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Personal Protective Equipment Adherence of Pediatric Resuscitation Team Members During the COVID-19 Pandemic

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Study objective: During the COVID-19 pandemic, health care workers have had the highest risk of infection among essential workers. Although personal protective equipment (PPE) use is associated with lower infection rates, appropriate use of PPE has been variable among health care workers, even in settings with COVID-19 patients. We aimed to evaluate the patterns of PPE adherence during emergency department resuscitations that included aerosol-generating procedures.

Methods: We conducted a retrospective, video-based review of pediatric resuscitations involving one or more aerosol-generating procedures during the first 3 months of the COVID-19 pandemic in the United States (March to June 2020). Recommended adherence (complete, inadequate, absent) with 5 PPE items (headwear, eyewear, masks, gowns, gloves) and the duration of potential exposure were evaluated for individuals in the room after aerosol-generating procedure initiation.

Results: Among the 345 health care workers observed during 19 resuscitations, 306 (88.7%) were nonadherent (inadequate or absent adherence) with the recommended use of at least 1 PPE type at some time during the resuscitation, 23 (6.7%) of whom had no PPE. One hundred and forty health care workers (40.6%) altered or removed at least 1 type of PPE during the event. The aggregate time in the resuscitation room for health care workers across all events was 118.7 hours. During this time, providers had either absent or inadequate eyewear for 46.4 hours (39.1%) and absent or inadequate masks for 35.2 hours (29.7%).

Conclusion: Full adherence with recommended PPE use was limited in a setting at increased risk for SARS-CoV-2 virus aerosolization. In addition to ensuring appropriate donning, approaches are needed for ensuring ongoing adherence with PPE recommendations during exposure. [Ann Emerg Med. 2021;78:619-627.]

Please see page 620 for the Editor's Capsule Summary of this article.

A **podcast** for this article is available at www.annemergmed.com.

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INTRODUCTION

Background and Importance

As of February 2021, the COVID-19 pandemic has led to more than 26 million infections and more than 460,000 deaths in the United States.¹ Health care workers have a more than 10-fold higher risk of contracting the virus compared to the general population.^{2,3} The US Centers for Disease Control and Prevention (CDC) has published several guidelines for reducing the risk of viral spread from patients to health care workers, including recommendations for universal personal protective equipment (PPE) standards (N95 mask, eye protection, gloves, and a gown), monitoring of PPE donning and doffing by trained observers, avoiding aerosol-generating procedures, and minimizing the number of providers with potential exposure.⁴ Although these

recommendations have been widely adopted, variable adherence to PPE use has been observed, even in settings at high risk for SARS-CoV-2 transmission.⁵

Several factors have been associated with PPE nonadherence, including the perceived likelihood of transmissible infection, workplace stress and fatigue, availability of adequate PPE, and prioritization of urgent patient need over appropriate PPE use.^{3,5-8} These factors are especially relevant in an emergency department (ED) setting, where patients with unknown COVID-19 status often require time-sensitive management by multidisciplinary teams. Even before the pandemic, variable adherence to recommended PPE use was observed in settings with a high risk of infection transmission, including pediatric and adult trauma resuscitations and ICUs.⁹⁻¹¹

Editor's Capsule Summary*What is already known on this topic*

Appropriate use of personal protective equipment (PPE) can prevent COVID-19 transmission.

What question this study addressed

How adherent were health care providers with the recommended PPE during pediatric emergency department resuscitations that include aerosol-generating procedures during the first 3 months of the COVID-19 pandemic?

What this study adds to our knowledge

In this single-center retrospective study using video review, 306 of 345 health care workers (89%) caring for 19 children were noncompliant with at least one recommended PPE item for at least part of the resuscitation.

How this is relevant to clinical practice

Approaches to improve adherence with PPE are needed to protect health care workers from COVID-19 exposure during resuscitations.

Goals of This Investigation

The goal of this investigation was to evaluate patterns of PPE use and identify factors associated with adherence and nonadherence to PPE use among health care workers during aerosol-generating procedures performed in an ED setting. We focused on pediatric resuscitations occurring at the beginning of the COVID-19 pandemic in the United States (March to June 2020) to evaluate evolving changes in PPE adherence.

MATERIALS AND METHODS**Study Design**

Using video review, we conducted a retrospective, observational study of PPE adherence among participants in pediatric resuscitations in the ED between the middle of March and the middle of June of 2020. To focus on periods with the highest risk for potential SARS-CoV-2 virus transmission to health care workers, we selected resuscitations that included one or more aerosol-generating procedures.¹² Resuscitations were video recorded with 3 views (from overhead, the head, and the foot of the bed). Consent was required for video use for research purposes. (Parental or guardian consent was attempted at the time of patient presentation. Consent may also have been obtained at any time during the hospital stay.) The Children's

National Hospital Institutional Review Board approved this study.

Setting

Children's National Hospital is a tertiary care hospital and accredited level 1 pediatric trauma center serving the greater Washington, DC area. The hospital has 2 resuscitation bays in the ED, where approximately 275 children are managed as medical resuscitations and approximately 600 injured children are managed as trauma resuscitations each year.

Population

A multidisciplinary team evaluates patients who are treated in the resuscitation bays. Leadership for these resuscitations includes an emergency attending physician and a documenting nurse for all events, a critical care physician for medical resuscitations, and a surgical coordinator (pediatric surgery fellow or senior surgical resident) for trauma resuscitations. Other team members include a bedside surveyor (emergency medicine resident, surgical resident, or nurse practitioner) responsible for the physical assessment, 2 or more bedside nurses or technicians, and an airway team comprised of an anesthesiologist and a respiratory therapist. A surgical attending physician and a critical care attending physician are present for children triaged to the highest level of trauma or medical resuscitations.

Before the COVID-19 pandemic, PPE requirements for health care workers participating in ED resuscitations at our hospital included only gloves and a water-resistant gown.⁹ After the start of the pandemic, hospital guidelines for PPE use in this area were changed to also include a recommendation for headwear (eg, scrub cap), required eyewear (eg, goggles, surgical glasses, face shield), and a face mask (N95 required) or powered air purifying respirator.⁴ N95 masks and eye protection were distributed to staff at the start of the study period. N95 mask supply early in the study period was limited, and individuals only received 1 mask. At the study midpoint (end of April 2020), an individual was stationed outside the resuscitation bay to help monitor PPE usage. Throughout the study period, the hospital conducted weekly or twice-weekly town halls for dissemination of information about issues related to the pandemic, including updates on appropriate PPE usage and PPE availability.

Data Collection

For the cases available for review, we assessed the time of each health care worker in the room ("individual room

time”) and the time spent in each category of adherence (ie, complete, inadequate, and absent). To identify lapses in PPE adherence during the highest risk periods, we evaluated PPE use by providers from the beginning of the first aerosol-generating procedure to the time of patient departure from the resuscitation area. When a provider left the room and returned, the time spent outside of the room was not included. We defined aggregate exposure time as the sum of the time of individuals in the room after the aerosol-generating procedure, regardless of the duration of individual exposure or whether individual exposure time was continuous or not. The approach using aggregate time is supported by the observation of viral transmission after multiple brief exposures.¹³ Analysis of indoor spreader events suggests that transmission risk is linearly related to exposure time.¹⁴ PPE items were identified and assigned an adherence level for each team member. If a team member changed their PPE use during the observation period, the separate durations of adherence and nonadherence (inadequate or absent adherence) were recorded.

Data Management and Outcomes

We developed a data dictionary to define aerosol-generating procedure type and PPE adherence level (complete, inadequate, or absent) for the 5 recommended or mandatory PPE items (headwear, eyewear, face masks, gowns, and gloves) (Appendix E1, available at <http://www.annemergmed.com>). Three observers were trained to use this data dictionary to independently assess the PPE adherence of each resuscitation participant using 3 resuscitations not included in the final data set. These raters achieved an interrater reliability of 0.72 (Fleiss’ kappa, indicating good agreement).¹⁵ Adherence with each PPE item was documented if the participant was properly wearing the item. The definitions of full adherence to PPE items followed CDC guidelines, including a secured isolation gown, an N95 respirator, a face shield or goggles that covered the eyes, and gloves covering the wrists.¹⁶ Nonadherence was categorized as inadequate protection (eg, wearing a regular face mask instead of an N95, not fully covering hands with gloves) or complete absence of the PPE item. Health care workers who properly wore a powered air purifying respirator were recorded as wearing complete head covering, eye protection, and face masks.

Statistical Analyses

We summarized the data of adherence time for each PPE item and examined associations with resuscitation type (“medical” or “trauma”) and across PPE types. We summarized categorical characteristics using counts and

frequencies and examined associations with resuscitation type using chi-square tests. We summarized counts or continuous variables with medians and interquartile ranges (IQRs) and tested for association with resuscitation type using the Wilcoxon rank sum test. To examine association between PPE items among health care workers, we used scatter plots and calculated Pearson correlation coefficients. We performed a mixed-effect logistic regression analysis to determine factors associated with nonadherence (inadequate use or absence) of each PPE item. This regression adjusted for the fixed effects of duration of room time of the provider, the chronological order of the resuscitation during the study period, and the random effects of subject. For interpretability of coefficients in this multivariable regression, we rescaled the order and time variables by subtracting the mean and dividing by the standard deviation. This rescaling transformed the regression coefficients to a similar scale. The random effect adjusted for correlation of repeated measures within the same subject (multiple PPE types) and within the same resuscitation (multiple health care workers). We calculated 95% confidence intervals (CIs) and used the Wald test for model-based significance testing. To compare adherence between different types of PPE usage, we varied the PPE type used as the reference group in the multivariable model. We then constructed a matrix representing the odds ratios using different reference and comparison PPE types. All statistical analyses were performed using R.¹⁷

RESULTS

Characteristics of Resuscitations

Thirty-four resuscitations (“medical” n=21, “trauma” n=13) involving aerosol-generating procedures occurred during the 3-month study period. Four resuscitations (“medical” n=4) were excluded due to absent videos or poor video quality, and 11 (“medical” n=3, “trauma” n=8) were excluded because consent was not obtained for video review. The final data set included 19 resuscitations containing 45 aerosol-generating procedure events (median, 2; IQR, 2 to 3 aerosol-generating procedure events per case). Among the included resuscitations, the majority were in the “medical” group (n=14, 77.8%). Intubation was the most frequent task requiring 1 or more aerosol-generating procedure events (n=12, 63.1%) (Table 1), followed by tracheostomy changes (n=5, 26.3%) and cardiopulmonary resuscitation (n=2, 10.5%). The identified aerosol-generating procedures included bag valve mask ventilation in every resuscitation (n=19, 42.2%), endotracheal tube insertion in 12 resuscitations (26.7%), suctioning in 12 resuscitations (26.7%), and

Table 1. Resuscitation characteristics.

Variable	Consented	Unconsented
No.	19	15
Medical resuscitation (no., %)	14 (73.7)	7 (46.7)
Type of main aerosol-generating procedure (no., %)		
Intubation	12 (63.1)	12 (80.0)
Tracheostomy change	5 (26.3)	0 (0.0)
CPR	2 (10.5)	3 (20.0)
Day time event (no., %)	15 (78.9)	6 (40.0)
Month (no., %)		
First	9 (47.4)	2 (13.3)
Second	7 (36.8)	4 (26.7)
Third	3 (15.8)	9 (60.0)
No. of providers per event, median (IQR)	17 (16–20.5)	
Duration in minutes, median (IQR)		
Event duration	44.0 (31.7–48.9)	
Length of room time of provider	17.2 (3.9–30.9)	

CPR, cardiopulmonary resuscitation.

cardiopulmonary resuscitation in 2 resuscitations (4.4%). Daytime resuscitations were most common (n=15, 78.9%). The distribution of the main aerosol-generating procedure type was similar between cases included and excluded from the study. Compared to excluded cases, included cases more often occurred during the daytime and earlier in the study period.

The observation period between the aerosol-generating procedure and patient departure had a median length of 44 minutes (IQR, 31.7 to 48.9); these periods were similar for both “medical” and “trauma” resuscitations (“medical” median duration, 42.9 minutes; IQR, 30.5 to 52.8; “trauma” median duration, 44 minutes; IQR, 40.4 to 45.8). Among the 19 patients included in the study, 17 (89.5%) were tested for SARS-CoV-2, and 1 (5.3%) had a positive result. A median of 17 providers (IQR, 16 to 20.5) participated in each event. Team size was similar for “medical” and “trauma” resuscitations (“medical” median, 17 providers, IQR, 16 to 20.8; “trauma” median, 18 providers; IQR, 17 to 19). The cumulative duration of potential viral exposure for team members present in the room following the start of the aerosol-generating procedure was also similar between event types (“medical” median, 350 minutes; IQR, 262.7 to 471.5; “trauma” median, 396 minutes; IQR, 392.4 to 415.2). The duration of nonadherence (inadequate or absent adherence) with each PPE item was similar between “medical” and “trauma” resuscitations (Table 1).

PPE Adherence

In total, 345 health care workers were observed during 19 resuscitations for a total exposure time of 118.7 hours. Among the 345 health care workers, 306 (88.7%) demonstrated nonadherence with recommended use of at least 1 type of PPE at some time during the resuscitation. Among health care workers who demonstrated nonadherence, 23 (6.7%) had no PPE, with an aggregate exposure time of 103 minutes. In contrast, 49 health care workers demonstrated complete adherence with all forms of PPE, with an aggregate exposure time of 19.5 hours. Providers were most often fully nonadherent with recommended headwear (n=204, 59.1%) (Figure 1).

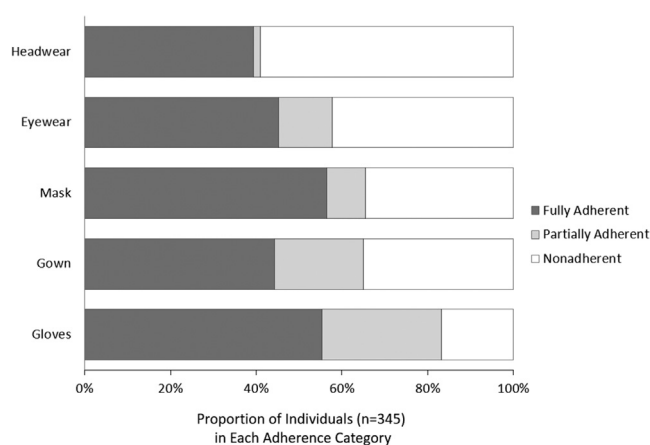


Figure 1. Proportion of individuals in each adherence category for each PPE item (N=345).

Because headwear was a hospital-specific recommendation not enforced by the CDC, we ran additional analyses excluding this PPE item. Similar proportions of health care workers were fully nonadherent with eyewear, masks, and gowns, while fewer providers were observed without gloves (n=58). Seventy-one (20.6%) individuals modified their gown use during the duration of the resuscitation. A similar proportion of individuals altered use of their eyewear and masks during the resuscitations (Figure 1). Thirty-one (9%) health care workers changed from adherent to nonadherent with mask use during the resuscitation, putting themselves at risk for 3.3 hours of exposure, while 43 (12.5%) health care workers modified their use of eyewear from adherent to nonadherent for 4.7 hours of exposure.

The median room time of the 345 providers after the start of the first aerosol-generating procedure in each resuscitation was 17.2 minutes (range, 0.1 to 84.6) (Table 1). Other than headwear, eyewear was the most absent among required PPE types (43.9 hours, 36.2%) (Figure 2). Masks were the PPE item accounting for the highest proportion of aggregate time with inadequate use, followed by gowns. We grouped providers into quartiles based on their exposure time to evaluate the association time with PPE adherence. Providers in the first quartile (shortest duration) were less adherent to PPE guidelines compared to those in other quartiles. Adherence to gown and glove use increased across quartiles. The health care

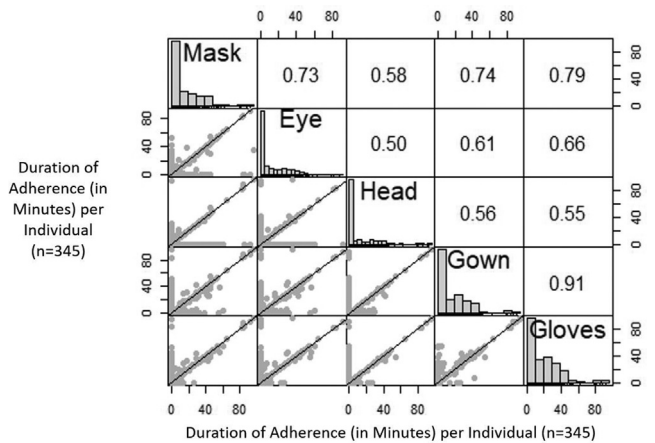


Figure 3. Correlation of times of use (in minutes) between PPE types. Diagonal panels, histogram of time (in minutes) of full adherence with each PPE item. Left lower panels, scatter plot of full adherence time for each pair of PPE items. Curves represent the locally linear fit (loess). Right upper panels, Pearson correlation of full adherence time for each pair of PPE items.

workers who spent the longest time in the resuscitation room (fourth quartile) were the most adherent with recommended PPE use. The duration of complete PPE use by each provider was right skewed, with shorter durations being most frequent (Figure 3). The duration of fully adherent gown and glove use by providers had the highest correlation (r=0.91), while the duration of fully adherent

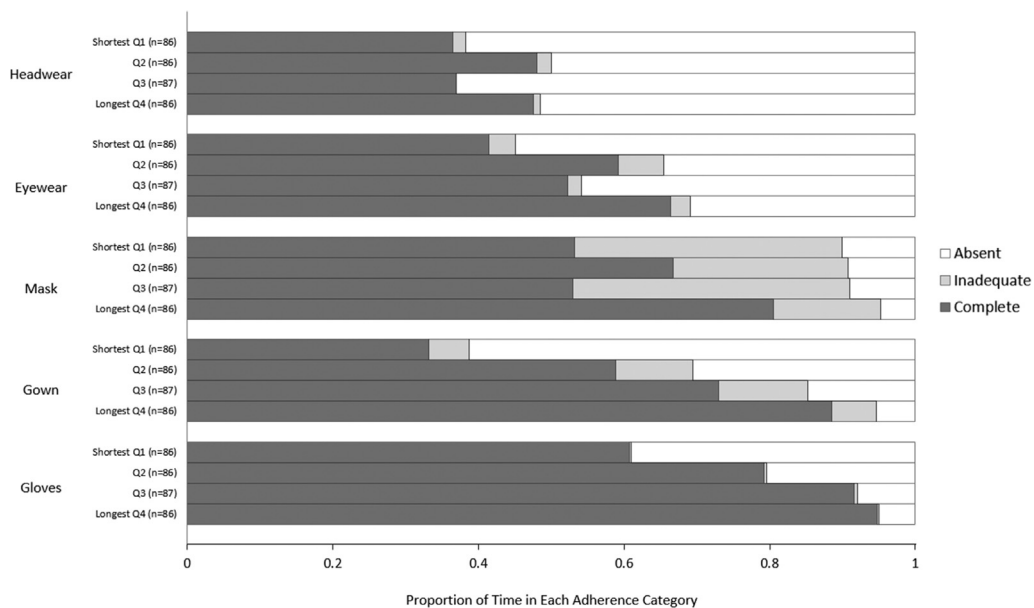


Figure 2. Proportion of aggregate room time of providers with complete, incomplete, and absent PPE after the start of the aerosol-generating procedure. Overall, N=345 individuals. Quartile 1, n=86 individuals, duration 0–3.9 minutes. Quartile 2, n=86 individuals, duration 3.9–16.9 minutes. Quartile 3, n=87 individuals, duration 16.9–30.9 minutes. Quartile 4, n=86 individuals, 30.9–96 minutes.

Table 2. Factors associated with PPE nonadherence by providers using multivariable logistic regression analysis: nonadherent (inadequate or absent) PPE use versus fully adherent use.

Variable	Odds Ratio	95% CI
Resuscitation order*	0.54	0.37–0.77
Length of room time of provider*	0.65	0.53–0.78
PPE type (reference = gloves)		
Eyewear	1.79	1.25–2.55
Mask	0.94	0.66–1.33
Gown	1.88	1.32–2.68

*Variable was rescaled to have mean 0 and standard deviation of 1 by subtracting overall mean and dividing by the standard deviation.

headwear use had the lowest correlation with the durations of other types of PPE use ($r=0.50$ to 0.58) (Figure 3).

In a multivariable analysis, nonadherence (either inadequate or absent adherence) with PPE use decreased throughout the study period (odds ratio 0.54, 95% CI 0.37 to 0.77) (Table 2). Nonadherence occurred less often when providers were in the room for a longer period of time after the start of the aerosol-generating procedure. Pairwise comparisons of individual types of PPE use showed a 2-level hierarchy of adherence: mask and glove use were equivalent, and providers had greater compliance with these items compared to eyewear and gown use, which were also equivalent (Table 3).

LIMITATIONS

This study has several limitations. First, this study was performed at a single institution. Our analysis was limited by the video coverage of the room. Although the video views included most of the room, providers may have been in other areas of the room not covered by our video recording system. Second, our analyses were limited to the resuscitations that were available for review. We observed differences between included and excluded cases based on the time of day and based on distribution throughout the study period. These

Table 3. Comparisons between the odds of nonadherence among PPE types using multivariable logistic regression analysis: nonadherent (inadequate or absent) PPE use versus fully adherent use.

	Eyewear	Gown	Gloves
Gown			0.53* (0.37, 0.76)
Eyewear		1.05 (0.74, 1.49)	0.55* (0.39, 0.80)
Mask	1.91* (1.34, 2.73)	2.01* (1.41, 2.87)	1.07 (0.75, 1.52)

Reference in parentheses

*Indicates statistically significant comparisons.

factors may have also contributed to differences in PPE adherence. Third, a large number of providers were present at each resuscitation. It is not known whether this feature is unique to resuscitations at our hospital or whether it may limit the generalizability of our findings. One study outside our institution counted team size during adult trauma resuscitations using video review. Although a maximum of 10 providers were observed, individuals in all roles or providers without a designated role who were briefly in the room were not counted.¹⁸ In our study, we included every person coming into the room, if only briefly. Validation of our findings will require replication at other sites using video review. Additional limitations of a single-center design include workplace culture, PPE availability, and institutional policies.⁸ PPE use may also vary in settings outside of the ED, where the workflow, risk of patient infection, and other factors influencing PPE use, differ.

We were not able to identify whether differences in PPE use were related to provider role, a factor previously associated with PPE use.^{19,20} Although we were able to track individuals in the video by their appearance, it was more difficult to identify roles when most individuals were wearing PPE covering their heads and faces. We were also not able to identify reasons for PPE nonadherence using video review. Tracking the pattern of PPE use and the impact of any intervention on these patterns is necessary for enhancing adherence and promoting provider safety. We did not evaluate the distances of providers from the patients as an assessment of relative risk of contact with aerosolized virus. Although some providers were consistently either near or at a distance from the patient, most moved throughout the room. Advanced tracking methods using optical particle sizers to assess air concentration may address the impact of distance on the patterns of PPE use.^{21,22} Finally, this study evaluated PPE use during what is widely accepted as the first 3 months of the US COVID-19 pandemic (March to June 2020). Our findings during this period showed improvements in PPE adherence as we adjusted to the pandemic.

DISCUSSION

Aerosol-generating procedures are often required during medical and trauma resuscitations for critically ill and injured children. Although the need for an aerosol-generating procedure can sometimes be anticipated before a resuscitation begins, it is sometimes only identified after a resuscitation starts. To reduce the risk of infection to health care workers and avoid delays in performing potentially lifesaving interventions, our hospital adopted a policy at the start of the pandemic that requires specific types of PPE before entering the resuscitation room. The zone of

detectable aerosolized virus extends to as much as 4 meters, and aerosolized virus may remain in the air for as long as 3 hours after an aerosol-generating procedure.²³⁻²⁵ Providers also may have increased risk of infection, even if their exposure time is brief.¹³ These factors support our hospital policy of requiring continued PPE use throughout the duration of each resuscitation, regardless of the need for an aerosol-generating procedure.

Despite the implementation of a hospital PPE policy to promote provider safety, we observed frequent nonadherence with required PPE use. We identified several factors associated with the frequency, duration, and type of nonadherence (inadequate or absent adherence), including the type of PPE being evaluated and the length of provider time in the room. Most providers had less than recommended PPE adherence and changed their PPE adherence throughout the resuscitation. Although nonadherence by individuals was often brief, viral transmission may occur with multiple brief exposures.¹³ Aggregation of the time of nonadherence across providers established a metric for evaluating the potential exposure of all individuals providing care.

Several explanations may account for variability in use based on PPE type. Before the pandemic, our hospital guidelines required only gowns and gloves for providers participating in medical and trauma resuscitations.⁹ After the start of the pandemic, these 2 types of PPE continued to be used with high frequency and were correlated in use among individuals. These findings suggest the influence of established practices, even after extension to other types of PPE. Although based only on findings from qualitative studies, a recent Cochrane review identified workplace culture as a facilitator of infection control practices in settings at risk for respiratory infection transmission.⁸ Improvements in adherence with all types of PPE during the study period may reflect a similar impact of workplace culture during the study period.

In March 2020, our hospital instituted a mandatory mask policy (surgical mask) for staff working in all locations. This requirement was supported by making surgical masks easily available to all employees. Despite a hospital-wide surgical mask policy, providers were observed without masks in the time period after aerosol-generating procedures in the resuscitation area. The aggregate length of time of providers without masks was small, showing that most without masks were in the room for a short time. Although we did not determine the reasons for nonadherence, this finding may be attributed to the perceived low risk of exposure during a short exposure time or the need to provide urgent patient care before donning appropriate PPE.^{5,8} The resuscitation area included an

additional requirement for either N95 masks or powered air purifying respirators to ensure that providers were prepared for the risks associated with potential aerosol-generating procedures. Switching from a paper surgical mask to an N95 or a powered air purifying respirator involves a change in PPE before entering the room. For powered air purifying respirators, this exchange can be time consuming. Early in the pandemic, N95 masks were in short supply at our hospital, with distribution prioritized to those at highest risk of exposure. These factors partially account for the observation that the use of only paper surgical masks was the most frequent type of partial mask adherence. As with all types of PPE use, adherence with mask protection increased during the study period, likely related to the availability of N95 masks and powered air purifying respirators and the development of a workplace culture expecting this type of protection. Because this study was retrospective, we were not able to determine whether nonadherence with recommended usage was related to PPE availability or personal choice. This distinction is needed to implement the most effective interventions for promoting adherence.

Inadequate and full adherence with headwear was the lowest among the types of PPE evaluated. More complete body coverage has been associated with a lower risk of exposure to contaminated body materials. Head coverings reduce contamination of the hair and other head areas, mainly resulting from hand-to-head contact. Despite this evidence, the CDC has not included headwear as a recommendation for preventing SARS-CoV-2 transmission.⁴ Although recommended in the ED and other high-risk clinical areas, headwear was not required in most areas in our hospital. Because many providers only work in the ED for resuscitations, work in this area requires donning headwear in addition to other types of PPE before entering the room. The lack of a national mandate and variability in local head covering practices likely contributed to high nonadherence with headwear.

Previous studies evaluating PPE use have focused on the periods of donning and doffing, with the assumption that period between these 2 procedures has static PPE use. In our study, we observed that providers frequently changed their PPE use while in the room by either modifying or removing equipment. Although we did not determine the reasons for premature doffing or modification of PPE, several factors may have contributed to these changes, including the comfort of the PPE items and the perceived risk of infection based on patient factors or proximity to the patient.^{3,8,26} The CDC has recommended the use of trained observers to promote adherence with PPE donning and doffing during previous disease outbreaks.²⁷ Although

widely adopted, these practices do not address variable PPE adherence that may occur after donning. In addition, these recommended observation practices are difficult to implement in a resuscitation setting, where providers need to rapidly assemble for a time-sensitive event, often arriving from other areas of the hospital with different PPE practices. These findings support the need for new approaches for monitoring the continuous use of PPE, particularly in settings requiring the participation of multidisciplinary providers.

To reduce potential viral transmission to health care workers, our ED leadership implemented several interventions. To reduce incorrect use or premature doffing of PPE, a PPE monitor was positioned outside of the resuscitation area to observe providers entering the room and ongoing PPE use through a window. This PPE monitor may have also helped reduce the number of providers present in the room, a CDC recommendation for reducing the risk of viral transmission to the medical team.²⁸ To increase awareness and promote understanding of recommended PPE use, hospital-wide guidelines based on CDC recommendations were disseminated in written form and presented at unit- and hospital-level conferences and at twice-weekly “town halls.” Educational videos showing the proper use of PPE, including donning and doffing, were developed and made available to providers. Although the relative contribution of these interventions is not known, these types of interventions have been identified as facilitators of adherence with infection control guidelines.^{19,20,29} These interventions occurred at different times during the study period, likely accounting for the contribution of resuscitation order as a predictor of adherence.

A final contributor to the variability in PPE use that we observed was our limited knowledge of the virus at the start of the pandemic.^{3,4,30} In March 2020, our understanding of the risks and modes of transmission associated with SARS-CoV-2 were rapidly increasing, particularly in health care settings. The evolution of our understanding of viral transmission has been accompanied by the rapid implementation of new PPE practices that protect frontline health care workers. The large contribution of viral transmission from asymptomatic children has also been recognized and supports the adoption of broad PPE protection among frontline health care workers providing pediatric care.³¹ This information has been disseminated in the nonmedical press and likely contributed to increased PPE use in the resuscitation area of our hospital.

In conclusion, we observed variability in patterns of PPE nonadherence in a high-acuity pediatric resuscitation setting in the United States in the early months of the

COVID-19 pandemic. PPE adherence improved over time, but partial and full nonadherence remained, even at the end of the observation period. We have shown the value of considering the aggregate exposure risk at the population level of providers rather than of individual providers. This measure may be more suitable for assessing risk in settings where frequent but short durations of PPE nonadherence occurs. Although PPE adherence was higher when individuals spent longer times in at-risk settings, many providers modified their PPE while working, supporting the need for continuous PPE monitoring during the entire period of required PPE use.

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Author contributions: ECA, JLF, KJO, and RSB conceptualized and designed the study. ECA supervised data collection that was performed by KHM, CAH, and JS. ZPM and RI provided statistical analysis. ECA, KJO, and RSB drafted the initial manuscript and all authors contributed to critical revision. All authors approved of the work in its final form. RSB takes responsibility for the manuscript as a whole.

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