, this study accounts for the autocorrelation that exists in repeated observations of measures over time. Finally, this study provides evidence that the ED occupancy rate may be used to measure ED crowding reliably and validly. The simplicity of the occupancy rate may make it possible for all EDs nationwide to measure ED crowding in a standardized way that allows for comparisons across sites.

The ED occupancy rate demonstrated similar discriminatory power as the EDWIN. Although neither was highly accurate in predicting leaving without being seen and ambulance diversion, both scales quantify crowding objectively. The ED occupancy rate has the advantage of being simpler than other crowding scales. Although the results of this study need to be validated in other settings and compared with other crowding instruments and criteria, emergency physicians may want to adopt this simple, objective measure of crowding as one of their core ED crowding measures. Having a common objective metric of ED crowding will allow us to measure ED crowding nationwide and to turn our attention to the more critical issue of understanding the impact of ED crowding on the quality of patient care.

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Table E1. Sensitivity (95% CI) and specificity (95% CI) of EDWIN at different threshold values for leaving without being seen and ambulance diversion.

		EDWIN Threshold Values					
		1.5		2.0		2.5	
Outcome	Site	Sensitivity, %	Specificity, %	Sensitivity, %	Specificity, %	Sensitivity, %	Specificity, %
Left without being seen	All sites	66 (42–90)	47 (27–68)	45 (21–68)	70 (53–86)	25 (10–41)	84 (74–94)
	A	90 (88–93)	21 (19–22)	71 (68–73)	47 (46–48)	45 (43–48)	69 (68–71)
	B	90 (89–92)	41 (37–45)	63 (61–66)	71 (69–73)	30 (28–32)	88 (88–89)
	C	27 (23–30)	68 (67–69)	13 (10–15)	83 (82–84)	6 (4–8)	92 (90–93)
	D	56 (52–59)	59 (57–61)	31 (27–35)	78 (76–80)	19 (16–22)	88 (86–90)
	E	66 (63–69)	62 (58–66)	30 (26–33)	84 (82–85)	13 (10–15)	94 (93–95)
	F	51 (46–56)	80 (78–83)	17 (13–20)	97 (96–98)	3 (2–4)	100 (100–100)
Ambulance diversion	All sites	64 (34–93)	58 (31–84)	40 (7–72)	76 (55–97)	26 (0–54)	87 (75–99)
	A	94 (92–95)	21 (21–22)	72 (70–75)	47 (46–47)	53 (49–57)	70 (70–71)
	C	23 (11–34)	69 (68–70)	4 (1–7)	83 (82–84)	2 (0–3)	92 (90–93)
	D	75 (70–81)	56 (55–57)	65 (57–72)	76 (75–77)	51 (41–61)	87 (85–87)
	F	60 (57–64)	84 (82–86)	20 (18–22)	98 (98–99)	3 (2–3)	100 (100–100)

Table E2. Sensitivity (95% CI) and specificity (95% CI) of ED occupancy rate at different threshold values for leaving without being seen and ambulance diversion.

		ED Occupancy Threshold Values					
		1.0		1.2		1.4	
Outcome	Site	Sensitivity, %	Specificity, %	Sensitivity, %	Specificity, %	Sensitivity, %	Specificity, %
Left without being seen	All sites	75 (61–89)	51 (40–62)	53 (31–76)	72 (59–85)	35 (15–55)	86 (77–95)
	A	84 (83–85)	44 (43–45)	65 (63–68)	61 (59–63)	47 (43–51)	77 (76–79)
	B	86 (85–88)	50 (48–51)	70 (68–72)	71 (68–73)	42 (41–43)	87 (86–88)
	C	48 (45–52)	59 (58–61)	13 (11–15)	88 (87–90)	2 (1–3)	99 (98–99)
	D	81 (78–95)	51 (50–52)	65 (64–69)	67 (65–68)	48 (46–51)	80 (79–82)
	E	85 (83–87)	59 (56–63)	57 (53–61)	84 (83–86)	26 (20–33)	96 (94–97)
	F	75 (69–80)	76 (75–77)	32 (25–38)	94 (93–95)	6 (3–8)	99 (99–99)
Ambulance diversion	All sites	79 (73–85)	57 (42–73)	53 (32–73)	77 (59–95)	32 (3–61)	88 (75–100)
	A	86 (85–97)	44 (43–44)	72 (71–72)	61 (60–62)	48 (46–49)	77 (76–78)
	C	74 (69–78)	60 (57–62)	31 (23–39)	89 (88–91)	8 (4–11)	99 (98–100)
	D	84 (77–89)	47 (46–48)	70 (63–77)	62 (61–63)	67 (61–73)	76 (76–77)
	F	73 (69–77)	78 (77–80)	40 (35–45)	97 (96–97)	8 (5– 12)	100 (100–100)

Table E3. AUC statistics (95% CI) for leaving without being seen and ambulance diversion, excluding imputed data.

Characteristic	Overall	Site A	Site B	Site C	Site D	Site E	Site F
Left without being seen							
EDWIN	0.68 (0.61–0.76)	0.61 (0.58–0.64)	0.72 (0.70–0.75)	0.52 (0.49–0.55)	0.72 (0.69–0.75)	0.79 (0.77–0.81)	0.74 (0.70–0.78)
Occupancy rate	0.72 (0.65–0.80)	0.69 (0.66–0.72)	0.77 (0.75–0.79)	0.55 (0.52–0.58)	0.72 (0.68–0.75)	0.79 (0.77–0.81)	0.81 (0.78–0.84)
Ambulance diversion							
EDWIN	0.70 (0.57–0.84)	0.68 (0.63–0.73)	N/A*	0.52 (0.45–0.59)	0.80 (0.67–0.94)	N/A*	0.81 (0.74–0.878)
Occupancy rate	0.77 (0.74–0.80)	0.72 (0.67–0.76)	N/A*	0.74 (0.67–0.81)	0.78 (0.62–0.94)	N/A*	0.81 (0.73–0.89)

*Site data excluded from the ambulance diversion analysis.

Table E4. AUC statistics (95% CI) for leaving without being seen and ambulance diversion allowing number of treatment bays to vary by open and staffed versus closed and unstaffed.

Outcome	Overall	Site A	Site B	Site C	Site D	Site E	Site F
Left without being seen							
EDWIN	0.63 (0.57–0.68)	0.61 (0.58–0.64)	0.66 (0.63–0.68)	0.55 (0.52–0.59)	0.55 (0.52–0.59)	0.67 (0.65–0.70)	0.73 (0.69–0.76)
Occupancy rate	0.72 (0.63–0.80)	0.69 (0.66–0.72)	0.73 (0.71–0.75)	0.51 (0.49–0.54)	0.72 (0.69–0.75)	0.81 (0.79–0.83)	0.83 (0.80–0.85)
Ambulance diversion							
EDWIN	0.66 (0.58–0.74)	0.68 (0.63–0.73)	N/A*	0.58 (0.50–0.66)	0.64 (0.46–0.83)	N/A*	0.79 (0.73–0.86)
Occupancy rate	0.75 (0.68–0.82)	0.72 (0.67–0.76)	N/A*	0.65 (0.57–0.73)	0.77 (0.60–0.95)	N/A*	0.82 (0.74–0.90)

*Site data excluded from the ambulance diversion analysis.