Association between Measured Teamwork and Medical Errors: A Prospective Observational Study

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Association between Measured Teamwork and Medical Errors: A Prospective Observational Study

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ABSTRACT

Objectives

The goal of this study was to examine the relationship between measured teamwork and adverse safety events in the prehospital emergency care of children using high-fidelity simulation. We posit that aspects of teamwork such as leadership, trust and communication are largely correlated with the clinical success of teams.

Design

Observational study.

Setting

Emergency Medical Services (EMS) responders were recruited from public fire and private transport agencies in Oregon State.

Participants

Forty-four fire/transport teams consisting of 259 EMS professionals consented to participate and completed simulations.

Primary and Secondary Outcome Measures

We estimated the odds of error with increasing Clinical Teamwork Score (CTS™), adjusting for clinical scenario and potential clustering.

Results

Across 176 simulations, the mean overall score on the CTS™ was 6.04 (SD = 2.10; range 1 = poor to 10 = perfect) and was normally distributed. The distribution of scores was similar across the four clinical scenarios. At least one error was observed in 82% of the simulations. In simulations with at least one observed error, the mean CTS™ score was 5.76 (SD = 2.05) compared with 7.16 (SD = 1.95) in scenarios with no observed error. Logistic regression analysis revealed the odds of an error decreased 28% with each unit increase in CTS™ score (Odds Ratio = 0.72, 95% CI 0.59 – 0.88). This relationship was not confounded by scenario.

Conclusions

This study found that overall teamwork among care delivery teams was strongly associated with the risk of serious adverse events in caring for critically ill and injured children.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- This research provides some of the first data that quantifies the relationship between clinical teamwork and the likelihood of medical errors.
- These data suggest CTS™ may be a useful tool to measure the immediate impact of interventions on teamwork that matter to the reduction of errors.
- Simulations replicated pediatric emergencies known to be high risk for errors and were conducted using professional actors and high fidelity pediatric simulators in the field with clinical EMS teams assembled and responding as they normally would reflecting every day clinical care as closely as possible.
- The appraisal of errors and assignment of teamwork scores were performed by clinicians who were not involved in EMS but were humans using their best judgement, which is a method subject to bias
- It remains uncertain whether poorer teamwork is the cause of errors or if it is simply associated with other deficits in performance that may be contributing, however, this finding provides a tool that can be used to measure impact before and after interventions.

INTRODUCTION

Medical errors, the failure of a planned action to be completed as intended or the use of a wrong plan to achieve an aim,[1] are estimated to be the third leading cause of death in the United States.[2] Medicine is both an important and imperfect field, combining science with art and humans with technology. In 1999, the world became aware that patients not only die from disease and traumatic events, some also die or are injured unintentionally through the provision of clinical care.[3] The landmark Institute of Medicine report estimated that the number of Americans who die every year due to preventable medical errors is equivalent to 3 jumbo jet crashes every 2 days, or one patient every 15 minutes, with over 1 million estimated to be harmed. Studies of medical errors have generally focused on adults and inpatient settings. However, medical errors are also an important source of harm for pediatric patients with estimates of 70,000 pediatric inpatients harmed per year by medical errors.[4, 5] Even less is known about the epidemiology, etiology, and risk factors for preventable adverse events in the care of children in the Emergency Medical Services (EMS) system where children first receive care for emergencies outside of the hospital.

Good communication and teamwork are critical in avoiding medical errors and assuring the safety of patients. Past reviews have indicated that aspects of teamwork such as leadership, trust and communication are largely correlated with the clinical success of teams.[6-8] For example, a study evaluating teamwork in the Intensive Care Unit indicated that 37% of teamwork failures were due to verbal communication errors between physicians and nurses.[9] There have been interventions to reduce medical errors such as implementing computerized provider order-entry systems, limiting residents' work shifts to consecutive hours, and implementing evidence-based care bundles. A large retrospective study from the VA found that inpatient surgical mortality was reduced 18% following team training interventions.[10] However, lack of prospective and detailed evaluation of teamwork elements and specific errors limit our understanding of the effectiveness of these practices.[11] The goal of this study was to examine the relationship between measured teamwork and adverse safety events in the prehospital emergency care of children using high-fidelity simulation.

METHODS

We followed STROBE guidance for reporting of observational studies.[12] The Oregon Health & Science University Institutional Review Board (IRB00006942) approved the study and all subjects signed both study and video consent prior to participation.

Study Participants

In total, 176 simulations were performed over a 6-month timeframe with 44 teams of emergency medical services (EMS) providers recruited from public fire and private transport crews in three large counties surrounding Portland, Oregon in the United States. Portland is the largest city in Oregon and the three county area that participated in this study serves a population of 1.8 million. The EMS system in this region has dual-Advanced Life Support response to all 911 calls with public fire agencies, responding in teams of 3-5 individuals with at least one paramedic, and a private transport agency, responding in 2-person teams with at least one paramedic. We conducted all simulations *in situ* with both fire and transport EMS teams responding to each scenario as they normally would when providing clinical care. Participants ranged from Emergency Medical Technician (EMT) to paramedic, with each team including at least one paramedic.

Forty-four fire/transport teams consisting of 259 EMS professionals were available in the three-county region during our study timeframe and consented to participate. All who consented completed the study. One individual withdrew consent to have his/her individual data analyzed after completing the simulation sessions for personal reasons, but agreed to analysis of team-level data for all simulation sessions he/she had participated. In total, we analyzed team-level data from 44 teams and individual-level data from 258 EMS professionals.

Patient Involvement

The EMS-C Children's Safety Initiative is an observational study with a specific focus on EMS providers. Patients were not involved in the design, recruitment, or conduct of the study.

Simulations

Each fire/ambulance team participated in four simulation scenarios: (1) cardiac arrest in newborn (Newborn Resuscitation Program, NRP), (2) cardiac arrest in child (Pediatric Advanced Life Support PALS), (3) non-accidental trauma (NAT), and (4) accidental trauma from pedestrian-motor vehicle collision (MVC). We conducted all simulations *in situ* at local EMS training centers all scenes and patient simulators were staged in standardized formats. In the NRP scenario, the patient presented as a newborn who was initially responsive upon delivery but subsequently developed a weak cry, flaccid extremities, bradycardia, and cyanosis requiring resuscitation. For the PALS case, the patient presented as a six-year-old boy with symptomatic bradycardia that progressed to pulseless electrical activity with a reported history of developmental disabilities, seizures, and cerebral palsy, living in a care facility. In the NAT case, a six-month-old patient had “fallen” from the couch and was unconscious and unresponsive with bruising consistent with inflicted injury. In the MVC scenario, the patient was a three-month-old child who, while in a stroller, was stuck by a car. The patient had a large scalp wound and was initially crying but shortly after developed decreased responsiveness, hypertension, bradycardia, and slow respirations. The simulators used for scenarios included the Victoria™ birthing patient simulator and the Newborn Hal™ simulator from Gaumard™, and Sim Jr.™ 6-year-old child and sim NewB™ newborn simulators from Laerdal™. Makeup was used to simulate bruising, bleeding and lacerations in a standardized manner for each scenario. Each scenario followed a previously determined algorithm for improvement or decompensation of the patient’s status along pre-specified time intervals according to performance of specific critical actions also specified in advance. All scenarios were pilot tested among EMS teams who did not subsequently participate in the study. Scenarios were revised as needed based on feedback from pilot testing. Professionally trained actors played all confederate roles in the scenarios to enhance realism.

Simulation scenarios concluded after approximately 10 minutes for standardization purposes. If the team initiated a procedure close to the 10-minute mark, such as calculating and drawing up a medication, the simulation was allowed to continue to complete observation of the task in process and reduce the chances of an awkward end to the scenario. If the care protocols proceeded rapidly, and the condition of the patient was stable and transport action had begun, the simulation could be concluded before the 10-minute point. After finishing all four scenarios, teams returned for a 30-minute debriefing session.

Simulation scenarios were presented to teams in random order to minimize the potential bias that may occur from conditioning as teams become familiar with the simulators and working with each other. Fire and transport crews responded to each scenario in their own fire engines and ambulances after receiving a scripted radio dispatch. Each crew used their own equipment or alternatively used training kits that were replicas of the kits they usually carry. The crews varied who arrived on scene first and at times arrived simultaneously to mimic local practice. Crews were able to move the patient simulators to the transport vehicle and mimic patient transport to the hospital. If transport was started, the crews would assign a driver and those who remained inside the transport vehicle would continue to administer patient care. All crews were aware they were participating in simulated emergencies and were oriented to the study and mannequins prior to participation. To allow for anonymous tracking of each participant by role, the crew members wore colored tape markers on their shoulders.

Data Collection

Prior to simulations, participants completed a survey asking about demographic characteristics, training and their experience in Emergency Medical Services.

Subject matter experts (SMEs) directly observed simulations in real time and measured teamwork using the Clinical Teamwork Scale (CTS^{TM}), a validated instrument that measures overall teamwork and 15 specific elements in 5 overarching domains: communication, decision, making, role responsibility (leadership and followership), situational awareness/resource management and patient-friendliness.[13] Teamwork performance is evaluated on a scale of zero (unacceptable) to 10 (perfect).

Error Measurement

During the simulations, the SMEs noted the number of errors and described what the error entailed using standard taxonomy. For purposes of this study, errors were collapsed into whether an error was present or not present. When there was uncertainty over whether an action may or may not have constituted an error, the team discussed to reach consensus.

Statistical analysis

We summarized error proportion by each simulated clinical scenario, and summarized teamwork (CTS^{TM} teamwork score) by the presence or absence of an error. We summarized teamwork as the overall CTS^{TM} score and also by each score in the five sub-domains of the CTS^{TM}. Scores were compared between groups using the Wilcoxon-Mann-Whitney test. We first used a univariate logistic regression model to estimate the odds of error with increasing CTS^{TM} score and then used a multivariable regression to estimate the odds of error with increasing CTS™ score while adjusting for scenario. We used a generalized estimate equation (GEE) model with an exchangeable correlation structure to account for potential clustering. Completed case analysis was used and a *p*-value of <0.05 was considered statistically significant.

RESULTS

Table 1 shows demographic characteristics and self-reported professional experience of EMS responders participating in the simulation sessions.

Table 1: Characteristics of EMS Personnel Participating in Simulations

Characteristic	N	(%)
Mean Age years (S.D)[a]	36.9	(8.47)
Gender[b]		
Female	36	(14.0)
Race/Ethnicity[c]		
White	220	(89.1)
Black or African American	0	(0)
American Indian or Alaska Native	6	(2.43)
Asian	4	(1.62)
Native Hawaiian or Other Pacific Islander	2	(0.81)
Hispanic or Latino	7	(2.83)
Other/Two or More Races	8	(3.24)
Training Level[b]		

Emergency Medical Responder (EMR)	0	(0)
Emergency Medical Technician (EMT)	100	(38.9)
Advanced EMT	2	(0.78)
EMT-Intermediate	25	(9.73)
Paramedic	128	(49.8)
Paramedic Intern	2	(0.78)
Years' Experience Working in EMS[d]	11.7	(7.84)
Proficiency in Pediatric EMS on a Scale of 1 ("Novice") to 5 ("Expert")[b]	2.55	(0.89)

a) n = 256, b) EMS n = 257, c) n = 247, d) n = 258

At least one error was observed in 82% of the 176 simulation scenarios for which the presence or absence of errors was recorded. Table 2 describes the types of errors observed.

Table 2: Taxonomy of Observed Errors

Errors	Type
Diagnostic & Management	Assessment, algorithm, diagnostic, management, decision making
Medication	Wrong medication, dose, route, sequence, type, IV fluid issue, etc.
Technical	Wrong device, size, bagging, intubation, CPR, defibrillator, immobilization
Scene/Environment	Scene safety, scene time, positioning, patient/family

The overall CTS™ score was normally distributed, with a mean of 6.04 (SD = 2.10; min =1 (poor) and max = 10 (perfect)) in the 170 simulations with recorded overall CTS™ scores. The distributions of overall CTS™ scores were similar across the four scenarios. In simulations with an overall CTS™ score and at least one observed error (n =138), the mean CTS™ score was 5.76 (SD = 2.05) compared with 7.16 (SD = 1.95) in scenarios with no observed error (n = 32). The Wilcoxon-Mann-Whitney test demonstrated that this difference was statistically significant (P<0.001). For each individual simulation scenario, teams with no errors had higher CTS™ scores than teams with one or more errors. There were statistically significant increases in CTS™ scores in teams with no errors in the Non-Accidental Trauma simulation and the Newborn Cardiac Arrest simulation compared to those with at least one error. Table 3 provides comparative data for CTS scores with and without errors by simulation scenario.

Table 3: CTS™ Overall Teamwork Score in Simulations with and without Any Observed Error

Simulation Scenario	No Error (mean, SD)	One or More Errors (mean, SD)	*P* Value
Motor Vehicle Collision	6.20 (2.25)	5.91 (1.96)	0.74
Non-Accidental Trauma	8.20 (1.10)	5.57 (2.03)	<0.01
Newborn Cardiac Arrest	7.55 (1.97)	5.79 (2.18)	0.01
Six-Year-Old Cardiac Arrest	7.17 (1.60)	5.78 (2.09)	0.15
All Simulations	7.16 (1.95)	5.76 (2.05)	<0.001

Logistic regression analysis revealed that the odds of an error decreased 28% with each unit increase in CTS™ (Odds Ratio = 0.72, 95% Confidence Interval 0.59 – 0.88). This relationship was not confounded by scenario. Within the simulations, the percentage of teams that completed a simulation without error was highest in the Newborn Cardiac Arrest simulation (25%). The simulation with the highest percentage of teams with one or more error was the Non-Accidental Trauma simulation, with 89% of simulation having at least one error. Bivariable analysis suggested that adverse safety events are more likely in teams with low teamwork scores.

Adverse safety events were also more likely in teams with lower individual scores in communication, situational awareness, decision-making, and leadership/followership (Table 4).

Table 4: CTS™ Domain-specific Ratings in Simulations with and without Any Observed Error

Error	CTS™ Item Rating		
CTS™ Item	*No Error (mean, SD)*	*One or More Errors (mean, SD)*	*P Value*
Overall Communication[a]	7.13 (2.21)	5.89 (2.00)	0.002
Overall Situational Awareness[b]	7.31 (2.07)	6.26 (2.25)	0.01
Overall Decision Making[c]	7.26 (2.07)	5.49 (2.35)	<0.001
Overall Role Responsibility (Leader/Helper)[d]	7.25 (1.74)	6.06 (1.92)	0.001
Patient Friendliness[d]	7.13 (2.56)	6.44 (2.17)	0.16

a) n = 160, b) n = 170, c) n = 167, d) n = 163

Compared with teams with one or more errors, teams without any errors had higher CTS™ scores across all itemized categories of the CTS™ (Overall Communication, Overall Situational Awareness, Overall Decision making, Overall Role Responsibility, and Patient Friendliness). Among these categories, the Wilcoxon-Mann-Whitney test revealed that teams with no error had significantly higher CTS™ scores for Overall Communication, Overall Situational Awareness, Overall Decision Making, and Overall Role Responsibility (Leadership/Helper).

DISCUSSION

In this study of simulated pediatric prehospital emergencies, we observed a higher frequency of errors in teams with lower-rated teamwork scores. This finding was observed consistently across a variety of clinical scenarios (e.g., both newborn cardiac arrest and non-accidental trauma) and teamwork sub-domains (e.g., communication and situational awareness). Our study builds on the prior research on the role of teamwork in medical errors, which has mostly been conducted in the hospital setting. Using high-fidelity simulation scenarios and a validated teamwork measurement tool, we extended this research to the pediatric prehospital emergency care setting, and found that teamwork was a significant contributor to medical errors.

The results were robust to multivariable regression adjustment, suggesting that breakdowns in teamwork are indeed a factor contributing to the high error rates observed in this study. These findings provide a nice complement to the work on surgical mortality and team training[10] as this provides a mechanism to measure the immediate intervening factors that are likely in the causal pathway. Given the large cost and morbidity burden associated with medical errors in our US healthcare system, these findings suggest directions for future research and also have policy implications. Most immediately, more studies are needed to confirm this association both in this specific healthcare setting as well as other clinical areas where team-based care is the norm. For example, future studies should examine the contribution of teamwork to medical errors in hospital emergency medical care to continue building our understanding of the role of teamwork beyond the ICU. We used a validated measure of teamwork, the CTS™; future studies should utilize this measure and also continue to refine methods for measuring the multi-modal concept of teamwork. Given the complexity of teamwork and the inherent challenges in measuring it (e.g., different evaluations based on different parties, the limitations of self-reported/self-scored data, etc.), additional research will be needed to provide a full picture of the role of teamwork in patient outcomes. In clinical settings where our findings are replicated, it will be essential to consider interventions, training, and policies to prevent teamwork-associated medical errors.

There are several important limitations to consider. We conducted simulations and measured teamwork in one geographic region with a specific EMS system design which may not be representative of other areas. Although we employed best-practices in conducting our simulations and measuring teamwork (e.g., cutting-edge simulation models, the use of trained actors, a validated teamwork measurement scale), our study still examined simulated healthcare encounters, rather than actual healthcare. However, due to the rare nature of critical pediatric emergencies in EMS, direct observation of care is not feasible on this scale. Next, we do not know if poorer teamwork is the cause of errors or if it is simply associated with other deficits in performance that may be contributing, such as medical knowledge. Further, the appraisal of errors and assignment of teamwork scores were performed by humans using their best judgement, which is a method subject to bias. Finally, while the amount of missing data were small, we dealt with missing data using complete-case analysis. The analytic approach to missing data continues to be a subject of active investigation with recent writings suggesting that the best approach is to think through the likely causes of bias and select the analytic method that is least likely to introduce bias and best able to reduce bias.[14] Although several options are available for addressing missingness (e.g., multiple imputation approaches), several features of our specific data raised questions about the applicability of these approaches in our study. Our data structure includes nested, non-independent observations, where the same clinical team participated in clinically distinct simulations and different clinical teams participated in each clinical simulation. Given this, it did not seem appropriate to impute scores from other clinical teams in the same clinical scenario to the team with missing data, as this would assume that the clinical performance of teams was homogeneous. In the same note, it did not seem appropriate to assume that one clinical team would perform similarly on clinical cases that were very distinct. Given that neither of these assumptions seemed appropriate and also that our total number of missing data was small, the most honest interpretation of our data seemed to be complete case analysis. In conclusion, we found that teamwork is highly correlated with errors in simulated pediatric prehospital emergencies and this finding was robust across four different simulation scenarios as well as across sub-domains of teamwork.

CONCLUSION

Overall teamwork is strongly associated with the risk of adverse events in critically ill and injured children.

DECLARATIONS

Acknowledgements

None

Ethics approval and consent to participate

The study was approved by Oregon Health & Science University's Institutional Review Board, IRB Approval# 00006942.

Competing interests

The authors have no conflict of interest to report.

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Author Contributions: All authors contributed significantly to this work. SH is first author. JMG and WL obtained funding. SH, MH, BS, JS, JM, WL, and JMG conceived and designed the study. SH, MH, BS, JM, TH, WL, and JMG performed the simulations and participated in acquisition of data. SH, BS, JS, and JMG analyzed the data. SH, BS, JS, WL, and JMG wrote the first draft of the paper. All authors have read, edited, and approved the final manuscript and are able to accept responsibility for the work.

REFERENCES CITED

1. Quality Interagency Coordination Task Force. Doing what counts for patient safety: Federal actions to reduce medical errors and their impact Rockville, MD: Agency for Healthcare and Research Quality; [cited 2017 May 12]. Available from: https://archive.ahrq.gov/quic/report/mederr4.htm.

2. Makary M, Daniel M. Medical error-the third leading cause of death in the US. BMJ. 2016;353:i2139.

3. Committee on Quality of Health Care in America. To err is human: Building a safer health system. Medicine Io, editor. Washington, DC: National Academy Press; 1999.

4. Kaushal R, Bates D, Landrigan C. Medication errors and adverse drug events in pediatric inpatients. JAMA. 2001;285(16):2114-20.

5. Woods D, Thomas E, Holl J, al. e. Adverse events and preventable adverse events in children. Pediatrics. 2005;115(1):155-60.

6. Baker D, Gustafson S, Beaubien J, al. e. Medical teamwork and patient safety: The evidence-based relation. Rockville, MD: Agency for Healthcare and Research Quality, 2005.

7. Manser T. Teamwork and patient safety in dynamic domains of healthcare: A review of the literature. Acta Anasthesiol Scand. 2009;53(2):143-51.

8. Sorbero M, Farley D, Mattke S, al. e. Outcomes measures for effective teamwork in inpatient care. Santa Monica, CA: RAND Corporation, 2008.

9. Donchin Y, Gopher D, Olin M, al. e. A look into the nature and causes of human errors in the intensive care unit. Crit Care Med. 1995;23(2):294-300.

10. Neily J, Mills P, Young-Xu Y, Carney B, West P, Berger D, et al. Association between implementation of a medical team training program and surgical mortality. JAMA. 2010;304(15):1693-700.

11. Landrigan C. Resident sleep deprivation and critical care: the unintended consequences of inaction. Crit Care Med. 2010;38(3):980-1.

12. von Elm E, Altman D, Egger M, Pocock S, Gøtzsche P, Vandenbroucke J. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. PLoS Med. 2007;4(10):e296.

13. Guise J, Deering S, Kanki B, al. e. Validation of a tool to measure and promote clinical teamwork. Simul Healthc. 2008;3(4):217-23.

14. Hernán M, Robins J. Per-protocol analyses of pragmatic trials. N Engl J Med. 2017;377(14):1391-8.

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any prespecified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	5-6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	6
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	NA
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-10
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	9
Bias	9	Describe any efforts to address potential sources of bias	8-9
Study size	10	Explain how the study size was arrived at	6-7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	10-11
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	10-11
		(*b*) Describe any methods used to examine subgroups and interactions	10-11
		(*c*) Explain how missing data were addressed	10,11,16
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	NA
		(*e*) Describe any sensitivity analyses	NA

Continued on next page

Results			Page #
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	7
		(b) Give reasons for non-participation at each stage	7
		(c) Consider use of a flow diagram	NA
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	7,11, 12
		(b) Indicate number of participants with missing data for each variable of interest	12
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	(NA)
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	(12-15)
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	NA
		Cross-sectional study—Report numbers of outcome events or summary measures	NA
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	(12-15)
		(*b*) Report category boundaries when continuous variables were categorized	(12-15)
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	NA
Discussion			
Key results	18	Summarise key results with reference to study objectives	14-15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	17
Generalisability	21	Discuss the generalisability (external validity) of the study results	15-16
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	18

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

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Keywords:	Patient Safety, Medical Errors, Patient Care Team, Emergency Medical Services, Teamwork, Pediatric

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Association between Measured Teamwork and Medical Errors: An Observational Study of Prehospital Care in the United States

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ABSTRACT

Objectives

The goal of this study was to examine the relationship between measured teamwork and adverse safety events in the prehospital emergency care of children using high-fidelity simulation. We posit that aspects of teamwork such as leadership, trust and communication are largely correlated with the clinical success of teams.

Design

Observational study.

Setting

Emergency Medical Services (EMS) responders were recruited from public fire and private transport agencies in Oregon State. Simulations were conducted *in situ* using high-fidelity patient simulators, scene design, and professional actors playing parents and bystanders.

Participants

Forty-four fire/transport teams consisting of 259 EMS professionals consented to participate and completed simulations.

Primary and Secondary Outcome Measures

We used a multivariable regression model to estimate the odds of error with increasing overall CTS™ teamwork score while adjusting for clinical scenario and potential clustering by team.

Results

Across 176 simulations, the mean overall score on the CTS™ was 6.04 (SD = 2.10; range 1 = poor to 10 = perfect) and was normally distributed. The distribution of scores was similar across the four clinical scenarios. At least one error was observed in 82% of the simulations. In simulations with at least one observed error, the mean CTS™ score was 5.76 (SD = 2.04) compared with 7.16 (SD = 1.95) in scenarios with no observed error. Logistic regression analysis

accounting for clustering at the team-level revealed that the odds of an error decreased 28% with each unit increase in CTS^{TM} (Odds Ratio = 0.72, 95% Confidence Interval 0.59 – 0.88).

Conclusions

This study found that overall teamwork among care delivery teams was strongly associated with the risk of serious adverse events in caring for critically ill and injured children.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- This research provides some of the first data that quantifies the relationship between clinical teamwork and the likelihood of medical errors in a pediatric prehospital setting.
- These data suggest CTS™ may be a useful tool to measure the immediate impact of interventions on teamwork that matter to the reduction of errors.
- Simulations replicated pediatric emergencies known to be high risk for errors and were conducted using professional actors and high fidelity pediatric simulators in the field with clinical EMS teams assembled and responding as they normally would reflecting every day clinical care as closely as possible.
- The appraisal of errors and assignment of teamwork scores were performed by clinicians who were not involved in EMS but were humans using their best judgement, which is a method subject to bias
- It remains uncertain whether poorer teamwork is the cause of errors or if it is simply associated with other deficits in performance that may be contributing, however, this finding provides a tool that can be used to measure impact before and after interventions.

INTRODUCTION

Medical errors, are estimated to be the third leading cause of death in the United States (US) and the 14th leading cause worldwide.[1-3] The total aggregated cost of adverse safety events and errors is estimated to amount to trillions of dollars each year. [3] Medicine is both an important and imperfect field, combining science with art and humans with technology. In 1999, the world became aware that patients not only die from disease and traumatic events, some also die or are injured unintentionally through the provision of clinical care.[4] The landmark Institute of Medicine report estimated that the number of people who die every year due to preventable medical errors in the US alone, is equivalent to 3 jumbo jet crashes every 2 days, or one patient every 15 minutes, with over 1 million estimated to be harmed. Studies of medical errors have generally focused on adults and inpatient settings.[5-7] However, medical errors are also an important source of harm for pediatric patients with estimates of 70,000 pediatric inpatients harmed per year by medical errors.[8, 9] A more recent report, emphasizes that the cost of medical errors is proportionately more devastating to countries of low economic status.[10] Even less is known about the epidemiology, etiology, and risk factors for preventable adverse events in the care of children in the Emergency Medical Services (EMS) system where children first receive care for emergencies outside of the hospital.

Good communication and teamwork are critical in avoiding medical errors and assuring the safety of patients.[3] The World Health Organization considers communication to be the leading cause of unintentional patient harm.[11] Past reviews have indicated that aspects of teamwork such as leadership, trust and communication are largely correlated with the clinical success of teams.[12-14] For example, a study evaluating teamwork in the Intensive Care Unit indicated that 37% of teamwork failures were due to verbal communication errors between physicians and nurses.[15] There have been interventions to reduce medical errors such as implementing computerized provider order-entry systems, limiting residents' work shifts to consecutive hours, and implementing evidence-based care bundles. A large retrospective study from the US Veterans Affair Hospital found that inpatient surgical mortality was reduced 18% following team training interventions.[16] However, lack of prospective and detailed evaluation of teamwork elements and specific errors limit our understanding of the effectiveness of these practices.[17] The goal of this study was to examine the relationship between measured teamwork and adverse safety events in the prehospital emergency care of children using high-fidelity simulation.

METHODS

We followed STROBE guidance for reporting of observational studies.[18] The Oregon Health & Science University Institutional Review Board (IRB00006942) approved the study and all subjects signed both study and video consent prior to participation.

Study Participants

In total, 176 simulations were performed over a 6-month timeframe with 44 teams of emergency medical services (EMS) providers recruited from public fire and private transport crews in three large counties surrounding Portland, Oregon in the United States. Portland is the largest city in Oregon and the three county area that participated in this study serves a population of 1.8 million. The EMS system in this region has dual-Advanced Life Support response to all 911 calls with public fire agencies, responding in teams of 3-5 individuals with at least one paramedic, and a private transport agency, responding in 2-person teams with at least one paramedic. We conducted all simulations *in situ* with both fire and transport EMS teams responding to each scenario as they normally would when providing clinical care. Participants ranged from Emergency Medical Technician (EMT) to paramedic, with each team including at least one paramedic.

Forty-four fire/transport teams consisting of 259 EMS professionals were available in the three-county region during our study timeframe and consented to participate. All who consented completed the study. One individual withdrew consent to have his/her individual data analyzed after completing the simulation sessions for personal reasons, but agreed to analysis of team-level data for all simulation sessions he/she had participated. In total, we analyzed team-level data from 44 teams and individual-level data from 258 EMS professionals.

Patient Involvement

The EMS-C Children's Safety Initiative is an observational study with a specific focus on EMS providers. Patients were not involved in the design, recruitment, or conduct of the study.

Simulations

Each fire/ambulance team participated in four simulation scenarios: (1) cardiac arrest in newborn (Newborn Resuscitation Program, NRP), (2) cardiac arrest in child (Pediatric Advanced Life Support PALS), (3) non-accidental trauma (NAT), and (4) accidental trauma from pedestrian-motor vehicle collision (MVC). Simulations were conducted *in situ* using high-fidelity simulators, scene design, and professional actors playing roles of parents and bystanders. EMS crews responded in their agency vehicles after receiving a radio dispatch. Simulators included

Victoria™ birthing patient simulator and the Newborn Hal™ simulator from Gaumard™, and Sim Jr.™ 6-year-old child and sim NewB™ newborn simulators from Laerdal™. Settings included street (motor vehicle collision or MVC), simulated apartment bedroom for birth (neonatal resuscitation protocol or NRP), disheveled family room (neonatal abuse trauma or NAT), simulated care facility for eight year old with cardiac arrest (pediatric advanced life support or PALS) and all simulations were allowed to continue though transport in the agency's own ambulances.

In the NRP scenario, the patient presented as a newborn who was initially responsive upon delivery but subsequently developed a weak cry, flaccid extremities, bradycardia, and cyanosis requiring resuscitation. For the PALS case, the patient presented as a six-year-old boy with symptomatic bradycardia that progressed to pulseless electrical activity with a reported history of developmental disabilities, seizures, and cerebral palsy, living in a care facility. In the NAT case, a six-month-old patient had "fallen" from the couch and was unconscious and unresponsive with bruising consistent with inflicted injury. In the MVC scenario, the patient was a three-month-old child who, while in a stroller, was stuck by a car. The patient had a large scalp wound and was initially crying but shortly after developed decreased responsiveness, hypertension, bradycardia, and slow respirations. Makeup was used to simulate bruising, bleeding and lacerations in a standardized manner for each scenario. Each scenario followed a previously determined algorithm for improvement or decompensation of the patient's status along pre-specified time intervals according to performance of specific critical actions also specified in advance. All scenarios were pilot tested among EMS teams who did not subsequently participate in the study.

Scenarios were revised as needed based on feedback from pilot testing. Professionally trained actors played all confederate roles in the scenarios to enhance realism.

For the purpose of standardization, simulation scenarios concluded after approximately 10 minutes. If the team initiated a procedure close to the 10-minute mark, such as calculating and drawing up a medication, the simulation was allowed to continue to complete observation of the task in process and reduce the chances of an awkward end to the scenario. If the care protocols proceeded rapidly, and the condition of the patient was stable and transport action had begun, the simulation could be concluded before the 10-minute point. After finishing all four scenarios, teams returned for a 30-minute debriefing session.

Simulation scenarios were presented to teams in random order to minimize the potential bias that may occur from conditioning as teams become familiar with the simulators and working with each other. Fire and transport crews responded to each scenario in their own fire engines and ambulances after receiving a scripted radio dispatch. Each crew used their own equipment or alternatively used training kits that were replicas of the kits they usually carry. The crews varied who arrived on scene first (ambulance or fire department) and at times arrived simultaneously to mimic local practice. Crews were able to move the patient simulators to the transport vehicle and mimic patient transport to the hospital. If transport was started, the crews would assign a driver and those who remained inside the transport vehicle would continue to administer patient care. All crews were aware they were participating in simulated emergencies and were oriented to the study and mannequins prior to participation. To allow for anonymous tracking of each participant by role, the crew members wore colored tape markers on their shoulders. The fire crews also varied the person-in-charge (PIC) assignment for each scenario, although the crew membership was consistent.

Data Collection

Prior to simulations, participants completed a survey asking about demographic characteristics, training and their experience in Emergency Medical Services.

One of two subject matter experts (JMG & MH) experienced in using the Clinical Teamwork Scale (CTS™) directly observed simulations in real time and measured teamwork using the CTS™, a validated instrument that measures overall teamwork and 15 specific elements in 5 overarching domains in addition to overall teamwork: communication, decision making, role responsibility (leadership and followership), situational awareness/resource management and patient-friendliness.[19] Evaluators rate the performance of the care team using a Likert scale of zero (unacceptable) to 10 (perfect) and are given space to insert narrative comments. In validation studies, the CTS™ has demonstrated substantial score concordance among raters, and excellent interrater reliability.[20-22] A systematic review of tools that have been used to measure teamwork recently concluded that CTS™ was superior to other tools for measuring teamwork citing content and construct validity as well as reliability and ease of use.[23] Prior to the study, simulations were pilot tested with EMS teams not involved in the study. During this time, both reviewers scored teamwork independently using CTS™ arrived at consensus and repeated independent assessments of new simulations to arrive at consistency. Reviewers checked in throughout the study to maintain consistency in scoring.

Error Measurement

During the simulations, the evaluators noted the number of errors and described what the error entailed using standard taxonomy. For purposes of this study, errors were collapsed into whether an error was present or not present. When there was uncertainty over whether an action may or may not have constituted an error, the team discussed to reach consensus.

Statistical analysis

We summarized error proportion by each simulated clinical scenario, and summarized teamwork (CTS^{TM} teamwork score) by the presence or absence of an error. We summarized teamwork as the overall CTS^{TM} score and also by each score in the five sub-domains of the CTS^{TM}. Scores were compared between groups using t tests for unequal variances A generalized estimate equation (GEE) logistic regression model was used to estimate the odds of error with increasing CTS^{TM} score and tested for confounding by scenario and years of EMS experience. Teams completed four different simulations yielding correlated data that was accounted for in the GEE model using an exchangeable correlation structure clustering by team. Completed case analysis was used and a *p*-value of <0.05 was considered statistically significant. All analyses were performed using SAS (version 9.4 SAS Institute Inc., Carey, NC)

RESULTS

Table 1 shows demographic characteristics and self-reported professional experience of EMS responders participating in the simulation sessions.

Table 1: Characteristics of EMS Personnel Participating in Simulations

Characteristic	N (%)	
Mean Age years (S.D)[a]	36.9	(8.47)
Gender[b]		
Female	36	(14.0)
Race/Ethnicity[c]		
White	220	(89.1)
Black or African American	0	(0)
American Indian or Alaska Native	6	(2.43)
Asian	4	(1.62)
Native Hawaiian or Other Pacific Islander	2	(0.81)
Hispanic or Latino	7	(2.83)
Other/Two or More Races	8	(3.24)
Training Level[b]		
Emergency Medical Responder (EMR)	0	(0)
Emergency Medical Technician (EMT)	100	(38.9)
Advanced EMT	2	(0.78)
EMT-Intermediate	25	(9.73)
Paramedic	128	(49.8)
Paramedic Intern	2	(0.78)
Years' Experience Working in EMS[d]	11.7	(7.84)
Proficiency in Pediatric EMS on a Scale of 1 ("Novice") to 5 ("Expert")[b]	2.55	(0.89)

a) n = 256, b) EMS n = 257, c) n = 247, d) n = 258

At least one error was observed in 82% of the 176 simulation scenarios for which the presence or absence of errors was recorded. Due to missing data for overall CTS™ score, data for six scenarios were not included in the logistic regression analysis. Table 2 describes the types of errors observed.

Table 2: Taxonomy of Observed Errors

Errors	Type
Diagnostic & Management	Assessment, algorithm, diagnostic, management, decision making
Medication	Wrong medication, dose, route, sequence, type, IV fluid issue, etc.
Technical	Wrong device, size, bagging, intubation, CPR, defibrillator, immobilization
Scene/Environment	Scene safety, scene time, positioning, patient/family

The overall CTS™ score was normally distributed, with a mean of 6.04 (SD = 2.10; min =1 (poor) and max = 10 (perfect)) in the 170 simulations with recorded overall CTS™ scores. The distributions of overall CTS™ scores were similar across the four scenarios. In simulations with an overall CTS™ score and at least one observed error (n =138), the mean CTS™ score was 5.76 (SD = 2.04) compared with 7.16 (SD = 1.95) in scenarios with no observed error (n = 32). The t tests demonstrated that this difference was statistically significant (p-value = 0.0007). For each individual simulation scenario, teams with no errors had higher CTS™ scores than teams with one or more errors. There were statistically significant differences in CTS™ scores between teams with no errors and teams with errors in the Non-Accidental Trauma simulation and the Newborn Cardiac Arrest simulation, with the no error teams having significantly greater CTS™

scores. Table 3 provides comparative data for CTS™ scores between teams with and without errors by simulation scenario.

Table 3: Comparing CTS™ Overall Teamwork Score Between Teams With and Without Errors by Simulation Scenario

Simulation Scenario	No Error (mean, SD)	One or More Errors (mean, SD)	t⁺	*P* value
Motor Vehicle Collision	6.20(2.25)	5.91(1.96)	0.37	0.72
Non-Accidental Trauma	8.20(1.10)	5.57(2.03)	4.39	*0.0019
Newborn Cardiac Arrest	7.55(1.97)	5.79(2.18)	2.5	*0.022
Six-Year-Old Cardiac Arrest	7.17(1.60)	5.78(2.09)	1.88	0.097
All Simulations	7.16(1.95)	5.76(2.04)	3.61	*0.0007

⁺Satterhwaite t-test for unequal variances
*significant at alpha=0.05

After comparing an unadjusted GEE logistic regression model to a model controlling for scenario and mean years of EMS experience, there were no significant differences in the effect estimate for CTS™ score or significance of estimates (Table 4). This indicates that the relationship between overall CTS ™ and odds of error was not confounded by scenario or years of EMS experience; thus, the final model reported is unadjusted for these variables. Logistic regression analysis accounting for clustering at the team-level revealed that the odds of an error decreased 28% with each unit increase in CTS™ (Odds Ratio = 0.72, 95% Confidence Interval 0.59 – 0.88).

Table 4. GEE Logistic Regression Models Testing Associations between Teamwork and Errors

	Unadjusted				Adjusted⁺			
Predictor Variable	OR	95% CI	Z	p-value	OR	95% CI	Z	p-value
CTS Score (1-unit increase)	0.72	(0.59,0.88)	-3.2	0.0014	0.73	(0.59,0.89)	-3.06	0.0022
MVC	-	-	-	-	0.45	(0.18,1.17)	-1.63	0.1034
NRP	-	-	-	-	0.46	(0.20,1.04)	-1.87	0.0618
PALS	-	-	-	-	0.88	(0.25,3.03)	-0.21	0.8352
NAT	-	-	-	-	REF	-	-	-
Mean Years EMS Experience	-	-	-	-	0.92	(0.79, 1.07)	-1.07	0.284

+Adjusted for clinical scenario (NAT = reference group) and mean years of EMS experience at the team level

Within the simulations, the percentage of teams that completed a simulation without error was highest in the Newborn Cardiac Arrest simulation (25%). The simulation with the highest percentage of teams with one or more error was the Non-Accidental Trauma simulation, with 89% of simulation having at least one error. Bivariable analysis suggested that adverse safety events are more likely in teams with low teamwork scores.

Adverse safety events were also more likely in teams with lower individual scores in communication, situational awareness, decision-making, and leadership/followership (Table 5).

Table 5: CTS™ Domain-specific Ratings in Simulations with and without Any Observed Error

Error	CTS™ Item Rating		
CTS™ Item	*No Error (mean, SD)*	*One or More Errors (mean, SD)*	*P Value*
Overall Communication[a]	7.13 (2.21)	5.89 (2.00)	0.002
Overall Situational Awareness[b]	7.31 (2.07)	6.26 (2.25)	0.01
Overall Decision Making[c]	7.26 (2.07)	5.49 (2.35)	<0.001
Overall Role Responsibility (Leader/Helper)[d]	7.25 (1.74)	6.06 (1.92)	0.001
Patient Friendliness[d]	7.13 (2.56)	6.44 (2.17)	0.16

a) n = 160, b) n = 170, c) n = 167, d) n = 163

Compared with teams with one or more errors, teams without any errors had higher CTS™ scores across all itemized categories of the CTS™ (Overall Communication, Overall Situational Awareness, Overall Decision making, Overall Role Responsibility, and Patient Friendliness). Among these categories, teams with no error had significantly higher CTS™ scores for Overall

Communication, Overall Situational Awareness, Overall Decision Making, and Overall Role Responsibility (Leadership/Helper).

DISCUSSION

In this study of simulated pediatric prehospital emergencies, we observed a higher frequency of errors in teams with lower-rated teamwork scores. This finding was observed consistently across a variety of clinical scenarios (e.g., both newborn cardiac arrest and non-accidental trauma) and teamwork sub-domains (e.g., communication and situational awareness). Our study builds on the prior research on the role of teamwork in medical errors, which has mostly been conducted in the hospital setting.[24, 25] Using high-fidelity simulation scenarios and a validated teamwork measurement tool, we extended this research to the pediatric prehospital emergency care setting, and found an association between teamwork and medical errors.

The results were robust to multivariable regression adjustment, suggesting that breakdowns in teamwork are indeed a factor contributing to the high error rates observed in this study. These findings add strength to the WHO's description of communication as a leading cause of unintentional harm and further elaborate on the importance of teamwork in decreasing errors.[11] Additionally, These findings provide a nice complement to the work on surgical mortality and team training[16] as this provides a mechanism to measure the immediate intervening factors that are likely in the causal pathway.

Given the large cost and morbidity burden associated with medical errors worldwide, these findings suggest directions for future research and also have policy implications.[3, 10] Most immediately, however, more studies are needed to confirm this association both in this specific healthcare setting as well as other clinical areas where team-based care is the norm. For example, future studies should examine the contribution of teamwork to medical errors in hospital emergency medical care to continue building our understanding of the role of teamwork beyond the ICU. This direction of research is important internationally, and may be particularly critical for countries of low economic means, who are impacted heavily by the financial burdens. [10]

We used a validated measure of teamwork, the CTS™. CTS™ has been used around the world in different settings and clinical care areas. [20-22] Future studies should utilize this measure and also continue to refine methods for measuring the multi-modal concept of teamwork in health care systems around the world. Given the complexity of teamwork and the inherent challenges in measuring it (e.g., different evaluations based on different parties, the limitations of self-reported/self-scored data, etc.), additional research will be needed to provide a full picture of the role of teamwork in patient outcomes. In clinical settings where our findings are replicated, it will be essential to consider interventions, training, and policies to prevent teamwork-associated medical errors.

There are several important limitations to consider. We conducted simulations and measured teamwork in one geographic region with a specific EMS system design which may not be representative of other areas. Although we employed best-practices in conducting our simulations and measuring teamwork (e.g., cutting-edge simulation models, the use of trained actors, a validated teamwork measurement scale), our study examined simulated healthcare encounters, rather than actual healthcare. However, due to the rare nature of critical pediatric emergencies in EMS, direct observation of care is not feasible on this scale. Next, we do not know if poorer teamwork is the cause of errors or if it is simply associated with other deficits in performance that may be contributing, such as medical knowledge. Further, the appraisal of errors and assignment of teamwork scores were performed by humans using their best judgement, which is a method subject to bias. Finally, while the amount of missing data were small, we dealt with missing data using complete-case analysis. The analytic approach to missing data continues to be a subject of active investigation with recent writings suggesting that the best approach is to think through the likely causes of bias and select the analytic method that is least likely to introduce bias and best able to reduce bias.[26] Although several options are available for addressing missingness (e.g., multiple imputation approaches), several features of our specific data raised questions about the applicability of these approaches in our study. Our data structure includes nested, non-independent observations, where the same clinical team participated in clinically distinct simulations and different clinical teams participated in each clinical simulation. Given this, it did not seem appropriate to impute scores from other clinical teams in the same clinical scenario to the team with missing data, as this would assume that the clinical performance of teams was homogeneous. In the same note, it did not seem appropriate to assume that one clinical team would perform similarly on clinical cases that were very distinct. Given that neither of these assumptions seemed appropriate and also that our total number of missing data was small, the most honest interpretation of our data seemed to be complete case analysis. In conclusion, we found that teamwork is highly correlated with errors in simulated pediatric prehospital emergencies and this finding was robust across four different simulation scenarios as well as across sub-domains of teamwork.

CONCLUSION

Overall teamwork is strongly associated with the risk of adverse events in critically ill and injured children.

DECLARATIONS

Acknowledgements

None

Ethics approval and consent to participate

The study was approved by Oregon Health & Science University's Institutional Review Board, IRB Approval# 00006942.

Competing interests

The authors have no conflict of interest to report.

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Data Sharing: Aggregated data specific to this publication would be made available upon request.

Author Contributions: All authors contributed significantly to this work. SH is first author. JMG and WL obtained funding. SH, MH, BS, JS, JM, WL, and JMG conceived and designed the study. SH, MH, BS, JM, TH, WL, and JMG performed the simulations and participated in acquisition of data. SH, BS, AS, JS, WL, and JMG analyzed the data. SH, BS, JS, WL, and JMG wrote the first draft of the paper. SH, AS, WL, JS, and JMG conducted additional analyses and made revisions to the paper from peer review. All authors have read, edited, and approved the final manuscript and are able to accept responsibility for the work.

REFERENCES CITED

1. Quality Interagency Coordination Task Force. Doing what counts for patient safety: Federal actions to reduce medical errors and their impact Rockville, MD: Agency for Healthcare and Research Quality; [cited 2017 May 12]. Available from: https://archive.ahrq.gov/quic/report/mederr4.htm
2. Makary M, Daniel M. Medical error-the third leading cause of death in the US. BMJ. 2016;353:i2139.
3. Slawomirski L, Auraaen A, Klazinga N. The economics of patient safety: Strengthening a value-based approach to reducing patient harm at national level. Paris, France: Organisation for Economic Co-operation and Development, 2017.
4. Committee on Quality of Health Care in America. To err is human: Building a safer health system. Institute of Medicine, editor. Washington, DC: National Academy Press; 1999.
5. Aranaz-Andres J, Aibar-Remon C, Vitaller-Burillo J, Requena-Puche J, Terol-Garcia E, Kelley E, et al. Impact and preventability of adverse events in Spanish public hospitals: results of the Spanish National Study of Adverse Events (ENEAS). Int J Qual Health Care. 2009;21(6):408-14.
6. Westbrook J, Li L, Lehnbom E, Baysari MT, Braithwaite J, Burke R, et al. What are incident reports telling us? A comparative study at two Australian hospitals of medication errors identified at audit, detected by staff and reported to an incident system. Int J Qual Health Care. 2015;27(1):1-9.

7. Giraldo P, Sato L, Sala M, Comas M, Dywer K, Castells X. A retrospective review of medical errors adjudicated in court between 2002 and 2012 in Spain. Int J Qual Health Care. 2016;28(1):33-9.

8. Kaushal R, Bates D, Landrigan C. Medication errors and adverse drug events in pediatric inpatients. JAMA. 2001;285(16):2114-20.

9. Woods D, Thomas E, Holl J, al. e. Adverse events and preventable adverse events in children. Pediatrics. 2005;115(1):155-60.

10. National Academies of Sciences, Engineering and Medicine. Crossing the Global Quality Chasm: Improving Health Care Worldwide. Washington, DC: 2018.

11. Katzenbach J, Smith D. The discipline of teams. Boston, MA: Harvard Business Press; 2008.

12. Baker D, Gustafson S, Beaubien J, al. e. Medical teamwork and patient safety: The evidence-based relation. Rockville, MD: Agency for Healthcare and Research Quality, 2005.

13. Manser T. Teamwork and patient safety in dynamic domains of healthcare: A review of the literature. Acta Anasthesiol Scand. 2009;53(2):143-51.

14. Sorbero M, Farley D, Mattke S, al. e. Outcomes measures for effective teamwork in inpatient care. Santa Monica, CA: RAND Corporation, 2008.

15. Donchin Y, Gopher D, Olin M, al. e. A look into the nature and causes of human errors in the intensive care unit. Crit Care Med. 1995;23(2):294-300.

16. Neily J, Mills P, Young-Xu Y, Carney B, West P, Berger D, et al. Association between implementation of a medical team training program and surgical mortality. JAMA. 2010;304(15):1693-700.

17. Landrigan C. Resident sleep deprivation and critical care: the unintended consequences of inaction. Crit Care Med. 2010;38(3):980-1.

18. von Elm E, Altman D, Egger M, Pocock S, Gøtzsche P, Vandenbroucke J. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. PLoS Med. 2007;4(10):e296.

19. Guise J, Deering S, Kanki B, al. e. Validation of a tool to measure and promote clinical teamwork. Simul Healthc. 2008;3(4):217-23.

20. Fransen A, van de Ven J, Merien A, de Wit-Zuurendonk L, Houterman S, Mol B, et al. Effect of obstetric team training on team performance and medical technical skills: a randomised controlled trial. BJOG. 2012;119(11):1387-93.

21. Miller D, Crandall C, Washington C, 3rd, McLaughlin S. Improving teamwork and communication in trauma care through in situ simulations. Acad Emerg Med. 2012;19(5):608-12.

22. Banga F, Truijens S, Fransen A, Dieleman J, van Runnard Heimel P, Oei G. The impact of transmural multiprofessional simulation-based obstetric team training on perinatal outcome and quality of care in the Netherlands. BMC Med Educ. 2014;14:175.

23. Fransen A, de Boer L, Kienhorst D, Truijens S, van Runnard Heimel P, Oei S. Assessing teamwork performance in obstetrics: A systematic search and review of validated tools. Eur J Obstet Gyn Reprod Biol. 2017;216:184-91.

24. van de Ven J, Houterman S, Steinweg R, Scherpbier A, Wijers W, Mol B, et al. Reducing errors in health care: cost-effectiveness of multidisciplinary team training in obstetric emergencies (TOSTI study); a randomised controlled trial. BMC Preg Childbirth. 2010;10:59.

25. McCulloch P, Mishra A, Handa A, Dale T, Hirst G, Catchpole K. The effects of aviation-style non-technical skills training on technical performance and outcome in the operating theatre. Qual Saf Health Care. 2009;18(2):109-15.

26. Hernán M, Robins J. Per-protocol analyses of pragmatic trials. N Engl J Med. 2017;377(14):1391-8.

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any prespecified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	5-6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	6
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	NA
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-10
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	9
Bias	9	Describe any efforts to address potential sources of bias	8-9
Study size	10	Explain how the study size was arrived at	6-7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	10-11
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	10-11
		(*b*) Describe any methods used to examine subgroups and interactions	10-11
		(*c*) Explain how missing data were addressed	10,11,16
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	NA
		(*e*) Describe any sensitivity analyses	NA

Continued on next page

Results			**Page #**
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	7
		(b) Give reasons for non-participation at each stage	7
		(c) Consider use of a flow diagram	NA
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	7,11, 12
		(b) Indicate number of participants with missing data for each variable of interest	12
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	(NA)
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	(12-15)
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	NA
		Cross-sectional study—Report numbers of outcome events or summary measures	NA
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	(12-15)
		(*b*) Report category boundaries when continuous variables were categorized	(12-15)
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	NA
Discussion			
Key results	18	Summarise key results with reference to study objectives	14-15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	17
Generalisability	21	Discuss the generalisability (external validity) of the study results	15-16
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	18

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Association between Measured Teamwork and Medical Errors: An Observational Study of Prehospital Care in the United States

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Keywords:	Patient Safety, Medical Errors, Patient Care Team, Emergency Medical Services, Teamwork, Pediatric

Association between Measured Teamwork and Medical Errors: An Observational Study of Prehospital Care in the United States

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Keywords: Patient Safety; Medical Errors; Cooperative Behavior; Patient Care Team; Emergency Medical Services; Teamwork; Patient Simulation; Child; Humans

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ABSTRACT

Objectives

The goal of this study was to examine the relationship between measured teamwork and adverse safety events in the prehospital emergency care of children using high-fidelity simulation. We posit that non-technical skills such as leadership, teamwork, situation awareness and decision making are associated with the clinical success of teams.

Design

Observational study.

Setting

Emergency Medical Services (EMS) responders were recruited from public fire and private transport agencies in Oregon State to participate in four simulations of pediatric emergencies using high-fidelity patient simulators, scene design, and professional actors playing parents and bystanders.

Participants

Forty-four fire/transport teams consisting of 259 EMS professionals consented to participate and completed simulations.

Primary and Secondary Outcome Measures

Teams were assessed using the CTS^{TM}, a validated instrument that measures overall teamwork and 15 specific elements in 5 overarching domains: communication, decision making, role responsibility (leadership and followership), situational awareness/resource management and patient-friendliness. We used generalized estimating equations to estimate the odds of error with increasing overall CTS^{TM} teamwork score while adjusting for clinical scenario and potential clustering by team.

Results

Across 176 simulations, the mean overall score on the CTS™ was 6.04 (SD = 2.10; range 1 = poor to 10 = perfect) and was normally distributed. The distribution of scores was similar across the four clinical scenarios. At least one error was observed in 82% of the simulations. In simulations with at least one observed error, the mean CTS™ score was 5.76 (SD = 2.04) compared with 7.16 (SD = 1.95) in scenarios with no observed error. Logistic regression analysis accounting for clustering at the team-level revealed that the odds of an error decreased 28% with each unit increase in CTS™ (Odds Ratio = 0.72, 95% Confidence Interval 0.59 – 0.88).

Conclusions

This study found that overall teamwork among care delivery teams was strongly associated with the risk of serious adverse events in simulated scenarios of caring for critically ill and injured children.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- This research provides some of the first data that quantifies the relationship between clinical teamwork and the likelihood of medical errors in a pediatric prehospital setting.
- These data suggest CTS™ may be a useful tool to measure the immediate impact of interventions on teamwork that matter to the reduction of errors.
- Simulations replicated pediatric emergencies known to be high risk for errors and were conducted using professional actors and high fidelity pediatric simulators in the field with clinical EMS teams assembled and responding as they normally would reflecting every day clinical care as closely as possible.
- The appraisal of errors and assignment of teamwork scores were performed by clinicians who were not involved in EMS but were humans using their best judgement, which is a method subject to bias
- It remains uncertain whether poorer teamwork is the cause of errors or if it is simply associated with other deficits in performance that may be contributing, however, this finding provides a tool that can be used to measure impact before and after interventions.

INTRODUCTION

Medical errors, are estimated to be the third leading cause of death in the United States (US) and the 14th leading cause worldwide.[1-3] The total aggregated cost of adverse safety events and errors is estimated to amount to trillions of dollars each year. [3] Medicine is both an important and imperfect field, combining science with art and humans with technology. In 1999, the world became aware that patients not only die from disease and traumatic events, some also die or are injured unintentionally through the provision of clinical care.[4] The landmark Institute of Medicine report estimated that the number of people who die every year due to preventable medical errors in the US alone, is equivalent to 3 jumbo jet crashes every 2 days, or one patient every 15 minutes, with over 1 million estimated to be harmed. Studies of medical errors have generally focused on adults and inpatient settings.[5-7] However, medical errors are also an important source of harm for pediatric patients with estimates of 70,000 pediatric inpatients harmed per year by medical errors.[8, 9] A more recent report, emphasizes that the cost of medical errors is proportionately more devastating to countries of low economic status.[10] Even less is known about the epidemiology, etiology, and risk factors for preventable adverse events in the care of children in the Emergency Medical Services (EMS) system where children first receive care for emergencies outside of the hospital.

Non-technical skills such as good communication and teamwork are critical in avoiding medical errors and assuring the safety of patients.[3] The World Health Organization considers communication to be the leading cause of unintentional patient harm.[11] Past reviews have indicated that aspects of teamwork such as leadership, teamwork, situation awareness and decision making are largely correlated with the clinical success of teams.[12-14] For example, a study evaluating teamwork in the Intensive Care Unit indicated that 37% of teamwork failures were due to verbal communication errors between physicians and nurses.[15] There have been interventions to reduce medical errors such as implementing computerized provider order-entry systems, limiting residents' work shifts to consecutive hours, and implementing evidence-based care bundles. A large retrospective study from the US Veterans Affair Hospital found that inpatient surgical mortality was reduced 18% following team training interventions.[16] However, lack of prospective and detailed evaluation of teamwork elements and specific errors limit our understanding of the effectiveness of these practices.[17] The goal of this study was to examine the relationship between measured teamwork and adverse safety events in the prehospital emergency care of children using high-fidelity simulation.

METHODS

We followed STROBE guidance for reporting of observational studies.[18] The Oregon Health & Science University Institutional Review Board (IRB00006942) approved the study and all subjects signed both study and video consent prior to participation.

Study Participants

In total, 176 simulations were performed over a 6-month timeframe with 44 teams of emergency medical services (EMS) providers recruited from public fire and private transport crews in three large counties surrounding Portland, Oregon in the United States. Portland is the largest city in Oregon and the three county area that participated in this study serves a population of 1.8 million. The EMS system in this region has dual-Advanced Life Support response to all 911 calls with public fire agencies, responding in teams of 3-5 individuals with at least one paramedic, and a private transport agency, responding in 2-person teams with at least one paramedic. We conducted all simulations in the field ,using high-fidelity simulators, scene design, and professional actors playing roles of parents and bystanders, with both fire and transport EMS teams responding to each scenario as they normally would when providing clinical care. Participants ranged from Emergency Medical Technician (EMT) to paramedic, with each team including at least one paramedic.

Forty-four fire/transport teams consisting of 259 EMS professionals were available in the three-county region during our study timeframe and consented to participate. All who consented completed the study. One individual withdrew consent to have his/her individual data analyzed after completing the simulation sessions for personal reasons, but agreed to analysis of team-level data for all simulation sessions he/she had participated. In total, we analyzed team-level data from 44 teams and individual-level data from 258 EMS professionals.

Patient Involvement

The EMS-C Children's Safety Initiative is an observational study with a specific focus on EMS providers. Patients were not involved in the design, recruitment, or conduct of the study.

Simulations

Each fire/ambulance team participated in four simulation scenarios: (1) cardiac arrest in newborn (Newborn Resuscitation Program, NRP), (2) cardiac arrest in child (Pediatric Advanced Life Support PALS), (3) non-accidental trauma (NAT), and (4) accidental trauma from pedestrian-motor vehicle collision (MVC). Simulations were developed by a diverse team with experience in patient safety, simulation, medical and EMS education, pediatric emergency medicine, advanced life support training, and emergency medical services. Professional actors who each had several years' experience working as standardized patients in simulations played the roles of patients and family members. They read through a standardized script and the full simulations and debriefings were beta tested exactly as they would run with participants with several EMS teams in two different EMS agencies, not participating in the study. Simulations were conducted in the field using high-fidelity simulators, scene design, and professional actors playing roles of parents and bystanders. EMS crews responded in their agency vehicles after receiving a radio dispatch. Simulators included Victoria™ birthing patient simulator and the Newborn Hal™ simulator from Gaumard™, and Sim Jr.™ 6-year-old child and sim NewB™ newborn simulators from Laerdal™. Settings included street (motor vehicle collision or MVC), simulated apartment bedroom for birth (neonatal resuscitation protocol or NRP), disheveled family room (neonatal abuse trauma or NAT), simulated care facility for eight year old with cardiac arrest (pediatric advanced life support or PALS) and all simulations were allowed to continue though transport in the agency's own ambulances.

In the NRP scenario, the patient presented as a newborn who was initially responsive upon delivery but subsequently developed a weak cry, flaccid extremities, bradycardia, and cyanosis requiring resuscitation. For the PALS case, the patient presented as a six-year-old boy with symptomatic bradycardia that progressed to pulseless electrical activity with a reported history of developmental disabilities, seizures, and cerebral palsy, living in a care facility. In the NAT case, a six-month-old patient had "fallen" from the couch and was unconscious and unresponsive with bruising consistent with inflicted injury. In the MVC scenario, the patient was a three-month-old child who, while in a stroller, was stuck by a car. The patient had a large scalp wound and was initially crying but shortly after developed decreased responsiveness, hypertension, bradycardia, and slow respirations. Makeup was used to simulate bruising, bleeding and lacerations in a standardized manner for each scenario. Each scenario followed a previously determined algorithm for improvement or decompensation of the patient's status along pre-specified time intervals according to performance of specific critical actions also specified in advance. All scenarios were pilot tested among EMS teams who did not subsequently participate in the study. Scenarios were revised as needed based on feedback from pilot testing. Professionally trained actors played all confederate roles in the scenarios to enhance realism.

For the purpose of standardization, simulation scenarios concluded after approximately 10 minutes. If the team initiated a procedure close to the 10-minute mark, such as calculating and drawing up a medication, the simulation was allowed to continue to complete observation of the task in process and reduce the chances of an awkward end to the scenario. If the care protocols proceeded rapidly, and the condition of the patient was stable and transport action had begun, the simulation could be concluded before the 10-minute point. After finishing all four scenarios, teams returned for a 30-minute debriefing session.

Simulation scenarios were presented to teams in random order to minimize the potential bias that may occur from conditioning as teams become familiar with the simulators and working with each other. Fire and transport crews responded to each scenario in their own fire engines and ambulances after receiving a scripted radio dispatch. Each crew used their own equipment or alternatively used training kits that were replicas of the kits they usually carry. The crews varied who arrived on scene first (ambulance or fire department) and at times arrived simultaneously to mimic local practice. Crews were able to move the patient simulators to the transport vehicle and mimic patient transport to the hospital. If transport was started, the crews would assign a driver and those who remained inside the transport vehicle would continue to administer patient care. All crews were aware they were participating in simulated emergencies and were oriented to the study and mannequins prior to participation. To allow for anonymous tracking of each participant by role, the crew members wore colored tape markers on their shoulders. The fire crews also varied the person-in-charge (PIC) assignment for each scenario, although the crew membership was consistent.

Data Collection

Prior to simulations, participants completed a survey asking about demographic characteristics, training and their experience in Emergency Medical Services.

One of two subject matter experts (JMG & MH) experienced in using the Clinical Teamwork Scale (CTS™) directly observed simulations in real time and measured teamwork using the CTS™, a validated instrument that measures overall teamwork and 15 specific elements in 5 overarching domains in addition to overall teamwork: communication, decision making, role responsibility (leadership and followership), situational awareness/resource management and patient-friendliness.[19] CTS™ was selected because the authors were skilled in its use having developed it over a decade ago with a diverse team (that included one of the founders of crew resource management (CRM)), it was designed specifically to allow quick assessments of teamwork during rapidly moving clinical emergencies, it is free, and has been successfully used by us and numerous others to measure teamwork in emergent clinical scenarios similar to our intended purpose: pediatric resuscitations, obstetrics, trauma, advanced cardiac life support, and emergency medical services.[20-27] Evaluators rate the performance of the care team using a Likert scale of zero (unacceptable) to 10 (perfect) and are given space to insert narrative comments. In validation studies, the CTS™ has demonstrated substantial score concordance among raters, and excellent interrater reliability.[26-28] A systematic review of tools that have been used to measure teamwork recently concluded that CTS™ was superior to other tools for measuring teamwork citing content and construct validity as well as reliability and ease of use.[29] Prior to the study, simulations were pilot tested with EMS teams not involved in the study. During this time, both reviewers scored teamwork independently using CTS™ arrived at consensus and repeated independent assessments of new simulations to arrive at consistency. Two reviewers were present, independently scored scenarios and came to consensus at the end of pilot tests and during more than half of all study simulations.

Error Measurement

During the simulations, the evaluators noted the number of errors and described what the error entailed using standard taxonomy. For purposes of this study, errors were collapsed into whether an error was present or not present. Similar to CTS, when both reviewers were present (>50% of the time) a consensus was reached at the end regarding errors. When there was uncertainty over whether an action may or may not have constituted an error, the team discussed to reach consensus. For the remaining scenarios, a single reviewer rated the errors.

Statistical analysis

A completed case analysis was used; due to missing data on key variables, 6 of 176 (3.4%) of simulation scenarios were dropped from analysis. We summarized error proportion by each simulated clinical scenario, and summarized teamwork (CTS^{TM} teamwork score) by the presence or absence of an error. We summarized teamwork as the overall CTS^{TM} score and also by each score in the five sub-domains of the CTS^{TM}. Scores were compared between groups using *t*-tests for unequal variances. A generalized estimating equation (GEE) logistic regression model was used to estimate the odds of error with increasing CTS^{TM} score in SAS GENMOD (version 9.4 SAS Institute Inc., Carey, NC). Although the order of the four simulation scenarios was randomized by EMS teams, in analysis we controlled for the potential correlation of errors by team using an exchangeable correlation structure clustered by teams. Our choice to use the exchangeable correlation structure also should be robust to errors in adjacent simulation scenarios and comparisons to those farther apart in time on the testing day, as well as scenarios that may share similar characteristics (e.g., same age of pediatric patient). assumes that the correlation between errors. We tested for confounding by scenario and years of EMS experience. A *p*-value of <0.05 was considered statistically significant.

RESULTS

Table 1 shows demographic characteristics and self-reported professional experience of EMS responders participating in the simulation sessions.

Table 1: Characteristics of EMS Personnel Participating in Simulations

Characteristic	N (%)

Mean Age years (S.D)[a]	36.9	(8.47)
Gender[b]		
Female	36	(14.0)
Race/Ethnicity[c]		
White	220	(89.1)
Black or African American	0	(0)
American Indian or Alaska Native	6	(2.43)
Asian	4	(1.62)
Native Hawaiian or Other Pacific Islander	2	(0.81)
Hispanic or Latino	7	(2.83)
Other/Two or More Races	8	(3.24)
Training Level[b]		
Emergency Medical Responder (EMR)	0	(0)
Emergency Medical Technician (EMT)	100	(38.9)
Advanced EMT	2	(0.78)
EMT-Intermediate	25	(9.73)
Paramedic	128	(49.8)
Paramedic Intern	2	(0.78)
Years' Experience Working in EMS[d]	11.7	(7.84)
Proficiency in Pediatric EMS on a Scale of 1 ("Novice") to 5 ("Expert")[b]	2.55	(0.89)

a) n = 256, b) EMS n = 257, c) n = 247, d) n = 258

At least one error was observed in 82% of the 176 simulation scenarios for which the presence or absence of errors was recorded. Due to missing data for overall CTS^{TM} score, data for six scenarios were not included in the logistic regression analysis. Table 2 describes the types of errors observed.

Table 2: Taxonomy of Observed Errors

Errors	Type
Diagnostic & Management	Assessment, algorithm, diagnostic, management, decision making
Medication	Wrong medication, dose, route, sequence, type, IV fluid issue, etc.
Technical	Wrong device, size, bagging, intubation, CPR, defibrillator, immobilization
Scene/Environment	Scene safety, scene time, positioning, patient/family

The overall CTS™ score was normally distributed, with a mean of 6.04 (SD = 2.10; min =1 (poor) and max = 10 (perfect)) in the 170 simulations with recorded overall CTS™ scores. The distributions of overall CTS™ scores were similar across the four scenarios. In simulations with an overall CTS™ score and at least one observed error (n =138), the mean CTS™ score was 5.76 (SD = 2.04) compared with 7.16 (SD = 1.95) in scenarios with no observed error (n = 32). The t tests demonstrated that this difference was statistically significant (p-value = 0.0007). For each individual simulation scenario, teams with no errors had higher CTS™ scores than teams with one or more errors. There were statistically significant differences in CTS™ scores between teams with no errors and teams with errors in the Non-Accidental Trauma simulation and the Newborn Cardiac Arrest simulation, with the no error teams having significantly greater CTS™ scores. Table 3 provides comparative data for CTS™ scores between teams with and without errors by simulation scenario.

Table 3: Comparing CTS™ Overall Teamwork Score Between Teams With and Without Errors by Simulation Scenario

Simulation Scenario	No Error (mean, SD)	One or More Errors (mean, SD)	t⁺	*P* value
Motor Vehicle Collision	6.20(2.25)	5.91(1.96)	0.37	0.72
Non-Accidental Trauma	8.20(1.10)	5.57(2.03)	4.39	*0.0019
Newborn Cardiac Arrest	7.55(1.97)	5.79(2.18)	2.5	*0.022
Six-Year-Old Cardiac Arrest	7.17(1.60)	5.78(2.09)	1.88	0.097
All Simulations	7.16(1.95)	5.76(2.04)	3.61	*0.0007

⁺Satterhwaite t-test for unequal variances
*significant at alpha=0.05

After comparing an unadjusted GEE logistic regression model to a model controlling for scenario and mean years of EMS experience, there were no significant differences in the effect estimate for CTS™ score or significance of estimates (Table 4). This indicates that the relationship between overall CTS ™ and odds of error was not confounded by scenario or years of EMS experience; thus, the final model reported is unadjusted for these variables. Logistic regression analysis accounting for clustering at the team-level revealed that the odds of an error decreased 28% with each unit increase in CTS™ (Odds Ratio = 0.72, 95% Confidence Interval 0.59 – 0.88).

Table 4. GEE Logistic Regression Models Testing Associations between Teamwork and Errors

	Unadjusted				Adjusted⁺			
Predictor Variable	**OR**	**95% CI**	**Z**	**p-value**	**OR**	**95% CI**	**Z**	**p-value**
CTS Score (1-unit increase)	0.72	(0.59,0.88)	-3.2	0.0014	0.73	(0.59,0.89)	-3.06	0.0022
MVC	-	-	-	-	0.45	(0.18,1.17)	-1.63	0.1034
NRP	-	-	-	-	0.46	(0.20,1.04)	-1.87	0.0618
PALS	-	-	-	-	0.88	(0.25,3.03)	-0.21	0.8352
NAT	-	-	-	-	REF	-	-	-
Mean Years EMS Experience	-	-	-	-	0.92	(0.79, 1.07)	-1.07	0.284

⁺Adjusted for clinical scenario (NAT = reference group) and mean years of EMS experience at the team level

Within the simulations, the percentage of teams that completed a simulation without error was highest in the Newborn Cardiac Arrest simulation (25%). The simulation with the highest percentage of teams with one or more error was the Non-Accidental Trauma simulation, with 89% of simulation having at least one error. Bivariable analysis suggested that adverse safety events are more likely in teams with low teamwork scores.

Adverse safety events were also more likely in teams with lower individual scores in communication, situational awareness, decision-making, and leadership/followership (Table 5).

Table 5: CTS™ Domain-specific Ratings in Simulations with and without Any Observed Error

Error	CTS™ Item Rating		
CTS™ Item	*No Error (mean, SD)*	*One or More Errors (mean, SD)*	*P Value*
Overall Communication[a]	7.13 (2.21)	5.89 (2.00)	0.002
Overall Situational Awareness[b]	7.31 (2.07)	6.26 (2.25)	0.01
Overall Decision Making[c]	7.26 (2.07)	5.49 (2.35)	<0.001
Overall Role Responsibility (Leader/Helper)[d]	7.25 (1.74)	6.06 (1.92)	0.001
Patient Friendliness[d]	7.13 (2.56)	6.44 (2.17)	0.16

a) n = 160, b) n = 170, c) n = 167, d) n = 163

Compared with teams with one or more errors, teams without any errors had higher CTS™ scores across all itemized categories of the CTS™ (Overall Communication, Overall Situational Awareness, Overall Decision making, Overall Role Responsibility, and Patient Friendliness). Among these categories, teams with no error had significantly higher CTS™ scores for Overall Communication, Overall Situational Awareness, Overall Decision Making, and Overall Role Responsibility (Leadership/Helper).

DISCUSSION

In this study of simulated pediatric prehospital emergencies, we observed a higher frequency of errors in teams with lower-rated teamwork scores. This finding was observed consistently across a variety of clinical scenarios (e.g., both newborn cardiac arrest and non-accidental trauma) and teamwork sub-domains (e.g., communication and situational awareness). Our study builds on the prior research on the role of teamwork in medical errors, which has mostly been conducted in the hospital setting.[30, 31] Using high-fidelity simulation scenarios and a validated teamwork measurement tool, we extended this research to the pediatric prehospital emergency care setting, and found an association between teamwork and medical errors.

The results were robust to multivariable regression adjustment, suggesting that breakdowns in teamwork are indeed a factor contributing to the high error rates observed in this study. These findings add strength to the WHO's description of communication as a leading cause of unintentional harm and further elaborate on the importance of teamwork in decreasing errors.[11] Additionally, These findings provide a nice complement to the work on surgical mortality and team training[16] as this provides a mechanism to measure the immediate intervening factors that are likely in the causal pathway.

Given the large cost and morbidity burden associated with medical errors worldwide, these findings suggest directions for future research and also have policy implications.[3, 10] Most immediately, however, more studies are needed to confirm this association both in this specific healthcare setting as well as other clinical areas where team-based care is the norm. For example, future studies should examine the contribution of teamwork to medical errors in hospital emergency medical care to continue building our understanding of the role of teamwork beyond the ICU. Improving team work is a relatively low cost intervention to improve patient outcomes. Thus this direction of research is important internationally, and may be particularly critical for countries of low economic means, who are impacted heavily by the financial burdens. [10]

We used a validated measure of teamwork, the CTS™. CTS™ has been used around the world in different settings and clinical care areas. [26-28] Future studies should utilize this measure and also continue to refine methods for measuring the multi-modal concept of teamwork in health care systems around the world. Given the complexity of teamwork and the inherent challenges in measuring it (e.g., different evaluations based on different parties, the limitations of self-reported/self-scored data, etc.), additional research will be needed to provide a full picture of the role of teamwork in patient outcomes. In clinical settings where our findings are replicated, it will be essential to consider interventions, training, and policies to prevent teamwork-associated medical errors.

There are several important limitations to consider. We conducted simulations and measured teamwork in one geographic region with a specific EMS system design which may not be representative of other areas. Although we employed best-practices in conducting our simulations and measuring teamwork (e.g., cutting-edge simulation models, the use of trained actors, a validated teamwork measurement scale), our study examined simulated healthcare encounters, rather than actual healthcare. However, due to the rare nature of critical pediatric emergencies in EMS, direct observation of care is not feasible on this scale. Next, we do not know if poorer teamwork is the cause of errors or if it is simply associated with other deficits in performance that may be contributing, such as medical knowledge. Further, the appraisal of errors and assignment of teamwork scores were performed by humans using their best judgement, which is a method subject to bias. Finally, while the amount of missing data were small, we dealt with missing data using complete-case analysis (170 complete of 176 available cases). The analytic approach to missing data continues to be a subject of active investigation with recent writings suggesting that the best approach is to think through the likely causes of bias and select the analytic method that is least likely to introduce bias and best able to reduce bias.[32] Although several options are available for addressing missingness (e.g., multiple imputation approaches), several features of our specific data raised questions about the applicability of these approaches in our study. Our data structure includes nested, non-independent observations, where the same clinical team participated in clinically distinct simulations and different clinical teams participated in each clinical simulation. Given this, it did not seem appropriate to impute scores from other clinical teams in the same clinical scenario to the team with missing data, as this would assume that the clinical performance of teams was homogeneous. In the same note, it did not seem appropriate to assume that one clinical team would perform similarly on clinical cases that were very distinct. Given that neither of these assumptions seemed appropriate and also that our total number of missing data was small, the most honest interpretation of our data seemed to be complete case analysis. In conclusion, we found that teamwork is highly correlated with errors in simulated pediatric prehospital emergencies and this finding was robust across four different simulation scenarios as well as across sub-domains of teamwork.

CONCLUSION

Overall teamwork is strongly associated with the risk of adverse events in critically ill and injured children.

DECLARATIONS

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None

Ethics approval and consent to participate

The study was approved by Oregon Health & Science University's Institutional Review Board, IRB Approval# 00006942.

Competing interests

The authors have no conflict of interest to report.

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REFERENCES CITED

1. Quality Interagency Coordination Task Force. Doing what counts for patient safety: Federal actions to reduce medical errors and their impact. Rockville, MD: Agency for Healthcare and Research Quality; [cited 2017 May 12]. Available from: https://archive.ahrq.gov/quic/report/mederr4.htm
2. Makary M, Daniel M. Medical error-the third leading cause of death in the US. BMJ. 2016;353:i2139.
3. Slawomirski L, Auraaen A, Klazinga N. The economics of patient safety: Strengthening a value-based approach to reducing patient harm at national level. Paris, France: Organisation for Economic Co-operation and Development, 2017.
4. Committee on Quality of Health Care in America. To err is human: Building a safer health system. Institue of Medicine, editor. Washington, DC: National Academy Press; 1999.
5. Aranaz-Andres J, Aibar-Remon C, Vitaller-Burillo J, Requena-Puche J, Terol-Garcia E, Kelley E, et al. Impact and preventability of adverse events in Spanish public hospitals: results of the Spanish National Study of Adverse Events (ENEAS). Int J Qual Health Care. 2009;21(6):408-14.
6. Westbrook J, Li L, Lehnbom E, Baysari MT, Braithwaite J, Burke R, et al. What are incident reports telling us? A comparative study at two Australian hospitals of medication errors identified at audit, detected by staff and reported to an incident system. Int J Qual Health Care. 2015;27(1):1-9.

7. Giraldo P, Sato L, Sala M, Comas M, Dywer K, Castells X. A retrospective review of medical errors adjudicated in court between 2002 and 2012 in Spain. Int J Qual Health Care. 2016;28(1):33-9.

8. Kaushal R, Bates D, Landrigan C. Medication errors and adverse drug events in pediatric inpatients. JAMA. 2001;285(16):2114-20.

9. Woods D, Thomas E, Holl J, al. e. Adverse events and preventable adverse events in children. Pediatrics. 2005;115(1):155-60.

10. National Academies of Sciences, Engineering and Medicine. Crossing the Global Quality Chasm: Improving Health Care Worldwide. Washington, DC: 2018.

11. Katzenbach J, Smith D. The discipline of teams. Boston, MA: Harvard Business Press; 2008.

12. Baker D, Gustafson S, Beaubien J, al. e. Medical teamwork and patient safety: The evidence-based relation. Rockville, MD: Agency for Healthcare and Research Quality, 2005.

13. Manser T. Teamwork and patient safety in dynamic domains of healthcare: A review of the literature. Acta Anasthesiol Scand. 2009;53(2):143-51.

14. Sorbero M, Farley D, Mattke S, al. e. Outcomes measures for effective teamwork in inpatient care. Santa Monica, CA: RAND Corporation, 2008.

15. Donchin Y, Gopher D, Olin M, al. e. A look into the nature and causes of human errors in the intensive care unit. Crit Care Med. 1995;23(2):294-300.

16. Neily J, Mills P, Young-Xu Y, Carney B, West P, Berger D, et al. Association between implementation of a medical team training program and surgical mortality. JAMA. 2010;304(15):1693-700.

17. Landrigan C. Resident sleep deprivation and critical care: the unintended consequences of inaction. Crit Care Med. 2010;38(3):980-1.

18. von Elm E, Altman D, Egger M, Pocock S, Gøtzsche P, Vandenbroucke J. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. PLoS Med. 2007;4(10):e296.

19. Guise J, Deering S, Kanki B, al. e. Validation of a tool to measure and promote clinical teamwork. Simul Healthc. 2008;3(4):217-23.

20. Gilfoyle E, Koot D, Annear J, Bhanji F, Cheng A, Duff J, et al. Improved Clinical Performance and Teamwork of Pediatric Interprofessional Resuscitation Teams With a Simulation-Based Educational Intervention. Pediatr Crit Care Med. 2017;18(2):e62-e9.

21. Lau Y, Chee D, Ab Hamid Z, Leong B, Lau S. Interprofessional Simulation-Based Advanced Cardiac Life Support Training: Video-Based Observational Study. Clin Sim Nurs. 2019;30:16-24.

22. Parush A, Mastoras G, Bhandari A, Momtahan K, Day K, Weitzman B, et al. Can teamwork and situational awareness (SA) in ED resuscitations be improved with a technological cognitive aid? Design and a pilot study of a team situation display. J Biomed Inform. 2017;76:154-61.

23. Ghazali D, Darmian-Rafei I, Ragot S, Oriot D. Performance Under Stress Conditions During Multidisciplinary Team Immersive Pediatric Simulations. Pediatr Crit Care Med. 2018;19(6):e270-e8.

24. Paull D, Deleeuw L, Wolk S, Paige J, Neily J, Mills P. The effect of simulation-based crew resource management training on measurable teamwork and communication among

interprofessional teams caring for postoperative patients. J Contin Educ Nurs. 2013;44(11):516-24.

25. Letchworth P, Duffy S, Phillips D. Improving non-technical skills (teamwork) in post-partum haemorrhage: A grouped randomised trial. Eur J Obstet Gynecol Reproductive Biol. 2017;217:154-60.

26. Fransen A, van de Ven J, Merien A, de Wit-Zuurendonk L, Houterman S, Mol B, et al. Effect of obstetric team training on team performance and medical technical skills: a randomised controlled trial. BJOG. 2012;119(11):1387-93.

27. Miller D, Crandall C, Washington C, 3rd, McLaughlin S. Improving teamwork and communication in trauma care through in situ simulations. Acad Emerg Med. 2012;19(5):608-12.

28. Banga F, Truijens S, Fransen A, Dieleman J, van Runnard Heimel P, Oei G. The impact of transmural multiprofessional simulation-based obstetric team training on perinatal outcome and quality of care in the Netherlands. BMC Med Educ. 2014;14:175.

29. Fransen A, de Boer L, Kienhorst D, Truijens S, van Runnard Heimel P, Oei S. Assessing teamwork performance in obstetrics: A systematic search and review of validated tools. Eur J Obstet Gynecol Reproductive Biol. 2017;216:184-91.

30. van de Ven J, Houterman S, Steinweg R, Scherpbier A, Wijers W, Mol B, et al. Reducing errors in health care: cost-effectiveness of multidisciplinary team training in obstetric emergencies (TOSTI study); a randomised controlled trial. BMC Preg Childbirth. 2010;10:59.

31. McCulloch P, Mishra A, Handa A, Dale T, Hirst G, Catchpole K. The effects of aviation-style non-technical skills training on technical performance and outcome in the operating theatre. Qual Safe Health Care. 2009;18(2):109-15.

32. Dong Y, Peng C. Principled missing data methods for researchers. SpringerPlus. 2013;2(1):222.

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any prespecified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	5-6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	6
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	NA
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-10
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	9
Bias	9	Describe any efforts to address potential sources of bias	8-9
Study size	10	Explain how the study size was arrived at	6-7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	10-11
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	10-11
		(*b*) Describe any methods used to examine subgroups and interactions	10-11
		(*c*) Explain how missing data were addressed	10,11,16
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	NA
		(*e*) Describe any sensitivity analyses	NA

Continued on next page

Results			Page #
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	7
		(b) Give reasons for non-participation at each stage	7
		(c) Consider use of a flow diagram	NA
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	7,11, 12
		(b) Indicate number of participants with missing data for each variable of interest	12
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	(NA)
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	(12-15)
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	NA
		Cross-sectional study—Report numbers of outcome events or summary measures	NA
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	(12-15)
		(*b*) Report category boundaries when continuous variables were categorized	(12-15)
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	NA
Discussion			
Key results	18	Summarise key results with reference to study objectives	14-15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	17
Generalisability	21	Discuss the generalisability (external validity) of the study results	15-16
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	18

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

BMJ Open

Association between Measured Teamwork and Medical Errors: An Observational Study of Prehospital Care in the United States

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Association between Measured Teamwork and Medical Errors: An Observational Study of Prehospital Care in the United States

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ABSTRACT

Objectives

The goal of this study was to examine the relationship between measured teamwork and adverse safety events in the prehospital emergency care of children using high-fidelity simulation. We posit that non-technical skills such as leadership, teamwork, situation awareness and decision making are associated with the clinical success of teams.

Design

Observational study.

Setting

Emergency Medical Services (EMS) responders were recruited from public fire and private transport agencies in Oregon State to participate in four simulations of pediatric emergencies using high-fidelity patient simulators, scene design, and professional actors playing parents and bystanders.

Participants

Forty-four fire/transport teams consisting of 259 EMS professionals consented to participate and completed simulations.

Primary and Secondary Outcome Measures

Teams were assessed using the CTS^{TM}, a validated instrument that measures overall teamwork and 15 specific elements in 5 overarching domains: communication, decision making, role responsibility (leadership and followership), situational awareness/resource management and patient-friendliness. We used generalized estimating equations to estimate the odds of error with increasing overall CTS^{TM} teamwork score while adjusting for clinical scenario and potential clustering by team.

Results

Across 176 simulations, the mean overall score on the CTS™ was 6.04 (SD = 2.10; range 1 = poor to 10 = perfect) and was normally distributed. The distribution of scores was similar across the four clinical scenarios. At least one error was observed in 82% of the simulations. In simulations with at least one observed error, the mean CTS™ score was 5.76 (SD = 2.04) compared with 7.16 (SD = 1.95) in scenarios with no observed error. Logistic regression analysis accounting for clustering at the team-level revealed that the odds of an error decreased 28% with each unit increase in CTS™ (Odds Ratio = 0.72, 95% Confidence Interval 0.59 – 0.88).

Conclusions

This study found that overall teamwork among care delivery teams was strongly associated with the risk of serious adverse events in simulated scenarios of caring for critically ill and injured children.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- This research provides some of the first data that quantifies the relationship between clinical teamwork and the likelihood of medical errors in a pediatric prehospital setting.
- These data suggest CTS™ may be a useful tool to measure the immediate impact of interventions on teamwork that matter to the reduction of errors.
- Simulations replicated pediatric emergencies known to be high risk for errors and were conducted using professional actors and high fidelity pediatric simulators in the field with clinical EMS teams assembled and responding as they normally would reflecting every day clinical care as closely as possible.
- The appraisal of errors and assignment of teamwork scores were performed by clinicians who were not involved in EMS but were humans using their best judgement, which is a method subject to bias
- It remains uncertain whether poorer teamwork is the cause of errors or if it is simply associated with other deficits in performance that may be contributing, however, this finding provides a tool that can be used to measure impact before and after interventions.

INTRODUCTION

Medical errors, are estimated to be the third leading cause of death in the United States (US) and the 14th leading cause worldwide.[1-3] The total aggregated cost of adverse safety events and errors is estimated to amount to trillions of dollars each year. [3] Medicine is both an important and imperfect field, combining science with art and humans with technology. In 1999, the world became aware that patients not only die from disease and traumatic events, some also die or are injured unintentionally through the provision of clinical care.[4] The landmark Institute of Medicine report estimated that the number of people who die every year due to preventable medical errors in the US alone, is equivalent to 3 jumbo jet crashes every 2 days, or one patient every 15 minutes, with over 1 million estimated to be harmed. Studies of medical errors have generally focused on adults and inpatient settings.[5-7] However, medical errors are also an important source of harm for pediatric patients with estimates of 70,000 pediatric inpatients harmed per year by medical errors.[8, 9] A more recent report, emphasizes that the cost of medical errors is proportionately more devastating to countries of low economic status.[10] Even less is known about the epidemiology, etiology, and risk factors for preventable adverse events in the care of children in the Emergency Medical Services (EMS) system where children first receive care for emergencies outside of the hospital.

Non-technical skills such as good communication and teamwork are critical in avoiding medical errors and assuring the safety of patients.[3] The World Health Organization considers communication to be the leading cause of unintentional patient harm.[11] Past reviews have indicated that aspects of teamwork such as leadership, teamwork, situation awareness and decision making are largely correlated with the clinical success of teams.[12-14] For example, a study evaluating teamwork in the Intensive Care Unit indicated that 37% of teamwork failures were due to verbal communication errors between physicians and nurses.[15] There have been interventions to reduce medical errors such as implementing computerized provider order-entry systems, limiting residents' work shifts to consecutive hours, and implementing evidence-based care bundles. A large retrospective study from the US Veterans Affair Hospital found that inpatient surgical mortality was reduced 18% following team training interventions.[16] However, lack of prospective and detailed evaluation of teamwork elements and specific errors limit our understanding of the effectiveness of these practices.[17] The goal of this study was to examine the relationship between measured teamwork and adverse safety events in the prehospital emergency care of children using high-fidelity simulation.

METHODS

We followed STROBE guidance for reporting of observational studies.[18] The Oregon Health & Science University Institutional Review Board (IRB00006942) approved the study and all subjects signed both study and video consent prior to participation.

Study Participants

In total, 176 simulations were performed over a 6-month timeframe with 44 teams of emergency medical services (EMS) providers recruited from public fire and private transport crews in three large counties surrounding Portland, Oregon in the United States. Portland is the largest city in Oregon and the three county area that participated in this study serves a population of 1.8 million. The EMS system in this region has dual-Advanced Life Support response to all 911 calls with public fire agencies, responding in teams of 3-5 individuals with at least one paramedic, and a private transport agency, responding in 2-person teams with at least one paramedic. We conducted all simulations in the field ,using high-fidelity simulators, scene design, and professional actors playing roles of parents and bystanders, with both fire and transport EMS teams responding to each scenario as they normally would when providing clinical care. Participants ranged from Emergency Medical Technician (EMT) to paramedic, with each team including at least one paramedic.

Forty-four fire/transport teams consisting of 259 EMS professionals were available in the three-county region during our study timeframe and consented to participate. All who consented completed the study. One individual withdrew consent to have his/her individual data analyzed after completing the simulation sessions for personal reasons, but agreed to analysis of team-level data for all simulation sessions he/she had participated. In total, we analyzed team-level data from 44 teams and individual-level data from 258 EMS professionals.

Patient Involvement

The EMS-C Children's Safety Initiative is an observational study with a specific focus on EMS providers. Patients were not involved in the design, recruitment, or conduct of the study.

Simulations

Each fire/ambulance team participated in four simulation scenarios: (1) cardiac arrest in newborn (Newborn Resuscitation Program, NRP), (2) cardiac arrest in child (Pediatric Advanced Life Support PALS), (3) non-accidental trauma (NAT), and (4) accidental trauma from pedestrian-motor vehicle collision (MVC). Simulations were developed by a diverse team with experience in patient safety, simulation, medical and EMS education, pediatric emergency medicine, advanced life support training, and emergency medical services. Professional actors who each had several years' experience working as standardized patients in simulations played the roles of patients and family members. They read through a standardized script and the full simulations and debriefings were beta tested exactly as they would run with participants with several EMS teams in two different EMS agencies, not participating in the study. Simulations were conducted in the field using high-fidelity simulators, scene design, and professional actors playing roles of parents and bystanders. EMS crews responded in their agency vehicles after receiving a radio dispatch. Simulators included Victoria™ birthing patient simulator and the Newborn Hal™ simulator from Gaumard™, and Sim Jr.™ 6-year-old child and sim NewB™ newborn simulators from Laerdal™. Settings included street (motor vehicle collision or MVC), simulated apartment bedroom for birth (neonatal resuscitation protocol or NRP), disheveled family room (neonatal abuse trauma or NAT), simulated care facility for eight year old with cardiac arrest (pediatric advanced life support or PALS) and all simulations were allowed to continue though transport in the agency's own ambulances.

In the NRP scenario, the patient presented as a newborn who was initially responsive upon delivery but subsequently developed a weak cry, flaccid extremities, bradycardia, and cyanosis requiring resuscitation. For the PALS case, the patient presented as a six-year-old boy with symptomatic bradycardia that progressed to pulseless electrical activity with a reported history of developmental disabilities, seizures, and cerebral palsy, living in a care facility. In the NAT case, a six-month-old patient had "fallen" from the couch and was unconscious and unresponsive with bruising consistent with inflicted injury. In the MVC scenario, the patient was a three-month-old child who, while in a stroller, was stuck by a car. The patient had a large scalp wound and was initially crying but shortly after developed decreased responsiveness, hypertension, bradycardia, and slow respirations. Makeup was used to simulate bruising, bleeding and lacerations in a standardized manner for each scenario. Each scenario followed a previously determined algorithm for improvement or decompensation of the patient's status along pre-specified time intervals according to performance of specific critical actions also specified in advance. All scenarios were pilot tested among EMS teams who did not subsequently participate in the study. Scenarios were revised as needed based on feedback from pilot testing. Professionally trained actors played all confederate roles in the scenarios to enhance realism.

For the purpose of standardization, simulation scenarios concluded after approximately 10 minutes. If the team initiated a procedure close to the 10-minute mark, such as calculating and drawing up a medication, the simulation was allowed to continue to complete observation of the task in process and reduce the chances of an awkward end to the scenario. If the care protocols proceeded rapidly, and the condition of the patient was stable and transport action had begun, the simulation could be concluded before the 10-minute point. After finishing all four scenarios, teams returned for a 30-minute debriefing session.

Simulation scenarios were presented to teams in random order to minimize the potential bias that may occur from conditioning as teams become familiar with the simulators and working with each other. Fire and transport crews responded to each scenario in their own fire engines and ambulances after receiving a scripted radio dispatch. Each crew used their own equipment or alternatively used training kits that were replicas of the kits they usually carry. The crews varied who arrived on scene first (ambulance or fire department) and at times arrived simultaneously to mimic local practice. Crews were able to move the patient simulators to the transport vehicle and mimic patient transport to the hospital. If transport was started, the crews would assign a driver and those who remained inside the transport vehicle would continue to administer patient care. All crews were aware they were participating in simulated emergencies and were oriented to the study and mannequins prior to participation. To allow for anonymous tracking of each participant by role, the crew members wore colored tape markers on their shoulders. The fire crews also varied the person-in-charge (PIC) assignment for each scenario, although the crew membership was consistent.

Data Collection

Prior to simulations, participants completed a survey asking about demographic characteristics, training and their experience in Emergency Medical Services.

One of two subject matter experts (JMG & MH) experienced in using the Clinical Teamwork Scale (CTS^{TM}) directly observed simulations in real time and measured teamwork using the CTS^{TM}, a validated instrument that measures overall teamwork and 15 specific elements in 5 overarching domains in addition to overall teamwork: communication, decision making, role responsibility (leadership and followership), situational awareness/resource management and patient-friendliness.[19] CTS™ was selected because the authors were skilled in its use having developed it over a decade ago with a diverse team (that included one of the founders of crew resource management (CRM)), it was designed specifically to allow quick assessments of teamwork during rapidly moving clinical emergencies, it is free, and has been successfully used by us and numerous others to measure teamwork in emergent clinical scenarios similar to our intended purpose: pediatric resuscitations, obstetrics, trauma, advanced cardiac life support, and emergency medical services.[20-27] Evaluators rate the performance of the care team using a Likert scale of zero (unacceptable) to 10 (perfect) and are given space to insert narrative comments. In validation studies, the CTS™ has demonstrated substantial score concordance among raters, and excellent interrater reliability.[26-28] A systematic review of tools that have been used to measure teamwork recently concluded that CTS™ was superior to other tools for measuring teamwork citing content and construct validity as well as reliability and ease of use.[29] Prior to the study, simulations were pilot tested with EMS teams not involved in the study. During this time, both reviewers scored teamwork independently using CTS™ arrived at consensus and repeated independent assessments of new simulations to arrive at consistency. Two reviewers were present, independently scored scenarios and came to consensus at the end of pilot tests and during more than half of all study simulations.

Error Measurement

During the simulations, the evaluators noted the number of errors and described what the error entailed using standard taxonomy. For purposes of this study, errors were collapsed into whether an error was present or not present. Similar to CTS, when both reviewers were present (>50% of the time) a consensus was reached at the end regarding errors. When there was uncertainty over whether an action may or may not have constituted an error, the team discussed to reach consensus. For the remaining scenarios, a single reviewer rated the errors.

Statistical analysis

A completed case analysis was used; due to missing data on key variables, 6 of 176 (3.4%) of simulation scenarios were dropped from analysis. We summarized error proportion by each simulated clinical scenario, and summarized teamwork (CTS™ teamwork score) by the presence or absence of an error. We summarized teamwork as the overall CTS™ score and also by each score in the five sub-domains of the CTS™. Scores were compared between groups using *t*-tests for unequal variances. A generalized estimating equation (GEE) logistic regression model was used to estimate the odds of error with increasing CTS™ score in SAS GENMOD (version 9.4 SAS Institute Inc., Carey, NC). Although the order of the four simulation scenarios was randomized by EMS teams, in analysis we controlled for the potential correlation of errors by team using an exchangeable correlation structure clustered by teams. Our choice to use the exchangeable correlation structure also should be robust to errors in adjacent simulation scenarios and comparisons to those farther apart in time on the testing day, as well as scenarios that may share similar characteristics (e.g., same age of pediatric patient). assumes that the correlation between errors. We tested for confounding by scenario and years of EMS experience. A *p*-value of <0.05 was considered statistically significant.

RESULTS

Table 1 shows demographic characteristics and self-reported professional experience of EMS responders participating in the simulation sessions.

Table 1: Characteristics of EMS Personnel Participating in Simulations

Characteristic	N (%)

Mean Age years (S.D)[a]	36.9	(8.47)
Gender[b]		
Female	36	(14.0)
Race/Ethnicity[c]		
White	220	(89.1)
Black or African American	0	(0)
American Indian or Alaska Native	6	(2.43)
Asian	4	(1.62)
Native Hawaiian or Other Pacific Islander	2	(0.81)
Hispanic or Latino	7	(2.83)
Other/Two or More Races	8	(3.24)
Training Level[b]		
Emergency Medical Responder (EMR)	0	(0)
Emergency Medical Technician (EMT)	100	(38.9)
Advanced EMT	2	(0.78)
EMT-Intermediate	25	(9.73)
Paramedic	128	(49.8)
Paramedic Intern	2	(0.78)
Years' Experience Working in EMS[d]	11.7	(7.84)
Proficiency in Pediatric EMS on a Scale of 1 ("Novice") to 5 ("Expert")[b]	2.55	(0.89)

a) n = 256, b) EMS n = 257, c) n = 247, d) n = 258

At least one error was observed in 82% of the 176 simulation scenarios for which the presence or absence of errors was recorded. Due to missing data for overall CTS^{TM} score, data for six scenarios were not included in the logistic regression analysis. Table 2 describes the types of errors observed.

Table 2: Taxonomy of Observed Errors

Errors	Type
Diagnostic & Management	Assessment, algorithm, diagnostic, management, decision making
Medication	Wrong medication, dose, route, sequence, type, IV fluid issue, etc.
Technical	Wrong device, size, bagging, intubation, CPR, defibrillator, immobilization
Scene/Environment	Scene safety, scene time, positioning, patient/family

The overall CTS™ score was normally distributed, with a mean of 6.04 (SD = 2.10; min =1 (poor) and max = 10 (perfect)) in the 170 simulations with recorded overall CTS™ scores. The distributions of overall CTS™ scores were similar across the four scenarios. In simulations with an overall CTS™ score and at least one observed error (n =138), the mean CTS™ score was 5.76 (SD = 2.04) compared with 7.16 (SD = 1.95) in scenarios with no observed error (n = 32). The t tests demonstrated that this difference was statistically significant (p-value = 0.0007). For each individual simulation scenario, teams with no errors had higher CTS™ scores than teams with one or more errors. There were statistically significant differences in CTS™ scores between teams with no errors and teams with errors in the Non-Accidental Trauma simulation and the Newborn Cardiac Arrest simulation, with the no error teams having significantly greater CTS™ scores. Table 3 provides comparative data for CTS™ scores between teams with and without errors by simulation scenario.

Table 3: Comparing CTS™ Overall Teamwork Score Between Teams With and Without Errors by Simulation Scenario

Simulation Scenario	No Error (mean, SD)	One or More Errors (mean, SD)	t⁺	*P* value
Motor Vehicle Collision	6.20(2.25)	5.91(1.96)	0.37	0.72
Non-Accidental Trauma	8.20(1.10)	5.57(2.03)	4.39	*0.0019
Newborn Cardiac Arrest	7.55(1.97)	5.79(2.18)	2.5	*0.022
Six-Year-Old Cardiac Arrest	7.17(1.60)	5.78(2.09)	1.88	0.097
All Simulations	7.16(1.95)	5.76(2.04)	3.61	*0.0007

⁺Satterhwaite t-test for unequal variances
*significant at alpha=0.05

After comparing an unadjusted GEE logistic regression model to a model controlling for scenario and mean years of EMS experience, there were no significant differences in the effect estimate for CTS™ score or significance of estimates (Table 4). This indicates that the relationship between overall CTS ™ and odds of error was not confounded by scenario or years of EMS experience; thus, the final model reported is unadjusted for these variables. Logistic regression analysis accounting for clustering at the team-level revealed that the odds of an error decreased 28% with each unit increase in CTS™ (Odds Ratio = 0.72, 95% Confidence Interval 0.59 – 0.88).

Table 4. GEE Logistic Regression Models Testing Associations between Teamwork and Errors

	Unadjusted				Adjusted⁺			
Predictor Variable	OR	95% CI	Z	p-value	OR	95% CI	Z	p-value
CTS Score (1-unit increase)	0.72	(0.59,0.88)	-3.2	0.0014	0.73	(0.59,0.89)	-3.06	0.0022
MVC	-	-	-	-	0.45	(0.18,1.17)	-1.63	0.1034
NRP	-	-	-	-	0.46	(0.20,1.04)	-1.87	0.0618
PALS	-	-	-	-	0.88	(0.25,3.03)	-0.21	0.8352
NAT	-	-	-	-	REF	-	-	-
Mean Years EMS Experience	-	-	-	-	0.92	(0.79, 1.07)	-1.07	0.284

⁺Adjusted for clinical scenario (NAT = reference group) and mean years of EMS experience at the team level

Within the simulations, the percentage of teams that completed a simulation without error was highest in the Newborn Cardiac Arrest simulation (25%). The simulation with the highest percentage of teams with one or more error was the Non-Accidental Trauma simulation, with 89% of simulation having at least one error. Bivariable analysis suggested that adverse safety events are more likely in teams with low teamwork scores.

Adverse safety events were also more likely in teams with lower individual scores in communication, situational awareness, decision-making, and leadership/followership (Table 5).

Table 5: CTS™ Domain-specific Ratings in Simulations with and without Any Observed Error

Error	**CTS™ Item Rating**		
CTS™ Item	*No Error (mean, SD)*	*One or More Errors (mean, SD)*	*P Value*
Overall Communication[a]	7.13 (2.21)	5.89 (2.00)	0.002
Overall Situational Awareness[b]	7.31 (2.07)	6.26 (2.25)	0.01
Overall Decision Making[c]	7.26 (2.07)	5.49 (2.35)	<0.001
Overall Role Responsibility (Leader/Helper)[d]	7.25 (1.74)	6.06 (1.92)	0.001
Patient Friendliness[d]	7.13 (2.56)	6.44 (2.17)	0.16

a) n = 160, b) n = 170, c) n = 167, d) n = 163

Compared with teams with one or more errors, teams without any errors had higher CTS™ scores across all itemized categories of the CTS™ (Overall Communication, Overall Situational Awareness, Overall Decision making, Overall Role Responsibility, and Patient Friendliness). Among these categories, teams with no error had significantly higher CTS™ scores for Overall Communication, Overall Situational Awareness, Overall Decision Making, and Overall Role Responsibility (Leadership/Helper).

DISCUSSION

In this study of simulated pediatric prehospital emergencies, we observed a higher frequency of errors in teams with lower-rated teamwork scores. This finding was observed consistently across a variety of clinical scenarios (e.g., both newborn cardiac arrest and non-accidental trauma) and teamwork sub-domains (e.g., communication and situational awareness). Our study builds on the prior research on the role of teamwork in medical errors, which has mostly been conducted in the hospital setting.[30, 31] Using high-fidelity simulation scenarios and a validated teamwork measurement tool, we extended this research to the pediatric prehospital emergency care setting, and found an association between teamwork and medical errors.

The results were robust to multivariable regression adjustment, suggesting that breakdowns in teamwork are indeed a factor contributing to the high error rates observed in this study. These findings add strength to the WHO's description of communication as a leading cause of unintentional harm and further elaborate on the importance of teamwork in decreasing errors.[11] Additionally, These findings provide a nice complement to the work on surgical mortality and team training[16] as this provides a mechanism to measure the immediate intervening factors that are likely in the causal pathway.

Given the large cost and morbidity burden associated with medical errors worldwide, these findings suggest directions for future research and also have policy implications.[3, 10] Most immediately, however, more studies are needed to confirm this association both in this specific healthcare setting as well as other clinical areas where team-based care is the norm. For example, future studies should examine the contribution of teamwork to medical errors in hospital emergency medical care to continue building our understanding of the role of teamwork beyond the ICU. Improving team work is a relatively low cost intervention to improve patient outcomes. Thus this direction of research is important internationally, and may be particularly critical for countries of low economic means, who are impacted heavily by the financial burdens. [10]

We used a validated measure of teamwork, the CTS™. CTS™ has been used around the world in different settings and clinical care areas. [26-28] Future studies should utilize this measure and also continue to refine methods for measuring the multi-modal concept of teamwork in health care systems around the world. Given the complexity of teamwork and the inherent challenges in measuring it (e.g., different evaluations based on different parties, the limitations of self-reported/self-scored data, etc.), additional research will be needed to provide a full picture of the role of teamwork in patient outcomes. In clinical settings where our findings are replicated, it will be essential to consider interventions, training, and policies to prevent teamwork-associated medical errors.

There are several important limitations to consider. We conducted simulations and measured teamwork in one geographic region with a specific EMS system design which may not be representative of other areas. Although we employed best-practices in conducting our simulations and measuring teamwork (e.g., cutting-edge simulation models, the use of trained actors, a validated teamwork measurement scale), our study examined simulated healthcare encounters, rather than actual healthcare. However, due to the rare nature of critical pediatric emergencies in EMS, direct observation of care is not feasible on this scale. Next, we do not know if poorer teamwork is the cause of errors or if it is simply associated with other deficits in performance that may be contributing, such as medical knowledge. Further, the appraisal of errors and assignment of teamwork scores were performed by humans using their best judgement, which is a method subject to bias. Finally, while the amount of missing data were small, we dealt with missing data using complete-case analysis (170 complete of 176 available cases). The analytic approach to missing data continues to be a subject of active investigation with recent writings suggesting that the best approach is to think through the likely causes of bias and select the analytic method that is least likely to introduce bias and best able to reduce bias.[32] Although several options are available for addressing missingness (e.g., multiple imputation approaches), several features of our specific data raised questions about the applicability of these approaches in our study. Our data structure includes nested, non-independent observations, where the same clinical team participated in clinically distinct simulations and different clinical teams participated in each clinical simulation. Given this, it did not seem appropriate to impute scores from other clinical teams in the same clinical scenario to the team with missing data, as this would assume that the clinical performance of teams was homogeneous. In the same note, it did not seem appropriate to assume that one clinical team would perform similarly on clinical cases that were very distinct. Given that neither of these assumptions seemed appropriate and also that our total number of missing data was small, the most honest interpretation of our data seemed to be complete case analysis. In conclusion, we found that teamwork is highly correlated with errors in simulated pediatric prehospital emergencies and this finding was robust across four different simulation scenarios as well as across sub-domains of teamwork.

CONCLUSION

Overall teamwork is strongly associated with the risk of adverse events in critically ill and injured children.

DECLARATIONS

Acknowledgements

None

Ethics approval and consent to participate

The study was approved by Oregon Health & Science University's Institutional Review Board, IRB Approval# 00006942.

Competing interests

The authors have no conflict of interest to report.

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Data Sharing: Aggregated data specific to this publication would be made available upon request.

Author Contributions: All authors contributed significantly to this work. SH is first author. JMG and WL obtained funding. SH, MH, BS, JS, JM, WL, and JMG conceived and designed the study. SH, MH, BS, JM, TH, WL, and JMG performed the simulations and participated in acquisition of data. SH, BS, AS, JS, WL, and JMG analyzed the data. SH, BS, JS, WL, and JMG wrote the first draft of the paper. SH, AS, WL, JS, and JMG conducted additional analyses and made revisions to the paper from peer review. All authors have read, edited, and approved the final manuscript and are able to accept responsibility for the work.

REFERENCES CITED

1. Quality Interagency Coordination Task Force. Doing what counts for patient safety: Federal actions to reduce medical errors and their impact. Rockville, MD: Agency for Healthcare and Research Quality; [cited 2017 May 12]. Available from: https://archive.ahrq.gov/quic/report/mederr4.htm
2. Makary M, Daniel M. Medical error-the third leading cause of death in the US. BMJ. 2016;353:i2139.
3. Slawomirski L, Auraaen A, Klazinga N. The economics of patient safety: Strengthening a value-based approach to reducing patient harm at national level. Paris, France: Organisation for Economic Co-operation and Development, 2017.
4. Committee on Quality of Health Care in America. To err is human: Building a safer health system. Institue of Medicine, editor. Washington, DC: National Academy Press; 1999.
5. Aranaz-Andres J, Aibar-Remon C, Vitaller-Burillo J, Requena-Puche J, Terol-Garcia E, Kelley E, et al. Impact and preventability of adverse events in Spanish public hospitals: results of the Spanish National Study of Adverse Events (ENEAS). Int J Qual Health Care. 2009;21(6):408-14.
6. Westbrook J, Li L, Lehnbom E, Baysari MT, Braithwaite J, Burke R, et al. What are incident reports telling us? A comparative study at two Australian hospitals of medication errors identified at audit, detected by staff and reported to an incident system. Int J Qual Health Care. 2015;27(1):1-9.

7. Giraldo P, Sato L, Sala M, Comas M, Dywer K, Castells X. A retrospective review of medical errors adjudicated in court between 2002 and 2012 in Spain. Int J Qual Health Care. 2016;28(1):33-9.

8. Kaushal R, Bates D, Landrigan C. Medication errors and adverse drug events in pediatric inpatients. JAMA. 2001;285(16):2114-20.

9. Woods D, Thomas E, Holl J, al. e. Adverse events and preventable adverse events in children. Pediatrics. 2005;115(1):155-60.

10. National Academies of Sciences, Engineering and Medicine. Crossing the Global Quality Chasm: Improving Health Care Worldwide. Washington, DC: 2018.

11. Katzenbach J, Smith D. The discipline of teams. Boston, MA: Harvard Business Press; 2008.

12. Baker D, Gustafson S, Beaubien J, al. e. Medical teamwork and patient safety: The evidence-based relation. Rockville, MD: Agency for Healthcare and Research Quality, 2005.

13. Manser T. Teamwork and patient safety in dynamic domains of healthcare: A review of the literature. Acta Anasthesiol Scand. 2009;53(2):143-51.

14. Sorbero M, Farley D, Mattke S, al. e. Outcomes measures for effective teamwork in inpatient care. Santa Monica, CA: RAND Corporation, 2008.

15. Donchin Y, Gopher D, Olin M, al. e. A look into the nature and causes of human errors in the intensive care unit. Crit Care Med. 1995;23(2):294-300.

16. Neily J, Mills P, Young-Xu Y, Carney B, West P, Berger D, et al. Association between implementation of a medical team training program and surgical mortality. JAMA. 2010;304(15):1693-700.

17. Landrigan C. Resident sleep deprivation and critical care: the unintended consequences of inaction. Crit Care Med. 2010;38(3):980-1.

18. von Elm E, Altman D, Egger M, Pocock S, Gøtzsche P, Vandenbroucke J. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. PLoS Med. 2007;4(10):e296.

19. Guise J, Deering S, Kanki B, al. e. Validation of a tool to measure and promote clinical teamwork. Simul Healthc. 2008;3(4):217-23.

20. Gilfoyle E, Koot D, Annear J, Bhanji F, Cheng A, Duff J, et al. Improved Clinical Performance and Teamwork of Pediatric Interprofessional Resuscitation Teams With a Simulation-Based Educational Intervention. Pediatr Crit Care Med. 2017;18(2):e62-e9.

21. Lau Y, Chee D, Ab Hamid Z, Leong B, Lau S. Interprofessional Simulation-Based Advanced Cardiac Life Support Training: Video-Based Observational Study. Clin Sim Nurs. 2019;30:16-24.

22. Parush A, Mastoras G, Bhandari A, Momtahan K, Day K, Weitzman B, et al. Can teamwork and situational awareness (SA) in ED resuscitations be improved with a technological cognitive aid? Design and a pilot study of a team situation display. J Biomed Inform. 2017;76:154-61.

23. Ghazali D, Darmian-Rafei I, Ragot S, Oriot D. Performance Under Stress Conditions During Multidisciplinary Team Immersive Pediatric Simulations. Pediatr Crit Care Med. 2018;19(6):e270-e8.

24. Paull D, Deleeuw L, Wolk S, Paige J, Neily J, Mills P. The effect of simulation-based crew resource management training on measurable teamwork and communication among

interprofessional teams caring for postoperative patients. J Contin Educ Nurs. 2013;44(11):516-24.

25. Letchworth P, Duffy S, Phillips D. Improving non-technical skills (teamwork) in post-partum haemorrhage: A grouped randomised trial. Eur J Obstet Gynecol Reproductive Biol. 2017;217:154-60.

26. Fransen A, van de Ven J, Merien A, de Wit-Zuurendonk L, Houterman S, Mol B, et al. Effect of obstetric team training on team performance and medical technical skills: a randomised controlled trial. BJOG. 2012;119(11):1387-93.

27. Miller D, Crandall C, Washington C, 3rd, McLaughlin S. Improving teamwork and communication in trauma care through in situ simulations. Acad Emerg Med. 2012;19(5):608-12.

28. Banga F, Truijens S, Fransen A, Dieleman J, van Runnard Heimel P, Oei G. The impact of transmural multiprofessional simulation-based obstetric team training on perinatal outcome and quality of care in the Netherlands. BMC Med Educ. 2014;14:175.

29. Fransen A, de Boer L, Kienhorst D, Truijens S, van Runnard Heimel P, Oei S. Assessing teamwork performance in obstetrics: A systematic search and review of validated tools. Eur J Obstet Gynecol Reproductive Biol. 2017;216:184-91.

30. van de Ven J, Houterman S, Steinweg R, Scherpbier A, Wijers W, Mol B, et al. Reducing errors in health care: cost-effectiveness of multidisciplinary team training in obstetric emergencies (TOSTI study); a randomised controlled trial. BMC Preg Childbirth. 2010;10:59.

31. McCulloch P, Mishra A, Handa A, Dale T, Hirst G, Catchpole K. The effects of aviation-style non-technical skills training on technical performance and outcome in the operating theatre. Qual Safe Health Care. 2009;18(2):109-15.

32. Dong Y, Peng C. Principled missing data methods for researchers. SpringerPlus. 2013;2(1):222.

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any prespecified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	5-6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	6
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	NA
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-10
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	9
Bias	9	Describe any efforts to address potential sources of bias	8-9
Study size	10	Explain how the study size was arrived at	6-7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	10-11
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	10-11
		(*b*) Describe any methods used to examine subgroups and interactions	10-11
		(*c*) Explain how missing data were addressed	10,11,16
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	NA
		(*e*) Describe any sensitivity analyses	NA

Continued on next page

Results			**Page #**
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	7
		(b) Give reasons for non-participation at each stage	7
		(c) Consider use of a flow diagram	NA
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	7,11, 12
		(b) Indicate number of participants with missing data for each variable of interest	12
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	(NA)
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	(12-15)
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	NA
		Cross-sectional study—Report numbers of outcome events or summary measures	NA
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	(12-15)
		(*b*) Report category boundaries when continuous variables were categorized	(12-15)
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	NA
Discussion			
Key results	18	Summarise key results with reference to study objectives	14-15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	17
Generalisability	21	Discuss the generalisability (external validity) of the study results	15-16
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	18

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.