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Ohio Pediatric Asthma Repository: Opportunities to Revise Care Practices to Decrease Time to Physiologic Readiness for Discharge

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Abstract

BACKGROUND: Large-scale, multisite studies in which researchers evaluate patient- and systems-level factors associated with pediatric asthma exacerbation outcomes are lacking. We sought to investigate patient-level risks and system-level practices related to physiologic readiness for discharge (PRD) in the prospective Ohio Pediatric Asthma Repository.

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Dr Simmons contributed to the conception and design of the study, interpreted results, and drafted the manuscript; Dr Biagini Myers contributed to subject recruitment and acquisition of data and the study design, interpreted results, and drafted the manuscript; Dr Martin contributed to the study design, oversaw, performed, and interpreted data analyses, and drafted the manuscript; Dr Kercsmar contributed to the conception and design of the study and data acquisition and interpreted results; Dr Schuler interpreted results and drafted the manuscript; Dr Pilipenko and Ms He performed data analyses and interpreted results; Mr Austin and Mr Kroner designed data collection instruments and supervised subject recruitment, data acquisition, and data management; Dr Nguyen interpreted results; Drs Ross, McCoy, Alter, Gunkelman, and Vauthy contributed to the conception and design of the study and oversaw subject recruitment; Dr Khurana Hershey conceived the Ohio Pediatric Asthma Repository, oversaw its design, implementation, and data acquisition, and interpreted results; and all authors reviewed and revised the manuscript and approved the final manuscript as submitted.

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METHODS: Participants were children ages 2 to 17 years admitted to an Ohio Pediatric Asthma Repository hospital for asthma exacerbation. Demographics, disease characteristics, and individual hospital practices were collected. The primary outcome was PRD timing (hours from admission or emergency department [ED] presentation until the first 4-hour albuterol spacing).

RESULTS: Data for 1005 participants were available (865 ED presentations). Several nonstandard care practices were associated with time to PRD ($P < .001$). Continuous pulse oximetry was associated with increased time to PRD ($P = .004$). ED dexamethasone administration was associated with decreased time to PRD ($P < .001$) and less ICU admittance and intravenous steroid use ($P < .0001$). Earlier receipt of chest radiograph, antibiotics, and intravenous steroids was associated with shorter time to PRD ($P < .05$). Care practices associated with shorter time to PRD varied markedly by hospital.

CONCLUSIONS: Substantial variation in care practices for inpatient asthma treatment exists among children's hospital systems in Ohio. We found several modifiable, system-level factors and therapies that contribute to PRD that warrant further investigation to identify the best and safest care practices. We also found that there was no standardized measure of exacerbation severity used across the hospitals. The development of such a tool is a critical gap in current practice and is needed to enable definitive comparative effectiveness studies of the management of acute asthma exacerbation.

Asthma is the most pervasive chronic childhood condition, affecting more than 7 million US children.[1] Hospital asthma admissions are costly,[2] and longer time to physiologic readiness for discharge (PRD) coincides with increased length of stay and cost.[3] Determinants of PRD for asthma exacerbations are multifactorial, reflecting in part disease heterogeneity, the presence of comorbid conditions,[4] and the rapidity of response to exacerbation therapies.[5–7] In addition to patient-level factors, the systems in which care occurs have the potential to influence PRD timing. System-level care practices may dictate the timing or duration of therapies, the use of diagnostic testing, preferred methods of medication administration, patient monitoring practices, discharge criteria, and other aspects of acute exacerbation care. System-level practices in asthma, particularly with regard to treatment standardization, guideline implementation,[8] and albuterol weaning protocols,[9] are associated with patient outcomes. However, there is a need for multisite studies in which researchers address the distinct and combined impact of patient-level risks and system-level care practices on PRD in acute asthma.

Our goal in this study was to investigate patient-level risks and system-level practices as they relate to PRD for asthma exacerbations using a unique, multicenter, statewide database called the Ohio Pediatric Asthma Repository (OPAR).[10] OPAR is a comprehensive, statewide, prospective study in which researchers link clinical, demographic, environmental, and health outcomes data from the 6 major children's hospitals in Ohio. By using OPAR, we are uniquely positioned to address how variability in patient- and system-level factors at each site impact PRD during acute asthma exacerbation.

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METHODS

Subject Identification and Eligibility

OPAR was initiated and funded by the state of Ohio to better understand and optimize asthma care practices.[10] Children aged 2 to 17 years who were admitted for asthma, wheezing, or reactive airway disease at 1 of 6 Ohio children's hospitals were eligible. Each participant's parent or legal guardian provided informed consent, and assent was obtained from children >7 years old. For this analysis, participants recruited between December 2012 and September 2013 were included. As previously reported, the mean proportion of eligible participants enrolled was 68% (53%–81%). Nonparticipants did not differ from participants by age or sex.[10] This study was approved by the Institutional Review Board.

Questionnaires and Clinical Data Collection

Participants completed questionnaires that were used to capture demographics, symptom history, and health care use for wheezing and/or asthma. Information from admission, emergency department (ED) course, and ICU course (including respiratory assessment tools used, drugs administered, and providers) was collected from the medical record.

Outcome Definition: PRD

Medical criteria for PRD varied. Four hospitals used albuterol spacing every 4 hours (q4h), and 2 hospitals used albuterol spacing every 6 hours.[10] To account for these differences, we defined PRD as the first time point at which the patient demonstrated sufficient clinical improvement while receiving albuterol inhalation treatments no more frequently than q4h. We measured the time from inpatient (IP) or ICU admission until the patient reached the first 4-hour albuterol spacing (PRD_{IP}) (Fig 1). If a patient was discharged before meeting q4h, then PRD_{IP} was the time from IP admission to discharge. We also measured PRD_{TOT} as the time from emergency department presentation to first 4-hour albuterol spacing (Fig 1). If a patient was discharged before meeting q4h, then PRD_{TOT} was defined as the time from ED presentation to discharge. Because of skewing, PRD_{IP} and PRD_{TOT} were log-transformed.

Covariate Definitions

Chronic Severity and Risk—Chronic asthma severity classification was assigned as intermittent, mild persistent, moderate persistent, or severe persistent on the basis of baseline symptom frequencies according to *Expert Panel Report 3*.[11] High risk for asthma readmission was defined as parental report of hospitalization for asthma in the past 12 months. We combined asthma severity and risk into 4 categories: intermittent, mild and low risk; moderate, severe and low risk; intermittent, mild and high risk; and moderate, severe and high risk.[10]

Nonstandard Care Practices—We defined nonstandard care practices as intravenous (IV) steroid use, IP ipratropium administration, ICU admission, chest radiograph, continuous albuterol, and antibiotic administration.

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Statistical Analyses

Our primary goal was to identify factors associated with PRD. Because demographics and care practices varied across hospitals,[10] analyses were performed with mixed linear models in which hospital was included as a random effect. Because the factors associated with PRD may be correlated, we used a multistep strategy. First, we determined the relationships between PRD_{IP} and each factor individually. These analyses reveal information about individual-level associations; however, they do not account for correlation between variables. Therefore, we next generated a multivariate model, considering variables exhibiting a marginal level of significance ($P < .2$) in the individual screens. Variables that were significant in the individual but not the multivariable analyses were evaluated for collinearity by using contingency tables. When collinearity existed, only 1 variable was included. The final multivariable model eliminated variables at $P > .2$. We used a similar strategy to evaluate factors associated with PRD_{TOT} but also evaluated ED practices. For antibiotic use, steroid administration route, and chest radiograph, we created combined variables with 4 categories (ED only, IP only, both, and none), which replaced the dichotomous variables. Because ED dexamethasone was used primarily at a single hospital, analyses using only that hospital were evaluated. Additionally, we modeled PRD_{IP} in the ED subpopulation to ensure consistency of results (data not shown).

To determine if hospital differences persisted after accounting for demographics, nonstandard care practices, and hospital practices, we performed multivariate modeling for hospital association. We included a fixed and a random effect for the number of nonstandard care practices received. We included demographic and IP practices that were significant in the multivariable PRD_{IP} model as covariates. We generated a second multivariable PRD_{IP} model that incorporated ED practices and location-dependent practices as covariates. These models allowed for the comparison of PRD among hospitals. Statistical analyses were performed by using SAS 9.4 (SAS Institute, Inc, Cary, NC).

RESULTS

Characteristics of the Study Population

The study population included 1005 children who were primarily boys, African American, and on public insurance (Fig 1). Because not all enrollees presented to an OPAR hospital-affiliated ED (direct admit), analyses of PRD_{IP} include fewer children ($n = 865$; Fig 1). PRD_{IP} and $PRD_{TOT,}$ as well as the proportion of patients who received nonstandard care practices, varied markedly among hospitals (Table 1).

Factors Influencing PRD_{IP}

In the individual screen, adolescent age, injected steroid route, oral steroids, ipratropium, ICU admission, chest radiograph, continuous albuterol, antibiotics, specialist overseeing physician, continuous pulse oximetry, and albuterol weaning by multiple providers were associated with increased PRD_{IP} (Supplemental Table 2).

Because factors associated with PRD_{IP} may correlate, we considered factors jointly. Demographics contributed to increased PRD_{IP} after accounting for nonstandard care and

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routine care practices. There was a 2-hour increase in PRD_{IP} for children with public compared with private insurance ($P = .02$) and a 2.7-hour increase for adolescents (aged 13–17 years) compared with younger children ($P = .04$; Fig 2).

Nonstandard care practices were also associated with PRD_{IP} in the multivariable model (Fig 2). The receipt of continuous albuterol increased PRD_{IP} by almost 4 hours ($P < .001$). Children receiving injected steroids had a 9.7-hour longer PRD_{IP} than those who only received oral steroids ($P < .001$). Receiving azithromycin increased PRD_{IP} by 5.9 hours ($P < .001$). The administration of ipratropium and receipt of a chest radiograph increased PRD_{IP} by 5.6 and 4.3 hours, respectively ($P < .001$ for both). ICU admission was not associated with PRD_{IP} ($P = .82$) because of its high correlation with continuous albuterol (Spearman's $\rho = 0.80$; $P < .0001$). These results support that nonstandard care practice use is associated with PRD_{IP}.

IP care practices also contributed to PRD_{IP} in the multivariable model (Fig 2). Children receiving continuous pulse oximetry, alone or in combination with spot checks, had a 3- to 3.5-hour longer PRD_{IP} than children receiving only spot checks ($P < .05$). Other than the small number of children discharged from the ICU, the provider performing weaning assessments did not markedly alter PRD_{IP}. PRD_{IP} was not associated with the managing physician ($P = .08$; Fig 2); however, children who were seen only by a generalist were less likely to receive nonstandard care practices (odds ratio = 0.20; confidence interval = 0.15–0.26; $P < .0001$; data not shown). These results reveal that continuous pulse oximetry is associated with longer PRD_{IP} after accounting for other factors.

Factors Influencing PRD_{TOT}

ED-specific and location-dependent factors (performed in the ED, IP, or both) that were individually associated with increased PRD_{TOT} included injected steroids outside the ED, not receiving ED dexamethasone, receiving ED magnesium sulfate, chest radiograph not performed in the ED, and the administration of IP and antibiotics outside of the ED (Supplemental Table 3). Because dexamethasone was used mainly at the Cleveland hospital, we tested the association between PRD_{TOT} and dexamethasone for Cleveland and found that it was strongly associated with shorter PRD_{TOT} ($P < .001$; data not shown).

In the multivariable model, location-dependent practices were associated with PRD_{TOT} (Fig 3). Receiving antibiotics only in IP was associated ($P \leq .001$) with a 6- to 6.7-hour longer PRD_{TOT} than receiving antibiotics in the ED and IP, ED only, and not receiving antibiotics. Furthermore, having chest radiographs in the IP only or in both the IP and ED was associated with 5.6- and 7.9-hour longer PRD_{TOT}, respectively, than not having a chest radiograph ($P < .001$). Individuals receiving a chest radiograph only in the ED did not have a significantly increased PRD_{TOT} ($P = .06$). Receiving IV steroids only in IP was associated with 8.4- and 7.1-hour longer PRD_{TOT} than receiving no IV steroids or only in the ED, respectively ($P < .001$).

Dexamethasone and magnesium administration in the ED were marginally significant in the multivariate model ($P \leq .14$), although they were highly significant individually (Supplemental Table 3). Individuals receiving magnesium sulfate were more likely to receive

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nonstandard care (odds ratio = 5.53; confidence interval = 3.87–8.05; $P < .001$; data not shown). To evaluate the effect of dexamethasone on PRD_{TOT}, we restricted the analyses to Cleveland. Those receiving dexamethasone were less likely to receive nonstandard care (60.2% vs 87.9%; $P = .0041$; data not shown), be admitted to the ICU (36.0% vs 69.7%; $P < .0001$), and to receive injected steroids (31.8% vs 72.7%; $P < .0001$). In a multivariate model that was not adjusted for nonstandard care, those receiving dexamethasone stayed for 11.7 hours less ($P = .007$; data not shown) than those who did not.

Variation in PRD_{IP} Among Hospitals is Due in Part to Variation in Hospital-Level Factors

After accounting for demographics, nonstandard care, and IP practices or demographics, nonstandard care, IP practices, and ED practices, the differences in PRD among the hospitals substantially decreased compared with what was seen in the unadjusted model (Fig 4). In the adjusted models, the longer PRD_{IP} at the Cleveland site observed in the unadjusted model decreased. Thus, hospital-level factors contributed substantially to PRD_{IP}. It is important to note that even after adjustment for system-level variation, differences in PRD_{IP} among the sites persisted, suggesting that other, unaccounted factors play a role.

Opportunities for Process Improvement by Site

To determine if there are opportunities for improvement within each hospital, we evaluated hospital practices that were associated with shorter PRD_{IP} by hospital (Table 1). The use of spot-only pulse oximetry monitoring was >72% at Dayton and Akron, but it is rarely exclusively performed in Cincinnati or Columbus. Dayton and Akron also had higher rates of the initiation of antibiotics and IV steroids in the ED compared with the other sites. ED dexamethasone use was limited almost exclusively to the Cleveland site but was associated with a significantly shorter PRD_{IP} when that site was evaluated alone.

DISCUSSION

When children are admitted for an acute asthma exacerbation, the goal is to use guideline-level care to bring the patient to PRD in the shortest amount of time. However, treatment guidelines for IP asthma exacerbation translate into practice differently, leading to wide variation in hospitals. In this article, using a prospective study of 6 major hospitals in Ohio (OPAR), we demonstrate that PRD timing is multifactorial and includes a substantial contribution from hospital-level factors. Although clearly influenced by patient factors, the differences in hospital practices identified herein may offer an opportunity for improvement. Specifically, our results reveal that when clinically indicated, using spot-only pulse oximetry may shorten time to PRD. Furthermore, because those who did not receive nonstandard care had markedly lower PRD, minimizing the use of nonstandard care practices unless medically warranted is critical. These results reveal that the use of standardized and evidence-based severity assessments to identify those who warrant nonstandard care is essential.

We found that continuous pulse oximetry use was associated with increased time to PRD. It has been recommended to limit continuous pulse oximetry in children with severe illness, who likely need intensive monitoring (eg, in the ICU), but those with mild and moderate

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respiratory disease can be managed with spot checks.[12] Furthermore, although pulse oximetry offers a noninvasive method for measuring arterial oxygen saturation, a major limitation is that of motion artifacts.[13] Continuous monitoring likely increases the observation of artifacts and other nonclinically significant, transient decreases in oxygen saturation that may lead to more aggressive care and increase time to PRD. In several of the OPAR hospitals, the use of continuous pulse oximetry is routine. Our results suggest that limiting the use of continuous pulse oximetry to only when it is clinically indicated may decrease time to PRD. Additional studies are required to verify this finding.

We also found that nonstandard care practice use is associated with increased PRD. One reason for nonstandard care practices use is the more severe or complex exacerbation. Previous researchers have found comorbid respiratory infections[14,15] and respiratory failure[16] to be associated with increased length of stay. In addition, the use of nonstandard care practices that contribute to delaying PRD may be related to physician preference or a lack of use of evidence-based practices across providers. Interestingly, in our previous article,[10] we noted a high rate of IP ipratropium use at the Cleveland hospital. It was determined that this high rate had no relation to exacerbation, but rather it was due to a standard order set. The routine use of ipratropium on the IP units in Cleveland has since been discontinued, but our data reveal the need to minimize nonstandard care unless it is medically warranted.

Notably, dexamethasone use in the ED was associated with shorter time to PRD. Previous studies have revealed potential benefits of dexamethasone, including decreased vomiting and improved adherence.[17] Furthermore, dexamethasone has been associated with shorter length of stay and comparable readmission rates.[18] We found that individuals receiving ED dexamethasone were less likely to be admitted to the ICU or receive IV steroids, suggesting that receiving ED dexamethasone may circumvent the need for more aggressive IP interventions. Because this finding was driven by nearly exclusive use in Cleveland, it requires confirmation. Early (within 1 hour of arrival) administration of systemic corticosteroid in the ED has been associated with fewer admissions and shorter length of stay.[19] Although the early administration of dexamethasone in the Cleveland ED could be an alternative explanation for the differential outcome, this was not the practice at this site. As part of process improvement, an evaluation of the use of dexamethasone in the ED has been implemented at Cincinnati on the basis of our findings, and data on readmission and hospital PRD are being prospectively collected.

The timing of certain care practices (chest radiographs, antibiotics, and/or IV steroids in the ED rather than IP) was also associated with shorter PRD timing among those who received the practice. There are 2 possible reasons for such an association. First, an earlier initiation of clinically important and indicated specific treatments may shorten PRD. When indicated by symptoms or physical findings (eg, fever, localized adventitious lung sounds, hypoxemia, or vomiting), initiating such interventions in the ED may shorten length of stay by 6 to 10 hours.[19,20] If this is the case, then there could be opportunities for improvement by incorporating evidence-based care algorithms in the ED, given the marked variations among the OPAR hospitals. Indeed, the use of validated assessment tools or development of more sensitive scores could expedite the identification of children with more severe illnesses who

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would benefit from an earlier initiation of treatments. It is also possible that nonstandard interventions may be used more indiscriminately in the ED on patients with milder exacerbations, and then these care practices are discontinued during the IP stay. However, we are unable to determine if certain nonstandard care practices, such as chest radiographs or antibiotics, were definitely indicated. Clearly, additional studies are warranted to determine guidelines for ED physicians; however, the routine use of such practices should be discouraged because children who do not require nonstandard care have shorter PRD.

Not surprisingly, patient-level factors, such as public insurance, were also associated with increased time to PRD. Our finding is consistent with previous studies in which researchers have found that children with public insurance had longer length of stay[21] and higher hospital charges.[22] This may be because socioeconomic status (for which insurance is a proxy) is considered a rough marker of environmental and/or behavioral exposures that may contribute to exacerbation severity.[23] Indeed, once matched for severity, researchers in a multisite study failed to find differences in length of stay by insurance.[24]

A major limitation of our study is that the 6 OPAR hospitals do not use consistent measures to evaluate exacerbation severity, such as the use of an established scoring system.[25–27] This is a critical gap in current practice and makes multisite quality improvement challenging. Although the nonstandard care practices that we examined herein may be indicators of a more severe course (confounding by indication), they are not exacerbation severity measures and cannot be used as such. Furthermore, it is important to recognize that simply shortening PRD may not result in optimal patient outcomes. Patients who fail standard ED therapy and then also fail to respond to or deteriorate with standard IP treatment will also require nonstandard care practices and longer time to PRD. It is important to note that even after adjustment for hospital-level practice variation, significant differences in PRD among the sites persisted, suggesting that other, unaccounted factors play a role. This suggests that factors such as adherence and underlying differences in disease biology (eg, treatment response phenotypes, immunologic phenotypes, and genetic variation) may also contribute.

CONCLUSIONS

Variation in care practices exists within and among children’s hospital systems in Ohio, and specific, system-level factors and therapies contribute to PRD. We found several modifiable factors that warrant further investigation. Furthermore, the assessment of exacerbation severity is critical to ensure that those who require nonstandard care receive it in a timely manner while minimizing nonessential care for those who are not likely to need it.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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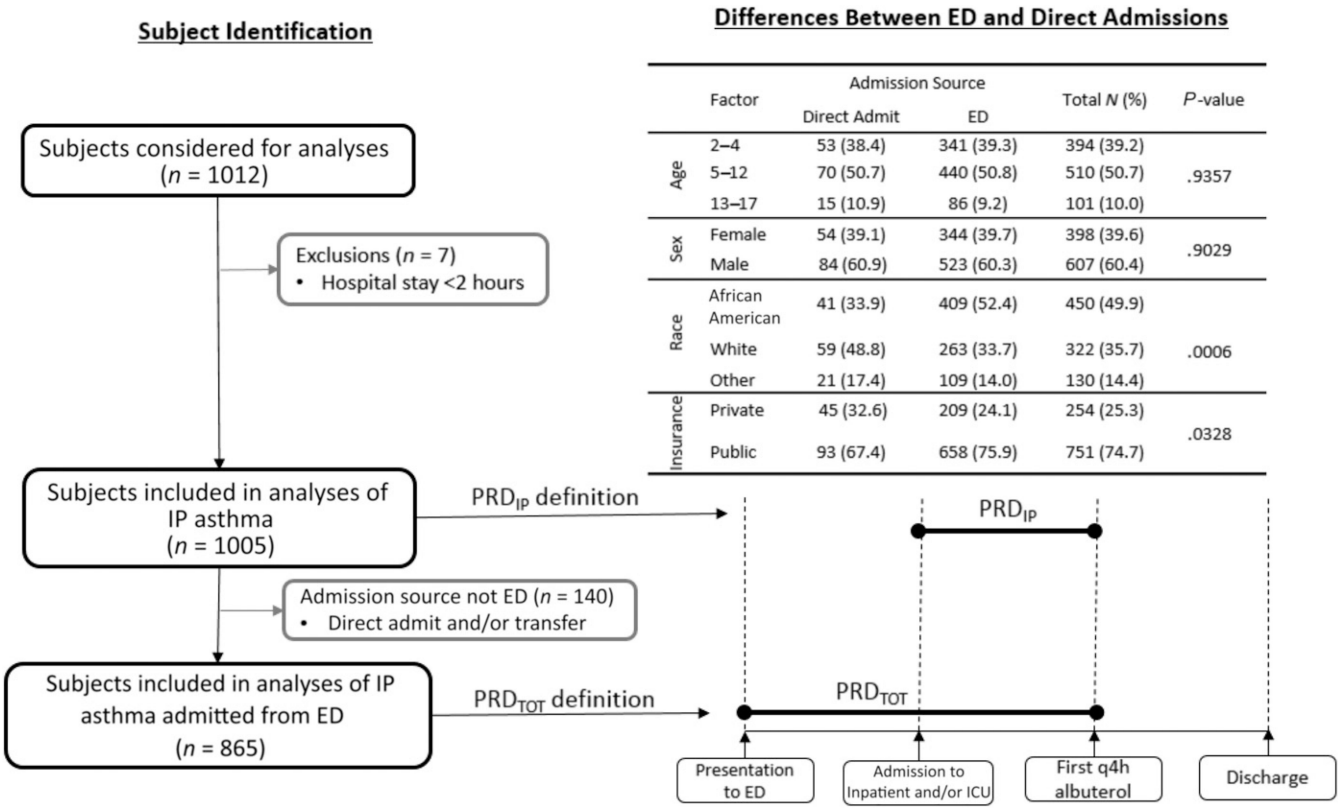

Differences Between ED and Direct Admissions

	Factor	Admission Source: Direct Admit	Admission Source: ED	Total *N* (%)	*P*-value
Age	2–4	53 (38.4)	341 (39.3)	394 (39.2)	.9357
	5–12	70 (50.7)	440 (50.8)	510 (50.7)	
	13–17	15 (10.9)	86 (9.2)	101 (10.0)	
Sex	Female	54 (39.1)	344 (39.7)	398 (39.6)	.9029
	Male	84 (60.9)	523 (60.3)	607 (60.4)	
Race	African American	41 (33.9)	409 (52.4)	450 (49.9)	.0006
	White	59 (48.8)	263 (33.7)	322 (35.7)	
	Other	21 (17.4)	109 (14.0)	130 (14.4)	
Insurance	Private	45 (32.6)	209 (24.1)	254 (25.3)	.0328
	Public	93 (67.4)	658 (75.9)	751 (74.7)	

FIGURE 1.
Subject identification and PRD definitions.

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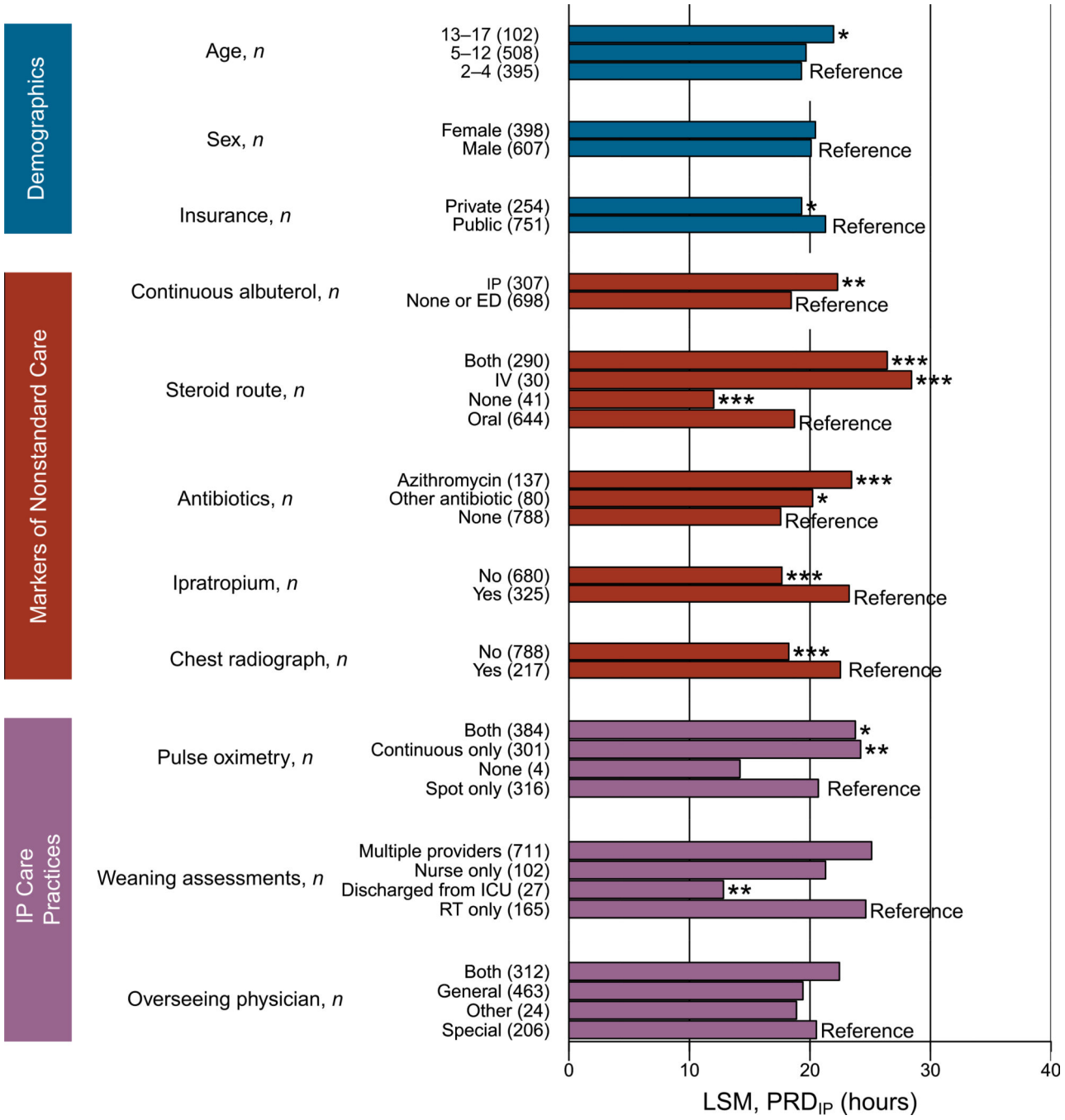

FIGURE 2.

Demographic, severity indicator practices, and IP practices are associated with PRD_{IP} in a multivariable model. LSM, least square mean; RT, respiratory therapist. * $P < .05$; ** $P < .01$; *** $P < .001$.

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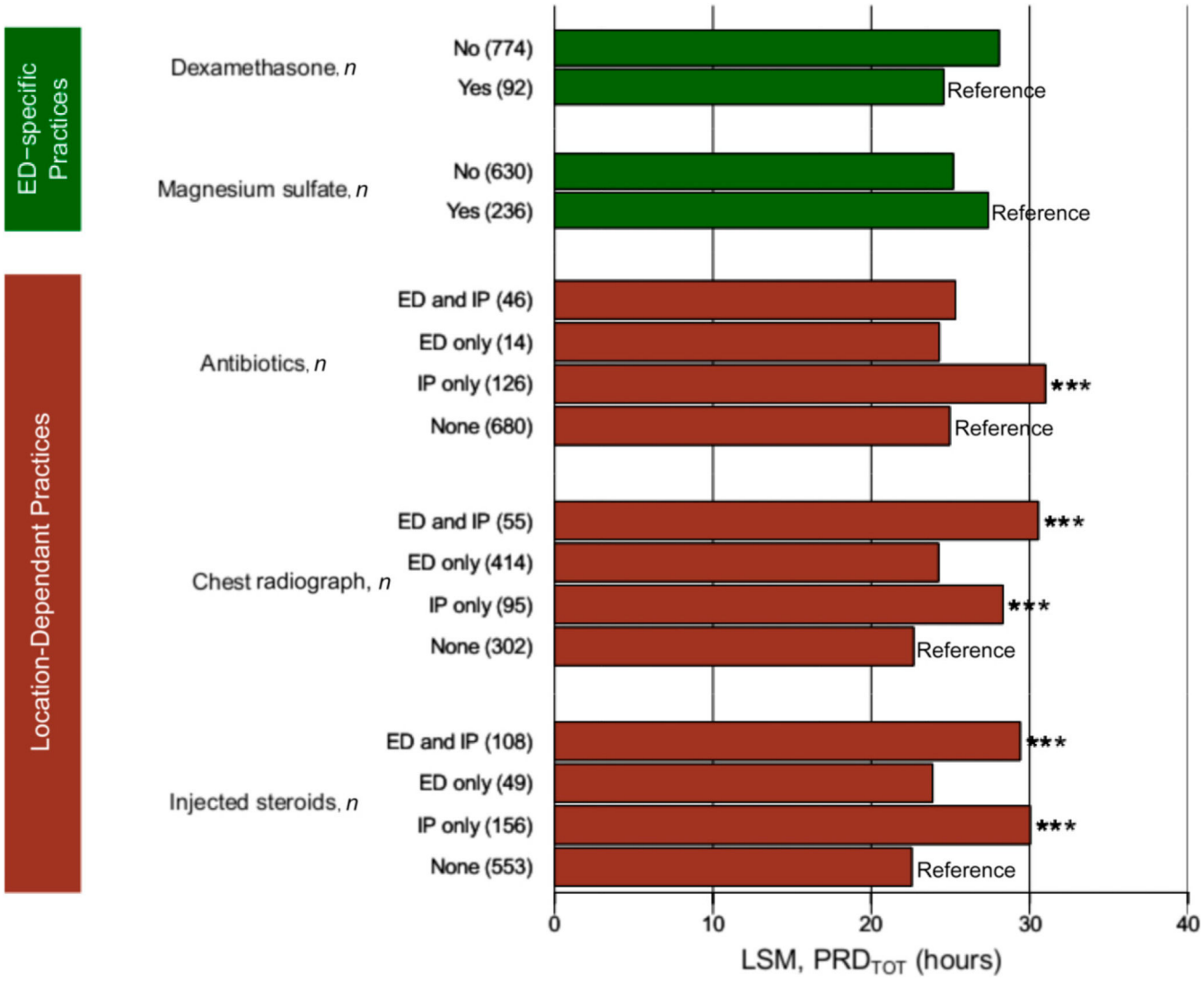

FIGURE 3.

ED practices and time-dependent practices associated with PRD_{TOT} in a multivariate model. LSM, xxx. * $P < .05$; ** $P < .01$; *** $P < .001$.

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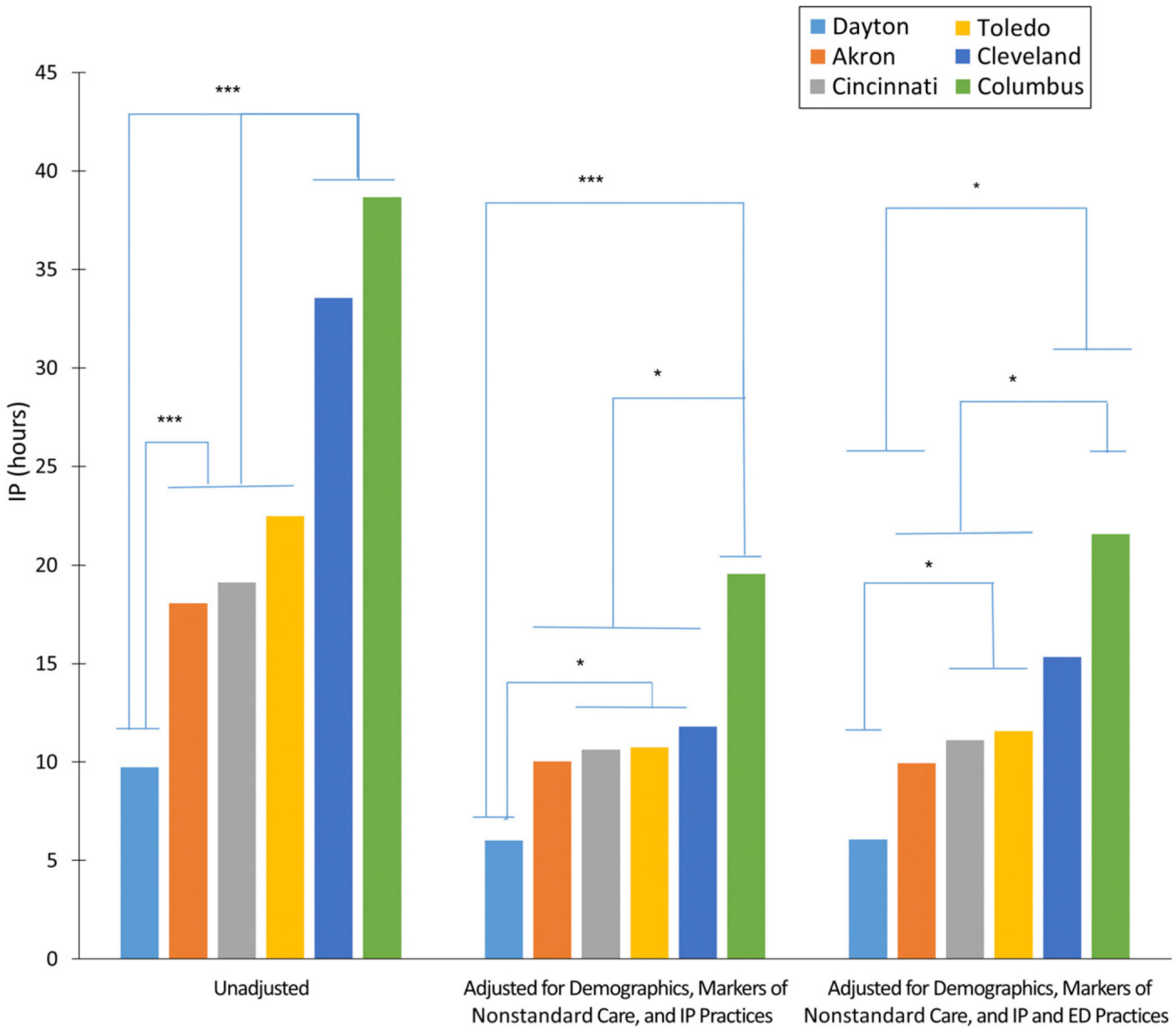

FIGURE 4.

Variation in timing to PRD by hospital is partially explained by demographics, exacerbation severity, and IP and ED practices. * $P < .05$; ** $P < .01$; *** $P < .001$.

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TABLE 1

Prevalence of IP and ED Practices Associated With Shorter Time to PRD by Hospital

	Dayton	Akron	Cincinnati	Toledo	Cleveland	Columbus
n, IP (ED)	115 (114)	103 (72)	365 (356)	58 (35)	196 (121)	168 (168)
PRD_{IP}, mean ± SD	9.74 ± 0.06	18.06 ± 0.07	19.13 ± 0.04	22.46 ± 0.09	33.57 ± 0.05	38.66 ± 0.05
PRD_{TOT}, mean ± SD	13.77 ± 0.05	20.77 ± 0.07	24.71 ± 0.03	26.09 ± 0.10	39.01 ± 0.05	44.60 ± 0.04
Receipt of nonstandard care, %	20.0	68.0	45.2	70.7	93.1	63.1
Intervention						
Pulse oximetry, % spot only (*n*)	77.4 (89)	72.8 (75)	8.8 (32)	67.3 (39)	39.3 (77)	4.8 (8)
ED dexamethasone % (n in ED)	0 (0)	1.4 (1)	0.2 (1)	0 (0)	72.7 (88)	0.6 (1)
ED antibiotics[a] % (n in ED)	6.1 (7)	13.8 (10)	3.9 (14)	11.4 (4)	9.1 (11)	8.3 (14)
ED chest radiograph[b] % (n in ED)	56.1 (64)	44.4 (32)	47.2 (168)	45.7 (16)	51.2 (62)	43.3 (73)
ED IV steroids[a] % (n in ED)	13.2 (15)	37.5 (27)	11.5 (41)	14.3 (5)	12.4 (15)	31.5 (53)
ED intervention among those receiving intervention						
Antibiotics[a], % (*n* in ED/*n* ever)	38.9 (7/18)	47.6 (10/21)	30.4 (14/46)	26.7 (4/15)	28.2 (11/39)	30.4 (14/46)
Chest radiograph[b], % (*n* in ED/*n* ever)	90.1 (64/71)	69.6 (32/46)	78.1 (168/215)	55.1 (16/29)	63.3 (62/98)	69.5 (73/105)
IV steroids[c], % (*n* in ED/*n* ED and IP)	77.8 (7/9)	64.7 (11/17)	18.1 (17/94)	12.5 (1/8)	8.9 (4/45)	28.1 (9/32)

[a]Initiated in ED.

[b]Received only in ED.

[c]Includes individuals who received during IP hospital course but excludes individuals receiving in both the ED and IP.